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Office of Radiation Programs
Criteria and Standards Division
Washington, D.C. 20460

FOREWORD

Production and use of plutonium and the other transuranium elements is projected to increase rapidly. Because of the long half-lives and high radiotoxicity of many nuclides of these elements, public and technical concern has been expressed regarding the possible environmental and health impact of releases of these elements to the environment. For this reason the Environmental Protection Agency has embarked on a program to evaluate the environmental impact of the transuranium elements and to consider whether further guidelines or standards are needed to assure adequate protection of the general ambient environment and of the public health from potential contamination of the environment by radionuclides of these elements.

As a part of this program public hearings were held in Washington, D.C., and Denver, Colorado, to gather information regarding the public and social implications of plutonium utilization; the factors involved in the balancing of costs vs. benefits; dosimetry, health, and environmental effects; environmental levels and pathways; applications using plutonium; and control and cleanup technology.

This Agency believes that the information resulting from these hearings constitutes a significant contribution to the public awareness and knowledge of this problem and that wide dissemination of these proceedings will be valuable.

W. D. Rowe, Ph.D.
Deputy Assistant Administrator
for Radiation Programs

PREFACE

Information was presented both orally and in written form at the hearings and, in addition, a number of letters were submitted directly to the Office of Radiation Programs of The U. S. Environmental Protection Agency for inclusion in the hearing record. This information is being published in three volumes: Volume 1 contains the proceedings of the hearing in Washington, D.C; Volume 2 the proceedings of the hearing in Denver, Colorado; and Volume 3 the additional material submitted. Where Written submittals are more complete, these are printed in lieu of the oral testimony.

CONTENTS

Opening Remarks, Dr. W. D. Rowe ..... page 3

General Electric Company

Dr. Bertram Wolfe ..... page 21

Atomic Industrial Forum, Inc.

Mr. Ralph Deuster ..... page 55
Dr. Leonard Sagan ..... page 59
Dr. Marvin Goldman ..... page 67
Dr. Herbert Parker ..... page 75

Natural Resources Defense Council, Inc.

Mr. J. G. Speth and Dr. T. B. Cochran ..... page 163
Dr. A. Tamplin ..... page 229

U. S. Atomic Energy Commission
(Energy Research and Development Administration)

Dr. J. L. Liverman ..... page 275
Dr. R. E. Yoder ..... page 291
Dr. McDonald E. Wrenn ..... page 377
Dr. B. Bennett ..... page 417
Dr. W. J. Bair ..... page 463
Dr. W. Burr ..... page 536
Dr. C. Richmond ..... page 541
Dr. R. Thompson ..... page 576
Biomedical Effects Panel,
Drs. Bair, Burr and Richmond
(Continued discussion) ..... page 711

Dr. F. Forscher, Energy Management Consultant ..... page 724

U. S. Atomic Energy Commission
(Nuclear Regulatory Commission)

Mr. Lester Rogers ..... page 751

Westinghouse Electric Corporation, Power Systems

Mr. F. W. Kramer ..... page 798
Dr. J. E. Wright ..... page 818

The Environmental Coalition on Nuclear Power

Ms. Judith H. Johnsrud ..... page 850

PROCEEDINGS

Dr. Mills: I would like to get this Public Hearing underway. This is a Public Hearing on Plutonium and the other Transuranium Elements.

This particular hearing was announced in the Federal Register on October 24, 1974.

To open the hearing, I would like to introduce Dr. W. D. Rowe, who is Deputy Assistant Administrator for Radiation Programs in EPA.

Dr. Rowe: Thank you, Bill

OPENING REMARKS

BY

W.D. ROWE, PH.D.

DEPUTY ASSISTANT ADMINISTRATOR
FOR RADIATION PROGRAMS

Washington, D.C.
December 11-12, 1974

Environmental Protection Agency
Washington, D.C.

I would like to extend a most cordial welcome to both participants and audience assembled here for the EPA public hearings on plutonium and the other transuranic elements. The Environmental Protection Agency in its role of providing Federal Radiation Guidance and setting standards is soliciting information from the scientific community, State and other Federal agencies, and the public at large requisite to developing applicable environmental standards and guidelines for these nuclides.

The functions of the AEC related to setting of generally applicable environmental standards were transferred to the EPA by the President's Reorganization Plan No. 3 of 1970. The functions of the former Federal Radiation Council were also transferred to the Administrator of the Environmental Protection Agency at the same time. It is under these authorities that the EPA is now attempting to place the standard-setting picture in perspective and determine whether current standards and guidelines are adequate or whether these should be revised or changed.

The establishment of regulatory standards and radiation guidance involves three different types of judgment which must be clearly recognized. It is information which will permit us to make such judgments that we here desire.

First, we have the technical judgment. Groups of related facts may on occasion be given a different interpretation by the experts, and result in different conclusions. The rationale and validity of these conclusions then needs to be examined from the viewpoint of their influence on standard setting. In addition, there are always areas where the results may not be definitive and uncertainties remain. While

it may be possible to conduct scientific experiments to reduce such uncertainties, the time to carry out these experiments may preclude the necessary information being available at the time action is needed. Therefore, experts in the technical problem area often must make collective value judgments on the interpretation of available information.

The second type of judgment is the one where the best technical information as to risks, costs and benefits is considered and balanced to achieve equitable standards for society as a whole. In making a regulatory balance of this type, not only must costs and benefits be balanced as a whole, but inequities where cost and risk impact on those who do not directly receive benefits must be considered in terms of the total and ultimate impact of this activity. In the case of plutonium and the actinides this involves consideration of potential health effects committed for long periods. This type of value judgment must be made by society as a whole and not by the technical community alone.

The third type of judgment is that when standards are set they must be capable of being implemented and enforced in a way that is visible, traceable and reportable, and can be substantiated in an evidentiary manner in the courts. Thus judgments of a managerial nature as to the best means of implementing a standard certainly affect the form of a standard.

It is not by chance that the Environmental Protection Agency's Office of Radiation Programs has selected plutonium and other transuranic elements as the first problem to be considered in this type

of forum. The toxicity and long life of plutonium and the transuranium elements, totally man-made elements, provide us with the need for making value judgments now which will have long-term significance.

The objective of these hearings is to provide a forum where all existing information on plutonium and other transuranic elements which affects radiation protection activities can be aired and considered in a meaningful way, where all points of view and all who wish to provide input can have an opportunity to be heard in a studied manner. It is our opinion at EPA that this information can be derived by the type of hearing format we are using here - where the procedures are informal and a panel of technical experts is used to assure that the information presented is sufficiently clear for public recognition of all viewpoints The information that we seek at these hearings is to provide a technical baseline of information on radiation protection aspects of the transuranics, but also can be addressed to any one or all of the value judgments that I have described.

We are earnestly seeking out all available information. The record of this hearing will constitute one of many sources of input of information to that end. I want to emphasize that point -- the record of this hearing will certainly make a significant contribution to establishing the information input, but it is by no means intended to be the only one. Our technical staff is already analyzing the problem, we have let a number of contracts, and we have also requested written submissions from the technical community and the general public by a Notice in the Federal Register of September 23, 1974. All of this

information will be studied and evaluated and only in this way can we hope to include all pertinent consideration in our standard-setting processes. It may be necessary for us to hold a second round of hearings in another part of the country, possibly Denver, as has been requested by local people if the demand for such a second hearing materilizes. In any case the record will remain open for 30 days after the final hearing date so that all may have an opportunity to comment or rebut and additional material may be provided. All material received will become part of the transcript of the hearings.

Now for some specifics of the problem before us. The elements which are under consideration here include plutonium, neptunium, americium, curium and all the others through atomic number 103. These elements are all man-made. Forty years ago they were unknown. Today, they are produced in large quantities in nuclear reactors. They form a central part of our national defense, nuclear power industry and space research program. They are beginning to appear in consumer items such as smoke detectors and static eliminators. Research and development is underway on such items as heart pacemakers and heart pumps. The list is expanding as larger quantities become available.

The potential hazards of exposure to plutonium were recognized very shortly after the first milligram quantities of this element were isolated at Oak Ridge in 1943. There is a long history of concern related to these elements. Much work has been done on the toxicology of plutonium -- but much has yet to be learned. Similarly, the environmental transport mechanisms -- especially those occurring over

extended periods of time -- are not yet well defined and much more work needs to be done. Yet the picture is not quite so bleak. Probably more work has been done, and more money has been spent, in trying to unravel the mysteries of plutonium than is the case for most potentially carcinogenic substances. The earlier studies were motivated primarily by a concern for the safety of plutonium workers, and most of the early guidelines were specifically for occupational exposure levels. Exposure guidelines have been gradually decreased as new information was developed and current maximum permissible body burden values were adopted by the NCRP and ICRP in 1959. These are under continuing consideration by all standard-setting organizations and cannot be considered to be static.

A central item in our considerations involves estimates of the total cost of plutonium utilization in terms of numbers of potential adverse health effects. For this purpose we intend to utilize the concept of a "dose commitment," which includes consideration of the cumulative effects of a persistent radionuclide over the entire time it is expected to remain in the ecosystem. This approach is especially important for the long-lived radionuclides, where the effect of their release to the environment is largely irreversible and preventive action is called for. The parameters required for such projections include an estimate of the growth of the plutonium inventory, estimates of release fractions, and estimates of exposed populations.

Estimates of plutonium inventories, other than those of the defense establishment, rest largely on projections of the future of the nuclear

power industry. Plutonium is produced in every light-water reactor. It is the utilization of this material that is largely in doubt. There are proposals to utilize mixed oxide fuels now pending before the AEC, which would increase the amount of plutonium to be recycled. Somewhere in the future there is probably the emergence of the fast breeder reactor, which would increase the total plutonium inventory by less than an order of magnitude but significantly increase the amounts to be reprocessed and recycled. Thus there is a degree of uncertainty in our projections and we are most interested in developing a better data base.

In order to develop a baseline for those judgments of a managerial nature which are concerned with adherence to a standard, it is necessary to know both the current contamination levels and the limits of the measurement processes. Much work has already been done in measuring environmental levels in the past, and the work is continuing. Analytical techniques are being refined and will become ever more capable of measuring smaller and smaller quantities with better accuracy.

As all of you probably know, there is already an existing worldwide inventory of plutonium. Most of this was contributed by the early weapons tests, with some additional contamination in the vicinity of certain facilities which have handled these materials. I should emphasize that, in relation to the large quantities handled, the releases from these facilities have been miniscule. This is a testament to the early recognition for strict control of such releases and the need for constant vigilance. There is nothing that can now be done

about the background levels already in existence. There is, however, a need to examine the somewhat higher levels in the environment around certain facilities, and to attempt to minimize releases in the future.

One important element of our standard-setting process is that other interested and involved Federal agencies be brought into our deliberations early and that their input be given due consideration. Only in this way can we develop standards which are truly representative of the entire Federal establishment. We have therefore set up an Interagency Advisory Committee to assist us in this task. Several members of this group are here this morning as observers to these proceedings. This group will provide both technical input and coordination. However, the final promulgation of standards rests with the Administrator of EPA and will follow EPA standard setting procedures. Nevertheless, the purpose of the Interagency Advisory Committee is to look at all aspects of the problem in a coordinated fashion. It is expected that participating regulatory agencies will set their own standards in conformance to EPA standards when they apply, and to set their own regulations in accordance with general Federal guidance when EPA generally applicable environmental standards do not apply. The objective is to achieve a total Federal approach to the problem, rather than a series of fragmented efforts.

There is one problem on which I would like to touch because I expect that it may occupy a major part of our attention during both this hearing and the deliberations to follow. The radionuclides of which we speak here are predominantly alpha emitters. The releases to the

environment are often in particulate form and may be inhaled. Because of the low penetrating power of alpha radiation, any damage to the tissue surrounding such an inhaled particle is restricted to the immediate vicinity of such a particle. The question that was first raised at the Chalk River Conference on Plutonium in 1949 and has perhaps never been conclusively answered is whether the total radiation dose received should properly be averaged over the receptor organ (which in this case is the lung) or whether the exposure limits should be based on the intense localized doses received. The Natural Resources Defense Council petitioned both the AEC and EPA in February of this year to lower the current guidelines for permissible air concentration values by a factor of more than 100,000 based on precisely this argument. We certainly intend to consider this aspect with all the attention it deserves.

Finally, let me repeat that this is an information gathering hearing. For purposes of conducting these hearings we have appointed a panel of distinguished scientists. Their job is to assure that all information is brought to light and that all sides of a question are considered fairly and adequately.

Now let me introduce the Panel:

MELVIN FIRST

Dr. Melvin First was born in Boston and received his Doctorate of Science in Industrial Hygiene from Harvard. He has served with the Michigan Department of Health and is now on the faculty of the Harvard School of Public Health. He is well known for his many contributions in air and gas purification.

KARL Z. MORGAN

Dr. K. Z. Morgan was born in Kannapolis, North Carolina, obtaining his Ph.D. in Physics from Duke University. He became Director of the Health Physics Division at Oak Ridge National Laboratory in 1943. He is a member of the NCRP as well as the ICRP and is presently the Neeley Professor in the Nuclear Engineering Department at Georgia Tech.

EDWARD RADFORD

Dr. Edward Radford was born in Springfield, Massachusetts. He earned his M.D. degree at Harvard where he taught at the School of Public Health. He is professor of Environmental Medicine at the Johns Hopkins School of Hygiene and Public Health.

JOHN GARNER

Dr. John Garner was born in the United Kingdom where he was educated, majoring in biochemistry and received his doctorate in Veterinary Science at Liverpool. After serving in several assignments in Africa and the U.K. he came to the U.S. in 1965. He served as the Director of the Collaborative Radiological Health Laboratory at Colorado State University from 1965 to 1972. He is now Director of the Experimental Biology Laboratory of EPA at Research Triangle Park in North Carolina.

WILLIAM A. MILLS

Dr. William A. Mills was born in Lynchburg, Virginia, received his Ph.D. in Biophysics from the Medical College of Virginia. He is a Commissioned Officer - U.S. Public Health Service, current rank Scientist Director. Past employment; Oak Ridge National Laboratory, The Southeastern Radiological Health Laboratory, Bureau of Radiological Health and is currently the Director of Criteria and Standards Division, Office of Radiation Programs, Environmental Protection Agency. Field of specialization is the Bioeffects of Radiation.

LAURISTON S. TAYLOR

Dr. Lauriston S. Taylor was born in Brooklyn, New York obtaining a D.Sc. degree from the University of Pennsylvania in 1960. He worked at the National Bureau of Standards for many years starting in 1927; becoming Chief of the Radiation Physics Division in 1960. He now serves as the President of the National Council on Radiation Protection and Measurement.

Dr. Mills will be the presiding officer at the hearing. Bill, let me turn the hearing over to you.

Dr. Mills: Thank you, Bill.

Let me briefly review some of the procedures and requirements that will be applicable to this hearing.

We need to say it was announced in the Federal Register. The hearing will be conducted informally. Technical rules of evidence will not apply. Discovery and cross examination of participants will not be permitted.

The hearing panel is appointed by Dr. Rowe, and will consist of a chairman and three or more experts in the field of radiation protection. The panel will conduct the hearing. The chairman of the hearing panel is empowered to conduct the meeting in a manner that in his judgment will facilitate the orderly conduct of business, to schedule presentations of participants, and to exclude material which is irrelevant, extraneous or repetitious.

Persons wishing to present an oral statement are asked to give notice no later than November 23, 1974, in order to be placed on the agenda. The time allotment for such oral statements shall be at the discretion of the chairman. Ordinarily, it will not exceed 20 minutes.

Persons wishing to submit written statements regarding the agenda items may do so either in advance or during the hearing. Such persons may also request an opportunity to present an oral statement.

Oral presentations may be presented by panel discussion of technical experts chosen to present a particular viewpoint in notices given. Time allotment for such panel discussions shall be at the discretion of the chairman, but shall not ordinarily exceed 60 minutes.

Requests at the time of the hearing for the opportunity to make oral statements with no previous notice shall be ruled on by the chairman, who is empowered to apportion the time available, but not ordinarily to exceed five minutes.

Questions may be propounded by members of the hearing panel only. I ask that questions be submitted to Dr. Gordon Burley for referral to the panel.

The use of cameras is permitted only before and after the hearing, and during recesses, not during the session.

A transcript of the hearing will be made, and a copy of the transcript, together with copies of all documents presented at the hearing will constitute the record of the hearing.

The copy of the transcript of the hearing will be available for public inspection and copy within 30 days after the conclusion of the hearing at the U. S. Environmental Protection Agency.

To assist the reporter and the audience, I ask that the speakers and panel members avail themselves of the microphones. Also, I would ask that the speakers attempt to limit their remarks in accord with the standard procedures, so that we can reasonably adhere to the agenda as it is shown.

With regard to the agenda, I am not sure I have all the changes, but we have been asked by the General Electric Company to allow them to be our first witness. If I could, I would like to call for the General Electric Company, Dr. Bertram Wolfe. Is he in the audience?

Dr. Radford: Mr. Chairman, before we get to that, I would like to ask, is it the intent that the panel of experts speaking for individual testifiers will be given 60 minutes automatically, or will it be held to a somewhat lower figure?

Dr. Mills: If you are talking about the discussion panel -

Dr. Radford: No. We have several groups coming in, Atomic Industrial Forum and so on who are presenting panel testimony, under the terms of the Federal Register statement.

There, it is stated that panels would not exceed 60 minutes. The question is, will they be given 60 minutes automatically?

Dr. Mills: We would hope that they would stay within a 60 minute limit. They will automatically be given 60 minutes.

Dr. Radford: They will automatically be given 60 minutes?

Dr. Mills: Yes, sir.

Is Dr. Wolfe in the audience?

Dr. Wolfe: Yes.

Dr. Mills and gentlemen, I personally and the General Electric Company are pleased to participate in this public hearing called by the Environmental Protection Agency.

I want to start by thanking the Atomic Industrial Forum for letting me go first. I have an unavoidable conflict this afternoon, and a plane

to catch.

As indicated in the Federal Register of October 24, this hearing concerns itself with the environmental impact of plutonium and other transuranium elements and consideration as to whether new guidelines or standards under the authorities of EPA are needed to assure adequate protection of the general ambient environment.

I have some written remarks on the subject which we will give to you and would like to have in the record. I will not go through the whole thing in the interest of saving time.

I want to indicate that my name is Bertram Wolfe and that I am General Manager of the Fuel Recovery and Irradiation Products Department of General Electric.

Sitting to my left is Mr. Terry Trumbull who is Counsel to the General Electric Nuclear Energy Division.

PUBLIC HEARING

UNITED STATES ENVIRONMENTAL PROTECTION AGENCY

DECEMBER 10, 1974

WASHINGTON, D.C.

PLUTONIUM AND OTHER TRANSURANIUM ELEMENTS

WRITTEN STATEMENT OF THE

GENERAL ELECTRIC COMPANY

NUCLEAR ENERGY DIVISION

175 CURTNER AVENUE

SAN JOSE, CALIFORNIA 95125

ORAL SUMMARY STATEMENT BY:

Bertram Wolfe

General Manager

Fuel Recovery & Irradiation Products Dept.

Terry A. Trumbull,
Counsel

The General Electric Company is pleased to participate in this public hearing called by the Environmental Protection Agency (EPA). As indicated in the Federal Register of October 24, this hearing concerns itself with the environmental impact of plutonium and other transuranium elements and consideration as to whether new guidelines or standards under the authorities of EPA are needed to assure adequate protection of the general ambient environment.

The General Electric Company believes that it would be helpful to both the nuclear industry and the public at large if a sound standard for ambient concentrations of plutonium, other transuranium elements, and other radioactive elements of concern were developed. The emphasis on development of any standard should be on the word *sound*. We believe that current practices in the nuclear industry today, in accordance with AEC regulations, assure that there is no risk to the public health from plants built in accordance with these regulations. Nevertheless, a sound standard would, we believe, provide a benchmark for the public with which they could judge the adequacy of industry measures to assure that the risk to public health is negligible. Similarly, a sound standard would provide a benchmark for industry and government regulatory agencies with which they could set design and surveillance requirements for plants and activities involving radioactive materials. In addition, a sound standard would allow meaningful trade-offs for public consideration as to whether national resources should be devoted to measures to further minimize ambient radioactive levels from human activities or whether these resources might more beneficially be devoted to other areas of public welfare. At present, with no quantitative standards, the public is left with a lingering concern about the health effects of nuclear activities. This is reinforced by the use of the philosophy of "as low as practical," which implies a lack of knowledge to the public and emphasizes continual backfitting or other improvements which are required without regard to any analysis of the costs and benefits to be gained. The use of this philosophy may result in electricity cost increases which are not commensurate with the benefits of relatively minor effluent control improvements.

As noted, the emphasis of our endorsement of the development of standards for plutonium and transuranium elements is on the word *sound*. As indicated

in the following remarks, we believe there is no risk to the public from nuclear activities envisioned in the near future under the AEC regulations. Thus, there is time to develop a sound standard, and the development of such a standard will require substantial research and study which we believe will take a number of years. We endorse the development of such a standard but suggest some general guidelines. First, the standard should consider the possible health effects on individuals in light of the unavoidable risks from radiation which occur because the atmosphere is subject to cosmic-ray bombardment and because the materials of our planet are, in part, naturally radioactive in any event. Further, an extensive cost-benefit analysis needs to accompany the development of any standard. It is imperative that the public as well as governmental decision-makers be aware of the cost of implementing any standard and the risk which would be avoided. For example, the public might be interested to learn what additional costs they can expect to their electric bill from a proposed standard and how the reduction in risk compares to normal risks such as would occur on an airplane flight or in moving from a wooden to a brick house.

Finally, we strongly suggest that if the EPA sets out to develop standards in the area of plutonium and transuranium elements that they work closely with the AEC to avoid the inefficiency of two governmental agencies working independently on the same problem.

I. RECOMMENDED APPROACH TO AMBIENT STANDARDS DEVELOPMENT

The emissions of plutonium and transuranium elements in effluents from nuclear facilities always have been limited by AEC regulations and license conditions. These emission limitations are accomplished by a system of requirements generally as follows:

a. Confinement of radioactive material inside multiple physical barriers;
b. Control of access to plant processing areas through additional physical barriers;
c. Ventilation control such that air flows from areas of lesser to areas of greater contamination potential;
d. Effluent treatment for air by filtration, for liquids by chemical means, and for solids by decontamination methods, all resulting in effluent radionuclide concentrations less than regulatory values.

In some cases, liquids are solidified;

e. Controlled burial of solid waste contaminated with radionuclides above regulatory values; and

f. Measurement of radionuclide concentrations in effluents and on items or materials, as well as other appropriate actions to assure that regulatory values are not exceeded.

These requirements have been successful in limiting the emissions of such materials from nuclear facilities to levels such that the resulting organ-man-rem dose to the public is very low compared to the same dose from naturally occurring alpha-emitting radionuclides.

The EPA estimates* the current annual internal radiation dose to bone (endosteal cells) from natural alpha radioactivity in the United States is 37.1 millirem average and to the lung is a minimum of 100 millirem. Using the EPA figure of 205 million persons in the USA in 1970,* the total organ-man-rem dose in 1970 to these organs is 7.6 and 21 million organ-man-rem, respectively.

Fuel reprocessing is expected to be the dominant source of release of transuranic elements.** The EPA's estimated annual dose accrued to the bone and lung of the United States population from fuel reprocessing in 1970 is 0.001 millirem per person from all radionuclides. About half of this dose results from alpha-emitting radionuclides. The total organ-man-rem dose in 1970 from reprocessing is calculated to be 0.0002 million man-rem to either lung or bone. These doses are 40,000 and 100,000 times less than the corresponding doses from natural alpha radioactivity.

Comparing similar bone and lung doses in the year 2000 for 321 million Americans shows that the natural alpha bone dose is 12 and 32 million man-rem, respectively. In the year 2000, the organ alpha doses from reprocessing plants are expected to increase by about a factor of two.

*ORP/CSD 72-1, "Estimates of Ionizing Radiation Doses in the United States, 1960 - 2000."

**Barr, N. F., "Quantitative Health estimates of Transuranic Releases," paper presented at the October 1974 meeting of the [illegible] Society, Washington, D. C.

Therefore, the total population bone and lung dose in the year 2000 would be 0.0004 million man-rem from this source. These doses are respectively approximately 30,000 and 80,000 times *less* than the corresponding doses from natural alpha radioactivity. Current emission control procedures, therefore, have been demonstrated effective, and the record of performance with these regulations and license conditions does not support a need for urgent change in the near term.

The amount of plutonium currently handled is relatively small. The AEC estimates* population doses always will remain at very low levels--even from the expected release of nuclides due to operation of 2,200,000 MWe of liquid metal fast breeder reactor (LMFBR) capacity anticipated in the year 2020. At any rate, during the next five or so years, the amount of plutonium handled is not likely to increase significantly and will remain very small compared to estimates of quantities to be handled after the end of the century. Thus, there is time to acquire needed information such as real pathways of plutonium to man and more realistic estimates of the effects of plutonium in humans upon which a practical environmental standard could be developed. We understand that Mr. Parker, speaking for the AIF, will describe in more detail some of the research needed. The information required should be delineated, and a specific research plan should be formulated to provide this information so that the development of appropriate environmental standards for ambient concentrations of transuranium elements can proceed on a sound basis.

Meanwhile, the American National Standards Institute should complete development of design criteria for mixed oxide fuel fabrication plants and initiate development of design criteria for fuel reprocessing plants. These design criteria should include specifications for achieving effluent emission control. Until the more quantitative standards are developed, the principle of limiting radionuclide releases to levels as low as practical may have to be utilized. We have indicated that we believe this to be a less than satisfactory long-term procedure, but also that

*ORP/CSD 72-1, op. cit.

it has been effective in limiting man-made ambient transuranium levels to below naturally occurring levels by several orders of magnitude. These design specifications should consider the relative effect of each element or nuclide on man, rather than assuming a single value for the entire class of transuranium elements. The technical reasons for this recommendation were set forth in the General Electric comments on the proposed amendment of 10 CFR 20 and 150 concerning disposal of transuranic waste by burial in soil.*

The AEC should continue its plant-by-plant control of radionuclide emissions by regulations and license conditions. Environmental monitoring should continue around nuclear facilities to obtain data useful in the overall research plan.

We should like to emphasize that meaningful standards on ambient concentrations of transuranium elements should be consistent with design and operating requirements for nuclear facility effluent control and waste management. Thus, development of such standards should involve a cooperative effort of all concerned governmental agencies to avoid both duplicative, costly efforts by these agencies and the confusion which would result if nuclear facilities were faced with the need to conform with inconsistent or conflicting requirements.

In summary, we believe that present regulatory requirements for the design and operation of nuclear facilities are effective in assuring that the public benefits from operation of these facilities are not negated by effects inimical to the public health. On the other hand, we believe that quantitative standards for ambient levels of transuranium elements, based on sound benefit-cost analysis data, would have significant additional benefit to the nuclear industry and the public at large. We support the development of such standards and the supporting research efforts necessary for their development.

II. GENERAL ELECTRIC DIRECT EXPERIENCE IN HANDLING AND USING PLUTONIUM

A. Experience with Plutonium at Vallecitos Nuclear Center

The General Electric Company has been actively engaged in the development of plutonium-bearing fuels since 1959 at its Vallecitos Nuclear Center (VNC),

*Letter to the AEC, dated 11/6/74, signed by A. N. Tschaeche of General Electric Co.

located in the San Francisco Bay Area. The plutonium laboratory was established at General Electric's Vallecitos Nuclear Center in 1962, expanded in 1967 to increase fuel fabrication capacity, and expanded again in 1971 to include scrap recovery. For over 15 years, VNC has been fabricating plutonium fuels, developing process and control methods and equipment, and studying fuel properties.

Plutonium work has not been confined to the Plutonium Laboratory. Examinations of mixed oxide fuel rods and capsules are carried out in the VNC site's alpha hot cells. Mixed oxide capsules are irradiated in General Electric Test Reactor (GETR) and neutrographed at the Neutron Test Reactor (NTR). Practically every facility on site has at one time or another performed work with plutonium.

Over 1100 fuel rods have been fabricated for fast and thermal reactor programs, using four process methods, six cladding methods, 60 kg of plutonium, over 1.2 metric tons of mixed oxide fuel and some 171,000 pellets. The fuel pins were fabricated under stringent product quality control conditions and were produced to meet a variety of design requirements. These fuel pins have been irradiated under varying conditions in five different test reactors and four commercial power reactors.

General layout and arrangements for plutonium handling facilities are based on multiple enclosure, separation of facilities and minimum fissile quantities. Construction materials, ventilation, glove-box design, lighting and radiological controls have also played a key role in safety considerations.

The VNC environmental monitoring program was established to measure any significant increase (above natural background levels) which may be attributed to plant operations and to ensure that the amounts of alpha as well as beta-gamma activity released to the environment are controlled. The radioactivity in the environment both on and adjacent to the site is measured.

The work performed at VNC over the last 15 years has been accomplished in a safe and efficient manner without [illegible]. Plutonium has been

controlled at all times to minimize release to the VNC environment to levels substantially below regulatory requirements and generally to several orders of magnitude below such requirements. For example, less than three microcuries of alpha-emitting materials have been released per year to the environment from the stack of the Plutonium Laboratory, and essentially all of these releases have been naturally occurring daughter products of uranium and thorium, not transuranium elements. These emissions are insignificant and illustrate the effectiveness of control at the Vallecitos site.

None of the individuals employed through the history of the plutonium work at the site has ever experienced an internal deposition of plutonium measurable with existing methods and procedures. It is estimated that about 350 man-years of work have been directly connected with plutonium at Vallecitos. There has been only one "reportable" occurrence involving plutonium at VNC and that consisted of a plastic bag being torn from a glove box during a maintenance operation. Contamination was confined to the room.

Vallecitos experience shows that the plutonium economy of the future can and should be approached with confidence. Further details on General Electric Vallecitos experience are contained in the references listed below.

References:

1. Quarterly Report and Accumulative Annual Summary of the Vallecitos Nuclear Center Self-monitoring Program, 1973 - 1974.

2. Annual Reactor Operating Reports, TR-1 (GETR) and R-33 (NTR).

3. VNC Stack Release--Ground Dose Rate Determinations in Support of the Zero Release Study, November 6, 1972.

4. GE/VNC Safety Standard titled, "Regulation of Radioactive Effluents," July 1974, No. 2.3.2.

5. Environmental Monitoring Manual, Vallecitos Nuclear Center, NEDO-12449, November 1973.

6. Statistical Evaluation of the VNC Environmental Sampling Program, 1965 - 1973, NEDO-12534, October 1974.

7. Environmental Surveillance for Radioactivity Vallecitos Nuclear Center (five operating history reports): NEDO-12481, NEDO-12405, NEDO-12341, APIO-1013-2 and APIO-1013-1.

B. Experience with Plutonium at SEFOR

General Electric has had significant experience with plutonium with the SEFOR facility. This reactor was operated for about three years (March 1969 through January 1972) using plutonium fuel. As a part of the extensive testing program, deliberate overpower transients which subjected the fuel to repeated dynamic conditions in excess of those in a commercial power reactor were induced to demonstrate the inherent shutdown capability of the LMFBR. During the entire period of SEFOR operation, there was no release of plutonium to the environment or deposition of plutonium in plant operating personnel as determined by standard detection and measurement instrumentation in environmental and personnel monitoring programs.

SEFOR was charged with 380.4 kg of plutonium and generated 25,764 MW hours of energy during a total operating time of 3,895 hours. The total operating experience includes about 117 man-years involving plant personnel.

Details of this plutonium experience gained during the operation of the reactor are contained in the references listed below.

References

1. Meyer, R. A., Reynolds, A. B., Stewart, S. L., Johnson, M. L., Craig, E. R., "Design and Analysis of SEFOR Core 1," GEAP-13598, June 1970.

2. Field, J. H., Johnson, M. L., Novak, P. E., "An evaluation of the Effect and Design and Operating Variables on SEFOR fuel and Fuel Cladding," GEAP-5309, December 1967.

3. "Southwest Experimental Fast Oxide Reactor Development Program, Thirty-First and Final Report, November 1971 - January 1972.

4. Rider, B. F., Ruiz, C. P., Peterson, Jr., J. P., McLaughlin, T. V., "BURNUP: A FORTRAN IV Code for Computing U and Pu Fuel Burnup from U, Pu, Nd Mass Spectrometric Measurements--Updated to Include Fast Reactor Fuels," GEAP-5355A, revised January 1970.

5. Noble, L. D., et al, "SEFOR Core I--Test Results to 20 MW," GEAP-13702, April 1971.

6. Noble, L. D., Kussmaul, G., Derby, S. L., "Experimental Program Results in SEFOR Core II," GEAP-13838, June 1972.

7. "Standard Method of Test for Atom Percent Fission in Uranium and Plutonium Fuel (Nd-148 Method)," ASTM Designation E321-67, General Test Methods, ASTM Standards, Part 30, [illegible].

8. Cohen, K. P., Greebler, P., Horst, K. M., Wolfe, B., "The Southwest Experimental Fast Oxide Reactor," VIII Nuclear Congress, Rome, Italy, June 17 - 20, 1963.

9. "SEFOR Preliminary Safeguards Summary Report," submitted to the Atomic Energy Commission on October 16, 1964, and Supplements 1, 2, 3 and 4.

10. "Southwest Experimental Fast Oxide Reactor Plant Operating Report," First Quarterly, May 1, 1969 through July 31, 1969.

11. "Southwest Experimental Fast Oxide Reactor Plant Operating Report," Second Quarterly, August 1, 1969 through October 31, 1969.

12. "Southwest Experimental Fast Oxide Reactor Plant Operating Report," Third Quarterly, November 1, 1969 through January 31, 1970.

13. "Southwest Experimental Fast Oxide Reactor Plant Operating Report," Fourth Quarterly, February 1 through April 30, 1970.

14. "Southwest Experimental Fast Oxide Reactor Plant Operating Report," Fifth Quarterly, May 1 through July 31, 1970.

15. "Southwest Experimental Fast Oxide Reactor Plant Operating Report," Sixth Quarterly, August 1, 1970 through October 31, 1970.

16. "Southwest Experimental Fast Oxide Reactor Plant Operating Report," Seventh Quarterly, November 1, 1970 through January 31, 1971.

17. "Southwest Experimental Fast Oxide Reactor Plant Operating Report," Eighth Quarterly, February 1, 1971 through April 30, 1971.

18. "Southwest Experimental Fast Oxide Reactor Plant Operating Report," Ninth Quarterly, May 1, 1971 through July 31, 1971.

19. "Southwest Experimental Fast Oxide Reactor Plant Operating Report," Tenth Quarterly, August 1, 1971 through October 31, 1971.

20. "Southwest Experimental Fast Oxide Reactor Plant Operating Report," Eleventh Quarterly, November 1, 1971 through January 31, 1972.

21. Regimbal, J. J., et al., "Fuel Failure Detection Capability at SEFOR," Trans. Am. Nucl. Soc. 14, p. 69, June 1, 1971.

III. NATIONAL INCENTIVES FOR USE OF PLUTONIUM AS REACTOR FUEL

Any national solution to our energy supply problems over the next few decades must include the expanding use of nuclear energy. Unless nuclear power is fully utilized, it is questionable whether we can meet our national energy needs without major degradation in our living standards and painful social and economic dislocations. Without nuclear power, there is no hope of coming close to national energy self-sufficiency.

The use of nuclear energy results in the production of plutonium which is a valuable commodity and at the same time, a potentially hazardous material which must be carefully managed. We have indicated previously that several decades of experience have shown that plutonium can be managed in accordance with AEC regulations so as to result in no effect on the public. Indeed, the use of this plutonium as recycle fuel in thermal reactors and ultimately in fast reactors will have significant overall benefits to the welfare of the public.

By the end of the next decade, operation of our nuclear plants will have produced over 500 tons of fissile plutonium. Use of this material in the form of mixed oxide fuel in present light water reactors will save the public over five billion dollars in cost of electricity. Perhaps more importantly, use of this plutonium in lieu of oil would save over ten billion barrels of oil and in excess of 100 billion dollars in foreign exchange.

In the longer term, plutonium used in fast breeder reactors can provide a low-cost energy supply for this nation and the world for the indefinite future. In the following discussion, the benefits of plutonium use in fast breeders are described in financial terms. This analysis may significantly understate the case, since without the fast breeder in the next century, the nation may be faced with energy needs which cannot be satisfied in any other acceptable manner.

III. NATIONAL INCENTIVES FOR USE OF FAST BREEDER REACTORS

In addressing factors involved in cost/benefit analyses for the use of plutonium, the General Electric Company recently participated in a study to evaluate the incentives for the fast breeder reactor, which uses

plutonium as its principal fuel. General Electric believes that the use of breeder would result in lower power costs, less [illegible], and substantial assistance toward achieving the national goal of energy self-sufficiency.

This in-depth economic study was initiated jointly several months ago by Commonwealth Edison and General Electric. Commonwealth Edison engaged the services of an economist from Harvard University and an experienced consulting engineer from the uranium mining industry.

For the study, a reference case was chosen on the basis of the best current projections for both the capital costs of a breeder reactor and the availability of uranium ore. An accurate means of comparing future benefits against development costs was also developed. This reference case indicated that there will be a 157 billion-dollar benefit through the year 2050 from the breeder, measured in 1974 dollars (discounted from an actual total benefit of 3.8 trillion dollars). These savings come mainly from uranium utilization, since the breeder converts the very abundant U-238 to usable plutonium fuel. The importance of using this U-238 in the achievement of energy self-sufficiency must also be considered, since projections show domestic high-grade uranium ores being depleted about the year 2000. After this, the United States would be forced to exploit very low-grade uranium shales, with an energy content that is no more than coal.

The critical projections input to this study was also modified in a sensitivity analysis in order to determine how sensitive these incentives for the breeder may be to varying future conditions. For example, analyses were run based upon assumptions that the currently estimated availability of uranium ore was doubled, the capital cost of breeders raised from 1-1/4 to 2-1/2 times that of light water reactors, and the electrical load growth rate was reduced from six to four percent per year. All cases still resulted in many tens of billions of dollars saved as a result of use of the breeder.

In addition to economic incentives, there are environmental reasons for choosing fast breeder reactors as a future source of energy,* as with all nuclear reactors, breeder reactors can operate with essentially no atmospheric pollution. Moreover, there will be no need to mine new breeder fuel for many decades and only minor amounts will be required after that, Conversely, without the breeder, both the coal and uranium mining industries will have to increase to many times their present sizes, much of it involving highly disruptive strip mining.

*Gibson, R. S., "The Liquid Metal Fast Breeder Reactor," Handbook of Energy Technology, McGraw-Hill Co., (to be published).

Dr. Mills: Thank you very much, Dr. Wolfe.

An initial question: In the experience of General Electric, how do you define "as-low-as-practical" in your use?

Dr. Wolfe: I am not sure, Dr. Mills, that there is indeed a definition of "as-low-as-practical." I think that is one of the difficulties the nuclear industry has in designing nuclear facilities in general.

One looks at the technology available and designs nuclear plants and new processing plants so that he gets as close to zero release of everything as he can.

But "as-low-as-practical" of course depends upon the state of the art at the particular time; if one develops, for example, a new instrument to measure radioactivity it now becomes practical to take other measures.

One of the problems we have in nuclear plants is that the release in terms of ambient levels at least is so low that one cannot measure the release around nuclear plants.

One of the other problems we have is that as new techniques are developed, it then does become possible to get lower and lower levels measured, which sometimes requires backfitting, which we believe in many cases may cause an increase of cost to the consumer without any real benefit.

Dr. Mills: I take it, what you are saying from your own experience, limiting the "as-low-as-practical" concept to give control technology to reduce the level of emission may not be sufficient if one looks at the

practicality of the measurement in the environment?

Dr. Wolfe: No. I think our feeling is that "as-low-as-practical" is to produce levels of radioactive emissions to the environmental picture very low compared to any sensible standard relative to public health.

Our concern with "as-low-as-practical" is its a nebulous concept. I am not able to define it very well for you, because it is nebulous. We think it implies to the public a lack of knowledge which the public might interpret as meaning there is an unknown hazard which might affect them.

We think also that the "as-low-as-practical" philosophy may be leading to increase in plant costs and, thus to cost to the consumer which really is not transferrable to any benefits they receive from perhaps minor deductions from effluents which may become practicable at the time.

I might add that this is not a unanimous view. I had breakfast with Mr. Parker who, in fact, does support the "as-low-as-practical" philosophy. I think it is a generally poor philosophy for an industry to follow.

I think no other industry follows it. I think we should understand where the threshold, the cost-benefit level, is reasonable in terms of providing benefit to the public relative to the risk. We should then set quantitative standards significantly below that.

I think the nuclear industry would agree with almost any reasonable standard that would be set.

Dr. Mills: Dr. Taylor?

Dr. Taylor: I have a comment. The big difficulty with this discussion of "as-low-as-practical" centers about the fact that the government has tried to quantitate the concept "as-low-as-practical."

If you read all the discussions of the NCRP and ICRP, you will find this was not supposed to be quantitated. It is good advice, generally; the numbers that are set by these bodies and others are believed to be numbers that are acceptably safe.

On the other hand, one should always use good judgment on improving on his protection practices, if he can. But you should not try to tie numbers to this.

You cannot put a numerical value on "as-low-as-practical." As soon as you do that, you have a new set of standards.

Dr. Mills: Dr. First, do you have any questions or comments?

Dr. First: I would like to echo what Dr. Taylor has just said, and also to point out, although, Dr. Wolfe, you have said that no other industry adheres to this practice, I think this is incorrect in that for many, many years, standards for occupational health have always included the provision that one must not exceed the standard, but at the same time, should expose the worker to no more of the mentioned substance than is practical.

I think this is a reasonable way to handle it. It is not unique for your industry.

I did, however, want to ask you a question on a statement on page 5 of your testimony. It says:

"We should like to emphasize that meaningful standards on ambient concentrations of transuranium elements should be consistent with design and operating requirements for nuclear facility effluent control and waste management."

Do I interpret that to mean the standard should follow with the best practice, rather than the best practice should try to meet the standards?

Dr. Wolfe: No. I think the statement is meant to be much less subtle than that. It really is meant to emphasize that a standard that the EPA comes out with on ambient levels should, in fact, be consistent with the requirements of the AEC or successor organizations that they placed on nuclear plants, that a meaningful standard on ambient levels should be reflected in AEC or NCRP requirements.

On the effluents from plants, the plant designer or plant operator should not be faced with perhaps inconsistent requirements.

With respect to your other comment, I want to make it clear, I do not think anyone in the nuclear industry suggests that one should not take reasonable measures whenever he can that would reduce effluents, even though he had already been well below the regulatory standards or regulatory requirements.

I do not think that there was any argument that one should use prudence in the same way as I take it the occupational hazard situation you are suggesting, that one should meet the standard but at the same time he should take all reasonable measures to further protect workers.

I do not think there is any inconsistency there with what I said. On the other hand, I think that if you look at occupational standards

rules, you do set standards and people are measured by those standards. I do not know that they are really measured by then going in and seeing how far below the standards they reach, which is the situation from a regulatory standpoint in the nuclear energy business.

Dr. Mills: Dr. Radford?

Dr. Radford: Dr. Wolfe, just for the record, I would like to say that I agree with you completely about the "as low as practicable" concept as it applies to trying to engineer control. I also do not think that the "stay as low as practicable" really helps the public very much in terms of deciding whether or not there are significant risks.

I would like now to ask you a few questions.

You mentioned that General Electric has now had about 25 years of experience in handling plutonium. Is that right?

Dr. Wolfe: We have had about 15 years in our commercial facility in San Jose. Of course, we were the contractor for Hanford prior to that, starting in the early 1940's.

Dr. Radford: In your current operations, you stated you had had this experience and that you had had no problems, or words to that effect?

Dr. Wolfe: That is correct.

Dr. Radford: How did you determine whether you had problems or not? What sort of programs do you have within the plant to determine this?

Dr. Wolfe: In the written testimony, Dr. Radford, we describe a number of measures that we take at Vallecitos in the laboratory.

We, of course, monitor the effluents coming out of the plant. The statement I made in the paper was the plutonium was controlled at all

times to minimize release to the environment. Of course, there are measurements that indicate that less than three microcuries of alpha emitting materials have been released per year to the environment from a stack of plutonium, in the material that goes out through the stack.

Essentially, all these releases have been the naturally occurring daughter products of uranium, not transuranium elements. So these are insignificant to illustrate the effectiveness of the site.

We take, of course, periodic and regular site surveys. I might also add that at the site we do have some very sophisticated measuring techniques that are not generally used industrially.

We use these to further examine plutonium and transuranium elements.

So that is the basis.

Dr. Radford: Then, you say you have not released more than x microcuries of alpha activities from the stack. Is that determined by actual measurements?

Dr. Wolfe: Yes, measurements.

Dr. Radford: At the stack?

Dr. Wolfe: Yes.

Dr. Radford: I see.

Dr. Wolfe: We, of course, monitor our personnel, looking for internal deposition of plutonium. Of course, the measuring techniques for this are very difficult, because you are trying to measure low levels of plutonium against a background.

We estimate that about 350 man-years of work has been directly connected with plutonium at Vallecitos. We have had only one reportable

occurrence involving plutonium, and that consisted of a plastic bag being torn from a block during maintenance operation, and contamination was confined to that room.

We essentially have had no measurable effects on any of the personnel working at Vallecitos.

Dr. Radford: Do all the workers who are working with plutonium get called for counting periodically?

Dr. Wolfe: Right.

Dr. Radford: The experience is that they have been close to background?

Dr. Wolfe: They have been close to background. This is a case where it is very difficult to measure. I will tell you that we have had one case where a new measuring technique came up and gave us a little bit of concern.

We then took these people and sent them to Los Alamos, where they had more sophisticated information for measuring devices. It turned out that the original measurements had been incorrect.

It is very difficult to make these measurements, as you know.

Dr. Radford: A question on the occupational part.

How many workers overall have been exposed to plutonium, or at least work with plutonium, during your 15 years?

Dr. Wolfe: The estimate I have here is about 350 man-years of work has been directly connected with plutonium.

The plutonium laboratory employs about 40 people. That has been

going on for nine or ten years.

Dr. Radford: This is essentially a research operation.

Dr. Wolfe: That is correct.

Dr. Radford: I see. Would you have any opinion about the ability of other facilities that are more commercially oriented towards handling plutonium?

Dr. Wolfe: I am not prepared to talk about existing facilities other than to know that the government facilities have handled plutonium in larger quantities than, of course, we have at Vallecitos.

I do feel that there is no reason why properly designed and operated facilities could not have the same good experience as we had in our smaller facilities at Vallecitos, or that the government has had in their operation of facilities.

Mr. Trumbull: I might also note that other commercial facilities are subject to the same requirements that we are at Vallecitos, such as those that are listed on pages 2 and 3 of the written testimony. There are six different types of requirements that all commercial facilities are directed to meet.

Dr. Radford: That is the thrust of my question. Do you believe that, in fact, these commercial facilities have adhered in all instances to federal regulations or state regulations as they apply?

Dr. Wolfe: Well, I read the papers, the way everyone else does. For example, to be very candid, I am just not prepared to discuss the recent Kerr-McGee publicity.

I just have no idea whether there is anything to it or not. I think the fact is that these facilities can be designed and operated safely, in accordance with government regulations.

Experience indicates that in fact we have. I see no reason why they cannot be and should not be. I think that handling plutonium requires that one exercise diligence and care.

I think the nuclear industry in general has exercised that care in the past.

Dr. Radford: Now specifically, you are aware that the Atomic Energy Commission required the Nuclear Fuel Service plant shut down?

Dr. Wolfe: Yes.

Dr. Radford: I am not saying over what issue, but certainly the issue being that there were breaches of their required containment.

The General Electric Company was to embark on the fuel reprocessing business but are not now planning to, or are they?

Dr. Wolfe: We have a plant at Morris, which we are presently looking at in terms of trying to decide whether we should modify it and operate it in the future as a reprocessing plant or whether, in fact, the design deficiencies on that plant which were turned up during the pre-operational phases before there was any radioactive material in the plant, whether those design deficiencies are such that, in fact, it would not be a sound commercial venture to go ahead with that plant.

I cannot answer you as to what the ultimate disposition of that plant will be. I will, if you will allow me, make the following statement about

that plant.

The technology that we used on that plant resulted in essentially no effluent release to the environment, the exception to that being some krypton and some tritium, a small amount that was released through the stack.

There was essentially no plutonium that was released. There were no fission products. They were all solidified, kept on site, stored, and would have been shipped to AEC facilities in accordance with regulations.

We had a problem at Morris which involved just an industrial process of handling solid powders, which we encountered when we operated the plant with natural uranium. It had nothing to do with radioactive fuel.

We believe that the technology that we used at Morris in the fuel recovery plant would be applicable to another facility which handles the product in a different way.

In fact, that plant would have operated as a plant based on the same principle and will operate with essentially no effluent release and no ill effects to the public.

Dr. Radford: That is all supposition, because the plant has never operated?

Dr. Wolfe: That is correct.

Dr. Radford: Technology has not yet operated, so that in terms of the record we have at the present time, we cannot really base it on that?

Dr. Wolfe: You certainly cannot use the Midwest Fuel Recovery Plant as an example of an operating plant.

Dr. Radford: Just a couple of other questions here, Dr. Wolfe.

You stated in the cost-benefits study which General Electric commissioned, some aspects of the problem of, say, the current light-water technology, one of them being, after the year 2000, the exploitation of base technology would require perhaps high energy as well as foreign exchange costs in obtaining adequate fuel.

Is that essentially correct?

Dr. Wolfe: It is basically correct. What we did was we used AEC estimates of available uranium. The AEC estimates require there is about two and a half million tons of uranium in concentrations above, say, a hundred parts of a million.

Thereafter, one would have to go to things like the Tennessee shales for concentrations below 80 parts. This would require huge mining efforts and might have environmental effects that would make it highly undersirable.

Dr. Radford: So that basically your point, I believe, was that we are really here talking about a breeder reactor program.

In other words, as far as future developments are concerned, it is essentially a breeder based program, correct?

Dr. Wolfe: I think when you are talking about the end of the century, hopefully we are talking about breeder programs.

In the interium period, I think plutonium recycle would have benefits to the nation in terms of augmenting the uranium supply, providing time for the breeder to come on.

In that period, we do, as I say, have some foreign exchange problem.

Dr. Radford: One further question, with regard to the number of millions of barrels of oil which are approximately consumed nowadays.

In terms of foreign exchange improvements, I believe it has been stated both by federal panels and others that if we have automobiles right today that got 20 miles to a gallon, we could, with no change in the numbers of automobiles operating, immediately eliminate all of our foreign exchange losses.

Do you agree with that?

Dr. Wolfe: I would like to answer that question in a more general sense.

I think there are a lot of things that the nation could do to take care of its future energy supply. In principle, some of them might be more desirable forms of energy.

Nuclear energy, I think, is beneficial to the nation. It does have potential problems connected with it. It does have a problem of the ultimate waste.

So there are a number of alternates that one could talk about to take care of the problem in a different way.

Let me answer your question on automobiles, because I think that is a short range problem.

The fact of the matter is that the world is going to run out of oil and fossil fuels, possibly by the end of the century. So the world is going to be faced with surviving on a ever less amount of fossil fuels, towards the end of the century. In this country, we have already -- Now,

you can look at alternates. The one I would like to mention is solar power.

This is a wonderful source of power which, in principle, if you listen to the advocates, has no problems. I think the problem with solar power-you know, several years ago when people were moving to California, Nevada put up a billboard on the boundary which said, "There is no California."

The fact of the matter is there is no solar energy. Solar energy is a dream. I think it should be worked on. I think we ought to go after it. But the fact of the matter is, nobody in this room today can describe to me a solar energy plant, what it looks like.

Furthermore, the idea that the solar energy plant will not have hazards is, in my opinion, fallacious. Depending upon how you approach it, you can have very hazardous conditions. If you go out to space and you beam the power to the earth, slight malfunctions in the beam could wipe out large areas of the country.

If you do it on land, you are talking about large areas of use which might have, for instance, climatic effects at least in a local sense. I do not know that it will, but at least these are things that you have to look out for.

A thousand megawatts solar plant would require about 40 square miles of area. If you used today's solar cells, the average household electricity bill would be about $50,000 a month.

If you took the 40 square miles and found out how to construct that plant so that total cost of construction in terms of solar cells,

supporting structures and all the other electrical needs such as battery storage, if that total construction could be brought down to the cost of an industrial building on a square foot basis, you would be talking about an electricity bill of about $5,000 a month in today's dollars.

That is not to say we should not go after solar power, but the fact is, it is not here today. As I said, no one can tell me what it looks like today.

We do know how to make nuclear plants. We have got breeder reactors. They are operating. It seems to me that we ought to follow the leads and take advantage of what we have.

At the very least, perhaps nuclear power in the breeder will provide time to develop more desirable energy sources if, in fact, it can be developed. I hope they will be.

Does that answer your question, in general, about the automobile?

Dr. Radford: More than answers.

Dr. Mills: Dr. Garner?

Dr. Garner: I am going to get Dr. Radford to change places with me, because he stole my two questions.

Let me pick up one of these points.

If I were a member of the public, I would be extremely skeptical of some of the things which you said. After all, these people can read.

They read about leakages of plutonium from commercial plants. They have heard about the recent Oklahoma incident. True, the plant is not a commercial plutonium separation plant, but in the last quarter report, we

read of the release per year over the last two years or so of curium, not plutonium.

I think we are entitled to be a little skeptical about the efficiency of present hold up systems and so forth for plutonium in a plant. This is not to decry the fact that G.E.C. has been very successful. I am merely saying that given the best of technology, the opportunity is there for plutonium and other materials to be released to the environment.

We have to recognize this. Now, having said that, I want to go to another point, because you said you are not going to comment on this.

I was going to ask if you would comment on it. I entirely agree with you about some of the things you said about solar energy. It is not with us yet, and is nowhere near us yet.

I do not agree with your statement about the effects of microwaves when solar energy comes. Perhaps the, we will have a hearing like this to discuss it.

The fact of the matter is, and I would like to bring this out right early in these proceedings, we have two alternative sources of energy, two practical sources of energy: fossil fuel that we are all familiar with, and nuclear energy which we are on the verge of.

Unfortunately, as in most cases, we are holding hearings on basically the health risks, I think is what it comes down to, of one particular form of energy production, that is nuclear energy production, and one particular aspect of it.

We are considering this in total isolation from the risk from

alternative sources. I think everybody has to understand that every source of energy has its risks. Some of these risks are nowhere nearly as well understood as the risks from plutonium and effluents from nuclear power plants or fossil fuel plants.

All I am saying is that things that are going to come out of this hearing, we have got to remember that what we hear has to be taken in the whole picture of energy production.

Dr. Wolfe: I could not agree more with that last statement. Let me just add one point to your comment, and Dr. Radford's, about releases from nuclear plants.

Plainly, I think you have to expect that on some occasions, things are not going to work out exactly as you had hoped. I think regulations and experience have shown that you can design good plants, can operate them, and that if you do, you can operate them well, and the risk to the public is nil.

I think on the other hand, even if you look at potential releases and past experience on accidents, and measure the benefits versus the risks, you will find that even on that basis, the benefits far outweigh the risks, I think.

That is the point to be made. For example, the fast breeder study that looked at nuclear reactors tried to assess this also.

The gist of your comment is that it is not possible to do anything perfectly. I guess I would have to agree with that. On the other hand, I think the experience is that one can design and operate these plants and the risk to the public is, in fact, negligible and less than the risk

which they normally are willing to undertake in their normal living.

Dr. Mills: Do you have any more, John?

Dr. Garner: No.

Dr. Mills: Dr. Taylor?

Dr. Taylor: I notice in several places in your written statement, you made reference to sound data, the need for more quantitative standards, and more sound data, and so on.

You also made reference in several places to the fact that there is time to develop sound data or otherwise.

I would like to ask your opinions about these two forms, but first comment that as you may know, the National Council of Radiation Protection has under review ready for release, two reports on plutonium, one dealing with the hot particle problem specifically and one with the general problem.

I am not prepared to say what the final recommendations in these reports will be except that they will say that there is no rush to do anything at the present time, even though we may want to make some small adjustments.

I would like to hear some more discussion about the question about sound data, quantitative standards, if you care to.

Dr. Wolfe: Well, with respect to the time, as I just commented, I think I have indicated in the testimony that the radioactivity from ambient plutonium release is very low compared to what is naturally occurring, which I think is the basis for the statement that there is time.

The concern that we have in the nuclear industry on the "sound"

statement, to answer your question more directly, is that if we had a quantitative standard which was "sound," the inference is that standard would be long enduring, and would have data in back of it, to answer the legitimate questions of concern of the public.

What we think would be perhaps worse than our present system of "as low as practicable" would be a standard which was not sufficiently well based, so that the standard would be periodically changed and then might impact on very costly nuclear installations and practices, when, in fact, it might not have to if we waited some time to allow for the accumulation of necessary data.

I do not know if I have said what you were looking for, or not.

Dr. Taylor: I think you probably have said as much as you can on that.

On page 3, you refer to organ-man-rem dose. I am not quite sure what you are talking about when you talk about organ-man-rem dose. In any case, if you are talking about man-rem doses, to what extent do you include in there the necessary dose rate and dose factors when you try to total up man-rem?

Dr. Wolfe: The data presented here comes from an EPA report which is referenced. What the engineer did who developed these numbers was to take the EPA estimates, multiply it by the population. These were estimated doses to the lung. We multiplied it by the population and came up then with that organ-man-rem number.

It is just a plain multiplication, nothing sophisticated.

Dr. Mills: As you know, there is no dose rate taken into account here.

Dr. Taylor: That is what I wanted to bring out.

Dr. Mills: There are no more questions.

Dr. Wolfe, we thank you very much for giving your opinions today.

Dr. Wolfe: I am glad for the opportunity.

Dr. Mills: The next on the schedule is a panel from the Atomic Industrial Forum.

Is Mr. Deuster in the audience? Dr. Sagan, Dr. Goldman, and Dr. Parker?

Mr. Deuster: Dr. Mills, gentlemen of the panel, ladies and gentlemen, my name is Ralph W. Deuster. I am chairman of the Atomic Industrial Forum's Nuclear Fuel Cycle Services Committee and president of Nuclear Fuel Services, Inc., a subsidiary of Getty Oil.

Before I go into my prepared testimony, I would like to make one comment to Dr. Radford's previous statement that Nuclear Fuel Service at West Valley plant was shut down.

We voluntarily closed the plant because of no business in reprocessing at the time and because of our plans to make modifications which require now the pursuit of a construction permit.

We still have our license and are paying our annual fees. That is the official record on our facility.

The Forum is a not-for-profit-membership association incorporated in the state of New York. It comprises some 625 corporate and institutional members of the United States, as well as in some 25 countries, all of which share a common interest in the development and application of atomic energy for peaceful purposes.

Because of the diversity of its members which include facilities, manufacturing companies, universities, labor unions, professional firms, financial institutions, government organizations, and other profit and non-profit entities, the Forum as a matter of policy does not take

independent positions on matters pending before the Congress or pending before other public interest and quasi-judicial bodies, such as this Board.

However, whenever possible, we do make an effort to identify relevant technical and legal policy considerations and provide a mechanism for determining and articulating the views of our various members.

Accompanying me today are Dr. Leonard Sagan of the Palo Alto Medical Clinic; Dr. Marvin Goldman of the University of California at Davis, California; Mr. Herbert Parker, a consultant from Richmond, Washington; Mr. Emmanuel Gordon, a nuclear fuel and financial projects manager of the Forum; Mr. Marvin Fertell, environmental projects manager of the Forum; and Mr. Harvey Price, Washington counsel of the Forum.

These people are all here under Forum sponsorship in addition to myself, you will hear from Messrs. Sagan, Goldman and Parker.

Dr. Sagan will speak on the criteria for limit setting. Dr. Goldman will speak on the empirical approach to plutonium toxicity. Mr. Parker will speak on plutonium limits.

Each of these persons will express his independent viewpoint.

We are pleased to have this opportunity to participate in this hearing which was called to evaluate the impact on the environment of plutonium and other transuranic elements.

We agree with the approach taken by the AEC that this study be

made prior to attempting to set new guidelines or standards for these materials.

Speaking as a fuel cycle representative whose business is concerned with plutonium and the transuranics, I believe that the immense body of work done by the AEC and others in prior years and currently has provided regulations and guidelines for the fuel cycle industry to protect the public adequately.

We believe the record so shows this. We therefore recommend that EPA give serious consideration to accepting the current limits and guidelines as established by the AEC as adequately protecting the public.

I am sure you are all aware that plutonium is a natural product of power reactor operations. In fact, in current water reactors, the plutonium generated in the reactor produces a significant portion of the energy output.

U. S. reactors use enriched uranium fuel, and reactor operators have always planned to reprocess spent fuel and to recycle the uranium and the plutonium. For economic reasons, we strongly recommend that in your considerations, you give great weight to the importance of recycling plutonium in light-water reactors.

Projected fuel cycle economics are as favorable as they are, partly because of the anticipated use of recycled plutonium. Not using plutonium will result in the need for more U. S. enrichment capacity. There is more involved, however, than not utilizing plutonium.

It is highly likely that without the economic benefits derived

from the recycle of plutonium, there would not be sufficient incentive to operate reprocessing plants, and therefore, enriched uranium would not be recovered from spent fuel.

Together with the plutonium, this would increase the need for yellow cake, uranium raw material, by about 20% annually, and for separative work from the enrichment plants by approximately equivalent amounts.

Put another way, failure to use plutonium then would lead to significant fuel cost increases which must be borne by the general public.

Also, failure to use plutonium which implies neither reprocessing nor recycle would bring the breeder program to an end and would foreclose on an energy course already in hand, having an energy equivalence greater than known coal, gas and oil reserves combined.

The Nuclear Fuel Cycle Services Committee, of which I am chairman, recently submitted two sets of comments to the Secretary of the AEC, both of which bear on the subject of this hearing.

They have been submitted to Dr. Burley. They are comments on the AEC's draft environmental impact statement, entitled "Management of Commercial High Level and Transuranium Contaminated Radioactive Wastes" known as WASH 1539, and the proposed amendments to 10 CFR and 10 CFR 50 concerning transuranium waste disposal.

These were submitted on October 25, 1974.

We also submitted comments on the draft, "Generic Environmental

Statement on the Use of Plutonium and Mixed Oxide Fuel in Light-Water Reactors" known as WASH 1327, and also as GESMO.

Those comments were submitted on October 28, 1974. The GESMO deals comprehensively with plutonium and its application as a mixed oxide fuel in light-water reactor fuel cycle. We request that you include these two statements in this hearing record and in your subsequent considerations.

We also hope that the EPA would consider, when setting standards on plutonium and other transuranium elements that such standards be based at levels that evolve from cost-benefit analyses.

The imposition of unnecessarily restrictive levels will have the inevitable consequence of placing undue burdens both financially and operationally on nuclear reactors and the supporting industry, which burden would ultimately fall on the American people and the national economy.

This concludes my statement.

For the remainder of the presentation, you will hear from Messrs. Sagan, Goldman and Parker, with Dr. Sagan being our next speaker.

Thank you for this opportunity to express our views.

Dr. Mills: Thank you, Mr. Deuster.

I would suggest that we go through the remarks and then entertain questions.

Dr. Sagan: My name is Leonard Sagan. I am a physician from Calfornia. I have an interest in human radiation effects.

I have worked in Japan among survivors of the atomic bombing. I have an interest in government regulations on radiation exposures. I have worked for the Atomic Energy Commission for a short period of time.

I have done some studies on health effects associated with nuclear power plants and also some studies of health effects associated with coal burning power plants.

In view of that experience, I would like to make some comments about how government goes about regulating the emissions and will make a proposal for an emission tax for plutonium.

If you will bear with me for just a few minutes, I would like to express just a personal view about how we as a society appear to approach societal problems, and I would like to emphasize that these are purely my own views. They do not reflect the views of the Forum or perhaps of anybody else.

If one reviews the past few years' experience, one sees a consistent pattern of crises generated or at least fostered by the media. Typically, the crisis is often followed by hasty and sometimes ill-considered government reactions.

We first had an environmental crisis, followed by an energy crisis. Now we seem to have a food crisis, or I am told that some people think we have a plutonium crisis.

By that I do not mean to suggest that in these examples that I have mentioned there are not genuine problems. On the contrary, I am certain that each of these I have mentioned does contain a problem.

But what I would deny is that each of these is a crisis that suddenly appears in the first year that it is brought to public attention. Rather, each of these, in my view, is a result of longterm historical forces. Each of these announcements of a crisis is typically followed by the hectic convening of experts who fly to Washington meetings.

This is followed shortly by the promulgation of new regulations or legislation, much of which is hastily conceived and in the long run, in my opinion, counterproductive to the public welfare.

One is also likely to see a proliferation of lapel buttons and bumper stickers urging simplistic and equally ill conceived solutions.

I bring this up and reflect on this this morning because I want to express my hope that EPA is not going to follow such a course with respect to plutonium. In all candor, however, I must admit that there are aspects of this meeting that give me some misgivings and about which I would like to comment.

For example, this is announced as a public hearing "to determine the adequacy of current guidelines for plutonium," I am quoting from the Federal Register," and the other transuranic elements in developing any new standards if deemed necessary."

If that were the objective, then why a hearing panel of scientists? Since standards require totals of the social and political nature, why should there not be economists, social scientists, union and management representatives, as well as representatives of all segments of society?

Questions surrounding the use of plutonium could go to the heart of the kind of society that we want, and everyone, not only radiobiologists, should have a voice in that decision, in my view.

On the other hand, the Federal Register announcement to this meeting, in explaining the details of the meeting, suggests that the agenda is to be highly technical. We are asked, for instance, to supply the panel with information such as theoretical models developed to predict transport to the ecosystem, highly technical material.

If the intent is to gather technical information from which standards should be derived, then why are we having a public hearing? Is a public hearing, I would ask, the appropriate forum in which to gather and appraise scientific information?

I would have preferred an approach such as that chosen by the BEIR Committee as far more appropriate for that purpose, the gathering of scientific information.

I would like to add, parenthetically, since I have this opportunity, to offer the complaint that the BEIR report was never circulated for public comment.

In my view, we do not have a plutonium crisis. I will not go over the reasons for that opinion in detail. Some have already been mentioned by Dr. Rowe this morning. For the past 30 years or so, there has been extensive experimentation with plutonium.

So far, no cancer has as yet been attributed to plutonium exposure. I would echo a comment made earlier that we do probably have better data

with which to understand the toxicity of plutonium than we do for the vast majority of other carcinogenic agents.

I then have in this written testimony a good deal of material about plutonium toxicity, but I see there are so many other people on this program, so much more expert than I, that I am going to skip over that and get to the material that I have a greater interest in.

Whereas, as I have just said, I do not consider there is any particular urgency regarding the development of new plutonium standards, I do feel that there is an urgent need for broad consideration of the nature of the standards themselves.

Over the past several years, we have witnessed widespread disagreement about the nature and function of standards.

There is, first all, the argument whether standards should be based on health effects or on the basis of economic and technological feasibilities. We have heard some allusion to that conflict in the questionning already this morning.

There has also been dispute regarding whether or not health effects can be demonstrated at the exposure levels permitted by standards.

All of you, I am certain, are aware of the present conflict with respect to auto emission standards and whether they are too stringent or should be relaxed. Frequently, the data, as in that case, simply is not adequate to resolve these conflicts.

In my opinion, there are a number of other problems associated with inflexible exposure standards. Number one, standards are in effect

permissible levels of pollution.

They invite engineers, operators, to pollute to whatever level is allowed. There are no economic incentives to reduce the emissions below permissible levels. There may be moral incentives, as was pointed out by Dr. First, but in our society, moral compunctions are not nearly so effective as economic.

There is little incentive to create or purchase new pollution control technology, nor is there the flexibility to incorporate newer knowledge of toxicity which might modify standards in either direction.

Thirdly, standards are arbitrary. The argument to the linear dose response curve to attack any standard as arbitrary, as insensitive to health effects. Agencies have characteristically great difficulty in justifying and defending standards which are not based on demonstrated health effects.

The ability to achieve risk estimates for radiation exposure allows a new approach, I believe, to standard setting. My own preference, as I indicated in the very beginning, is for a tax emissions.

I would like to spend a few moments discussing how I see that with respect to plutionium.

A tax emissions is not by any means my own creation. It is a proposal that has been made frequently and recently by a number of economists.

An emission tax avoids many of the problems already mentioned above and is compatible with the currently accepted concept of a linear

relationship in dose response. I would foresee that a tax should be linear.

A tax would be assessed for even the smallest of emissions and so would provide an incentive for reduction of even these smallest emissions. A tax would not be incompatible with standards, however, as a maximum.

However, if one wished, such a tax might work in the following way: Some estimate would be established of the relationship between a curie of release and its ultimate health effect.

Our legal apparatus has long experience in assigning monitary values for health effects. This experience could be exploited to establish the monitary value associated with the health effects of released radionuclides which would incorporate knowledge of environmental transport to the human metabolism and carcinogenesis.

In this way, the emission tax would satisfy the requirement that environmental control be related to health needs. Management in response would make careful assessment of the cost of reducing emissions and would optimize at the lowest level of emissions compatible with currently available emission control equipment, thereby satisfying the need for economic and technologic feasibility.

An emission tax is clearly experimental, both for government and industry. The only example known to me is the example of its use in controlling emissions into the Rhine River where it is said to have been very effectively used.

I believe that plutonium is a particularly appropriate substance from which to gain experience, if this need be, for an emission tax,

since the sources for plutonium release will be very few.

Record keeping and surveillance will be rigid and releases easily detected. My preference would be to compute an emissions tax, or call it an emissions penalty if you like, on the resultant human exposure rather than on the absolute quantity emitted.

For example, a tax would be considerably less in a sparsely populated area than in a densely populated area. The effect, then, would be to provide an economic incentive to locate such a facility in remote areas.

I would also insist that the penalty apply to occupational as well as to public exposure outside the facility.

There is another advantage to tax emissions that I should like to mention briefly. As I have spoken to people about pollution and health over the years, I have found there is a widespread implicit assumption that thresholds do exist, that through scientific investigation these thresholds can be determined.

The public wants to know generally, whether it is air, food or water, they want to know is it safe or not? The question implies a threshold.

In my own opinion, such questions can rarely be answered with any certainty or precision now or in the future.

An emissions tax emphasizes the absence of an easily definable threshold level. Inflexible standards for environmental emissions reinforce the common misconception regarding absolute levels of safety.

In summary, then, I see no threat to the public health in current use of plutonium that requires urgent regulatory intervention. I do feel that the effect of widespread dissatisfaction with the use of inflexible standards is such as to justify fundamental review of the standard setting process as a means of controlling the environment.

In my opinion, the Environmental Protection Agency should give serious thought to more flexible means of control, such as that offered by an emissions tax. Such consideration should be a collaborative effort with representatives of all sectors of society and not solely the effort of scientists.

I believe the characteristics of plutonium production and toxicity recommend it as an excellent starting point from which to organize this new regulatory frontier.

Thank you.

Dr. Goldman: I am Marvin Goldman, Professor of Radiobiology at the University of California. I have been involved in problems relating to the biomedical effects of radionuclides in all of my scientific career.

I would like to try and present a few comments today to put into perspective some views that I have with respect to plutonium as a radionuclide, and how it fits into our overall biomedical world, as it were.

These are my own comments and do not represent necessarily the views of anyone else here.

I feel that with the publicity and comments that keep cropping up

with respect to plutonium, is it presumptuous for me to perhaps sit back from it a few feet and see what we know about it and how it fits into what we know about biomedical science and the effects of radiation, from an empirical approach.

Is there something unique, is there some mystique or some violation of the natural laws of physics, chemistry or biology intended to plutonium that requires a special and separate consideration from that which accompanied the evolution of our knowledge with regard to radionuclides?

In summary, I do not believe this is so. As you all know, and I suspect we will hear quite a bit of it in the next few days, there is considerable discussion of the internal emitters. The scientists with whom I associate usually categorize one another as lumpers or splitters.

I may try to lump today and in so doing, I may omit or condense or perhaps compromise some of the technical information, but I think it is important, perhaps, to get the overall pattern of information into focus and then to evolve questions regarding the lack of specific information and the applicability of existing information.

We live in a radioactive world. A lot comes from the soil which has several disintegrations per minute in every gram on this planet. Much of this is alpha activity from the decay of uranium and radium. Therefore, there is no such thing in my view as zero.

We will start with that point. Plutonium is another alpha emitter. It has about the same kind of energy as do these other natural radio-

nuclides and we have found that plutonium has probably been present in microscopic quantities in this planet since its formation.

We have more of it now, and that seems to be the crux of consideration. It has a very long life, but so do radium and uranium, and we know a lot about some of these other nuclides as well.

In nature, it is my opinion, that plutonium and the other trans-uranium elements such as americium and curium appear to me, on the basis of the information I have evaluated, and I certainly cannot say that I have seen everything that has been printed or written about it, this is my impression: It appears to me that it moves more slowly and less efficiently and effectively than other elements in the surface of this planet.

When it is very dilute and particulate, plutonium appears to age, such that it forms a non-radioactive aggregate, particles which even further slow down its movement and maybe enlarge the effective particle size.

This may render an increasing fraction of surface plutonium, as it were, that is, non respirable. Often it is the manufacture of plutonium compounds that can get into the deep lung, that position problem, that is of concern.

Thus, it would appear that with increasing time, whatever the concentration or content of plutonium, based on some of the information to which I had access, this appears to, in a sense, become diluted and buries itself and becomes less and less environmentally available; as

a quantitative observation which I think has some substantiation in fact.

Now, the amount of plutonium that I think may be air borne from soil deposition is characterized in many ways by a whole science of atmospheric dynamics and solar chemistry in arriving at chemical and physical factors, much of which I do not propose to tell you I am an expert in, but which experts summarize a kind of ratio or factor or resuspension ratio, which somehow relates to concentration in the air to the concentration on the surface of that plutonium, and therefore, gives a crude indication of the amount of the soil bound plutonium that might be air borne.

These numbers have a variety of physical factors in them. Usually, the ones I have seen are in terms of the microcuries of plutonium per unit volume of air, to the microcuries on the surface of the soil below. These ratios, in my view, are exceedingly small numbers.

It is something of the order, 10^{-7} or 10^{-10} units of microcuries per gram. Perhaps much of this is in the form of non-respirable aggregates and that perhaps with increasing time, all other things being equal, (and maybe we could generalize a bit) that fraction gets even smaller and smaller.

The thing I have spent many an agonizing year and night recently over has to do with the assessment of health consequences when the factors in molecular event that relate to all of those things that occur following the deposition of a packet of radiation in energy in

the biological system, and the ultimate appearance of some deleterious effects some time down the road.

These facts and details are necessary. They may never be available to us. But that does not mean that we do not know something about the toxicity of radio elements such as plutonium.

Although I understand some accidential exposures have occurred from the literature that I have had available to me, I believe that no health effects from plutonium exposures have been seen in man. Thus our knowledge on plutonium health effects primarily is data based on animal studies in laboratories.

Following the ingestion of plutonium, it is apparently not very effectively or efficiently absorbed into the body relative to the elements such as potassium or radium.

I estimate on the basis of the data I have reviewed that this fraction absorbed might be of the order of 1/100,000 of that which is ingested. Perhaps for elements in insoluble form, such as americium, it might be 1/1,000, which is quite similar to natural radium uptake percentages.

Following inhalation, acute exposures result in something of the order of 1/5 of the inhaled deep lung fraction retained as what some call an initial lung burden. I am sure you will hear from people far more knowledgeable on that.

The toxic quality, when this amount is very large, as with any radionuclides study in toxic effects, effects may become manifest in

the case of the lung as cancerous. For plutonium, the empiric ratio that I seem to be able to derive from experimental data that has been published might suggest that it is about ten times worse than for chronic exposure to x-rays, gamma rays, or beta particles emitting radionuclides also deposited in the deep lung of experimental animals.

What I am trying to say is that the absorbed radiation dose ratios of effects differ by about a factor of 10 over much of the body of experimental data that we have. As the dose diminishes, it may be that the ratio, the beta gamma type effect, also diminishes.

Now, as to the dose distribution from inhaled plutonium particulates, all the animal studies that I know of in this country and abroad, most of the ones abroad I think are not funded by the same agency that funds the ones here, do seem to support a rather conservative assessment.

The more uniformly the radioactivity is distributed, whether it be in lung or bone or liver or total body, the more effective that given radiation dose is.

The more non-uniformly the particulates are, the less effective is the burden in reducing the effects of concern.

In my view, plutonium is not uniquely or mysteriously toxic, but it appears to follow fairly predictable and well studied radiobiologic principles relative to a uniform x-ray or beta ray dose, plutonium appears to be about ten times more effective in producing tumors in experimental animals, with the absorbed radiation dose in rems used in the comparison.

Thus, without any specific knowledge of the sequence of events, from alpha particle absorption to tumor appearance, one can use the empiric observation in animal experiments to independently assess plutonium toxicity, and by comparison with other radiation experience in man can arrive at a realistic assessment of possible plutonium effects, realizing of course, as in most biological experiments performed in laboratories, precision and accuracy may have something to do with factors of two or three of uncertainty, but not many orders of magnitude.

In our laboratory, we have a sign that says, "The animal is always right." Our job is to get the message that the experimental animal is trying to tell us.

While all of our questions about plutonium are not yet answered, the available information on plutonium toxicity derived over the last 30 years provides an impressive spectrum of important information.

You probably know more about the relative toxicity of plutonium than for any other agent; in my opinion, the toxicity, following incorporation into the body, is in no way uniquely strange, or different. It follows certain general radiobiologic generalizations.

The first of these is that the effects appear to depend upon distribution of the radionuclides and its characteristic, whether it is an alpha, beta or gamma emitter, whether the emitted radiation energy is uniformly or non-uniformly distributed amongst the cells at risk.

Secondly, the dose rate for radionuclides is generally protracted

rather than acute and is continually changing rather than constant.

Thus, the dose rate relationship from internally deposited radionuclides requires consideration not only of the total radiation absorbed dose, but of the dose rate pattern by which it is acquired.

Thirdly, plutonium as well as the other radionuclides has its site of effects only on those cells which are irradiated and radio induced tumors are usually found in tissues in which cellular injury has been seen and tissue injury as well.

Fourthly, for low and intermediate radiation dose patterns, the major end point has been tumorogenesis, which appears to account entirely for any of the life shortening observed in these experiments with animals.

At very high levels, administered radioactivity, life shortening may be quite marked and not solely due to tumorogenesis; while at exceedingly low lovels of radiation, in which tumorogenesis is rare or absent, no life shortening effect is observed relative to comparable unirradiated populations.

There appear to be no unique hazards from elements such as plutonium, which are apparent when the dosage pattern is comparable to the exposure to x or gamma radiation, if external.

With regard to the particular effects, it is significant to me that dose effect occurs with beta gamma emitters; alpha emitters follow a qualitatively parallel pattern regardless of the non-uniform distribution of alpha dose.

The mean rad dose ratio for beta-gamma effects studies versus alpha emitters for a comparable tumor incidence range only between the factor

of about 5 and 20. No assumption regarding the carcinogenicity of individual particulates are needed or implied.

A comparison with a relative, uniform beta gamma radiation in the lung, for example, with non-uniform alpha radiation can be derived solely from the toxicity data. I think it is important to recognize that the appropriate models needed to describe the complete sequence of events leading to cancer are, in my opinion, of secondary importance to a valid determination of the relative toxicity of the two radiations.

This, in my view, is the most fundamental criteria in hazard assessment.

In conclusion, I feel I would like to share these views with you. On the basis of the two decades that we are worried about; these internal emitters, I do not personally find anything unique, mysterious, strange or in violation of the physical and biological laws that I have learned that are associated with plutonium.

We do have a particulate exposure. There are some quantitative differences, but in a qualitative sense, I do not believe, as Dr. Sagan said, there is necessarily a plutonium crisis.

I hope the assessment of this will more or less be put back into perspective.

Thank you.

Dr. Mills: Thank you, Dr. Goldman.

Dr. Parker.

Dr. Parker: My name is H. M. Parker and I have been connected

in some form with plutonium limits since the early days of the Plutonium Project.

My notes, if useful to the panel and the agency, will give reference to some of those early limits. What I would like to do this morning is to use material that arose at a symposium at the Los Alamos scientific laboratory in May of this year under the topic of "Plutonium: Health Implications for Man" in which I asked to summarize the issues as I saw them.

I understand that this material is to be published in the journal, Health Physics. I recommend your attention to that. I propose to use essentially the same material here.

It will come out as a very random collection of six comments with no intended thesis threading its way through those comments.

Number one: It is titled "Plutonium - the most toxic element known to man?" It says here the health physicists of the Plutonium Project had the task of rapidly developing a respect for plutonium in some hundreds of scientists, technicians and operators.

They did it mainly by drawing parallels with the experience with radium, and by describing plutonium as one of the most toxic elements known to man. That statement, I think, tended to be converted to the absolute form, the most toxic; and I think became one more tool to encourage possible emotional reaction against the possible environmental release of plutonium.

As measured by actual experience to date in man, the statement I think can be called preposterous. A recent bulletin of the National Radiological Protection Board of Great Britain speaks somewhat to this point.

With currently accepted permissible limits, it draws the conclusions, skipping some finer points, that plutonium on a mass basis is 400 times less toxic than iodine 131, 16 times more toxic than tritium as tritiated water for inhalation, and some 200 times less toxic than tritiated water for ingestion.

I think this is to some degree game playing, but I would perhaps suggest if I may be so bold to the Agency that a balanced agency statement on the toxicity of plutonium relative to other materials would be helpful to all of us.

Point number two is entitled "Relative reliance on human data and animal data." If quantitative data on the effects of exposure of man exist, they would clearly be the data of choice.

Where they are diffuse and scanty, as in the somatic aspects of general radiation exposure of man, the present interpretations tend to depend more on plausible theory than on demonstrated fact.

In the very valuable NAS-BEIR Report, the emphasis on linearity between effect and dose is more a matter of prudence than demonstration.

Some observers, including this one, believe that the relevant animal data sometimes tend to show non-linear dependence on dose, at least for some of the biological end points.

For the specific case of plutonium, we must at this time use the animal data since human data are virtually non-existent. Two clear areas that need research seem to come from this.

Number one, for the animal data, to review periodically the estimated shape of the dose-effect curves, especially for the very low doses expected in environmental exposure and acknowledging possible differences for different biological end points.

Number two, for the human data, to extract what information may become available in such mechanisms as the U. S. Transuranium Registry and the Mancuso study of atomic energy workers.

Here, I think it must be accepted that persuasive evidence on either of these is much more likely to come by decades than by single years. I recall that this is for the occupation case. Direct information for the environmental case does not seem likely to be valid in a reasonable timespan.

I would suggest that such a very arbitrary device as commitment now to a formal national five year review plan of these data could offer significant benefits for orderly improvements of environmental limits from time to time.

Point number three is the "hot particle problem." Let me say if I may that I excluded this from the Los Alamos review on the fairness doctrine that representatives of one rather novel posture were not present at that meeting.

So here I would like to make only a side observation that concern

for various aspects of the hot particle problem, not specifically plutonium hot particles, dates back in my experience to at least 1944.

I have previously documented concern that a single hot particle in the lung may generate a tumor that would not have arisen from the same activity in distributed form. I shall continue part of that concern until I feel that we really understand the various environmental factors that go into the initiation, promotion or proliferation of a viable tumor in man.

For the present, however, I believe that the data presented in such documents as WASH 1320 which I am sure will be coming later in this hearing are more persuasive than the contrary views.

To oversimplify, hot particles can clearly be more hazardous than depositions if there is either a threshold dose or some form of a sigmoidal effect curve with respect to carcinogenesis.

If total linearity is accepted, as in the BEIR Report, it seems plausible that hot particles will waste some of their activity in killing some of the adjacent cells that need only have been damaged.

However, as a very personal opinion, I would expect that plutonium limits should be lowered, and lowered now, by about one order of magnitude. I base this on hearing Dr. R. C. Thompson's review of the animal data as defended at Los Alamos, and in the timing of this meeting, I expected that it would already have been presented to you, Dr. Mills, but it will, I am sure.

This, to me, with some allowance for uncertainties in both symmetries, seems to say that absorbed doses of some few tens of rads --

let me make it that indefinite, if I may -- some few tens of rads do indeed give demonstrable yields in various animals.

Conventional permissible dose in man permits the accumulation of a somewhat light dose throughout an occupational lifetime. That does not reflect the conservatism that we have generally felt would apply to high radiation limits.

Some fear, again a very personal fear, that limit reduction of this kind will be resisted because we could no longer then measure so-called permissible lung burden by external means.

That, of course, would suggest a clear area of research to improve that sensitivity by a factor of about a thousand which, unfortunately, I think is impossible. It would be most helpful.

For EPA purposes, this particular inhibition fortunately will not affect your wise decision because you are way below the possibility of doing this during life in the human.

Let me inflict point number four on you at this time. That is called the "indifference level." Industry will expect to have high standards to minimize plutonium releases from their facilities and to transfer principal radioactive wastes to carefully designed, federal engineered storage or other ultimate disposal.

A continually growing problem remains with the disposal of relatively large volumes of relatively low activity waste. For this, some agreed indifference level of residual activity level is needed.

Conceivably, one might have rather a series of such levels,

accounting for possible transfers to the public domain from working materials, mostly pieces of paper that may not have remaining elements of plutonium on them, from the clothing of workers, from the skin of workers, and mechanisms that will be obvious, from the emissions from the internal contamination of workers, all of which will put some amount of plutonium into the environment.

It will be a major contribution if we could achieve a consensus for a basis for such a level or levels, if that is the way it turns out. Should it be set relative to natural alpha contamination, as proposed by some, reflecting the existing weapons plutonium contamination which to all intents and purposes in our background would tend to remove that, or on some other more sophisticated basis? I offer no solution. I hope intention to that decision will loom large in the efforts of the agency.

Point number five: This has to do with the funny behavior of "The isotopes of plutonium and the transplutonium elements."

The apparent matabolic behavior of two such nuclides as plutonium 238 and plutonium 239 is, in the laboratory, often markedly different for two reasons, partly because the mass used for normal experimentation is different. You choose an expert, and where you have a measurable activity, separate what mass goes with that -- and partly because, or so it seems, the intense bombardment near the shorter lived source may produce what you might call local chemistry, which certainly changes the behavior, allegedly of insoluble particles such as plutonium oxide

in the lung.

Now, environmentaml research, which you seek answers, needs to be based on transfers of very small masses. These are best measured if you go at it experimentally by one of the short life nuclides, although in nature I presume plutonium 239 will remain the main real contaminant.

Another problem in the general area of these mixed up isotopes is that the radiobiological studies, normally conducted with one nuclide at a time, the experimental thing to do, may or may not, more likely not, permit reliable deduction of the effects of the expected mixtures to be used in the developing nuclear industry.

Those mixtures eventually in low degree will invade the public domain. So a program to study the environmental and radiobiological behavior of one or two representative mixtures, reasonably from the advance light-water reactor and LMFBR systems should be considered at this time, we suggest.

My final point, Mr. Chairman, is entitled "Mixed oxides." It maintains that the probable nuclear economy for the next one or two decades is predominantly a mixed uranium and plutonium oxide fuel economy.

As an extension of the previous section, knowing what plutonium can do, we very much need to know the real environmental and radiobiological behavior of actual mixed oxides, which does not seem to have been worked on to any extent.

One would expect some pencil and paper work, in the ordinary way, that the hazard from this mixed oxide particle would fall well below that of plutonium alone; as with so many of the cases here, you can visualize some conditions that would lead to the contrary result, I think the knowledge is most important to the ultimate welfare.

Also, I believe that variations of behavior with time, which Dr. Goldman mentioned, plutonium may change its behavior with time. In this case, it may change in a very different pattern and is one of the channels through which one could conceive a growth of hazards through time with immunition.

Above all in directly recommending studies of this nature, I would consider it essential that it be done in two forms. Study the behavior of mechanically mixed oxides, those turned through the years, and begin the work now with chemically precipitated mixtures which may be different in their behavior upon release and the ultimate industry choice of these two forms may not yet have been determined.

Something quite unrelated to our health hazards may be the determinant of that because you could make a proposition that the economy which continually has only co-precipitated mixed oxides would be very much safer from the diversionary attach point of view which I believe is unrelated to our endeavors here.

Mr. Chairman, thank you.

Dr. Mills: Thank you very much, Dr. Parker, for some very constructive comments.

84

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October 25, 1974

Secretary of the Commission
U.S. Atomic Energy Commission
Washington, D.C. 20545

Subject: Comments on Draft Environmental Impact Statement "Management of Commercial High Level and Transuranium-Contaminated Radioactive Wastes," WASH-1539, and Proposed Amendments to 10 CFR 20 and 10 CFR 150 Concerning Transuranic Waste Disposal

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Dear Sir:

The comments herein were prepared by the Subcommittee on Radioactive Waste of the Atomic Industrial Forum's Committee on Nuclear Fuel Cycle Services and are submitted in response to Federal Register notices of September 12, 1974. A list of the subcommittee members is attached hereto.

We endorse the concept of the U.S. Atomic Energy Commission that it take physical possession of and assume permanent responsibility for both the high level radioactive waste generated from the aqueous recovery of spent nuclear fuel and transuranium-contaminated radioactive wastes. Further, the Commission's intent to provide interim retrievable surface storage of radioactive high level waste is endorsed as the logical interim step. The committee believes that any of the three alternate interim retrievable surface storage systems described in WASH-1539 is adequate from the standpoint of reliability and for the protection of public health and safety for generations to come.

The draft states that the AEC will continue its efforts to establish a permanent disposal system for high level radioactive wastes based on placement in geologic formations. It is the subcommittee's opinion that such ultimate disposal techniques should be defined as soon as possible.

In determining the preferred location for a surface storage waste facility (or facilities) for both types of waste, the Commission should give consideration to the cost of transportation from

the generation sites to the interim facilities as well as the cost of transportation from the interim facilities to a permanent disposal site. We also recommend that the AEC accept title to the wastes at the earliest possible date following their conversion to an acceptable form and that waste form and the interim storage concept be based on cost effectiveness considerations rather than on the existence of an AEC operating site.

State of the art technologies for protecting the public health and safety are now available. Hence, specific criteria for interim storage packaging could be and should be written now. The adoption of such technologies, however, should not foreclose the use of future technological refinements which might provide further safety margins or greater efficiency without invalidating earlier approved technologies.

If the requirements of the draft statement are to be implemented within the time frame indicated, the schedules for developing the required technology and facilities must be accelerated. For example, the development program for permanent disposition of transuranium-contaminated hulls calls for initial operation of the storage system in the period FY 1981 to FY 1983. At that time, significant quantities of hulls will already have been generated and should have been sent to interim surface storage facilities.

To minimize handling and shipping, we recommend that consideration be given to AEC ownership of both the interim high level waste and the transuranic waste storage facilities at the individual production sites. However, these facilities could be owned either by industry or by the AEC, or operated for the AEC by industry.

Complete separation of transplutonium elements from high level waste should be recognized as developmental at best. Endorsement of this concept may subsequently be shown to be in conflict with cost benefit considerations.

The problems of disposal of large, high gamma-alpha contaminated waste, such as failed equipment, has not been properly addressed in the draft statement.

We also wish to point out that the draft statement has the nature of a development program and, while the goals are clearly delineated, the draft does not present a firm time schedule nor does it furnish enough hard data for industry to make investment decisions which are required in the very near term.

Since transuranium-contaminated wastes are treated in both the draft impact statement and the notices on proposed changes to 10 CFR Part 20 and Part 150, our comments on these two notices follow.

Although we agree that wastes which contain substantial quantities of transuranics should be placed under Federal control and that the interim retrievable surface storage systems should be owned by the Commission, we are concerned that none of the management methods proposed for interim storage for commercial transuranium waste offers the optimum in terms of cost effectiveness. We recommend that a program be initiated promptly to accomplish this goal and we would be pleased to work with the Commission on such a program.

We also note that the proposed amendments to 10 CFR Part 20 do not contain a definition of transuranic wastes. The introductory remarks discussing the proposed amendments make reference to general classifications of certain types of wastes as transuranic on the basis of their origin or upon a measurement at a 10 nanocuries per gram level. This latter type of classification is not practical in commerical nuclear facilities, considering the low concentrations encountered with many types of waste. For example, it is stated in WASH-1539 (p. B-3) that "at present, external radiation measurements on waste packages cannot detect plutonium at this low a concentration." The general classifications are too broad and subject to too much interpretation. A preferred alternative, not dependment upon questionable or undeveloped measurement techniques, would be to classify wastes upon the likelihood of their direct and substantial contact with transuranic materials, a procedure that we believe is now followed at AEC facilities. We propose that the following basis be adopted for classifying wastes with respect to transuranic content.

1. Transuranic wastes:

Those wastes which have been in direct contact with materials containing transuranium bearing elements; for example, wastes originating in enclosures and process glove boxes containing transuranic elements.

2. Non-transuranic wastes:

Wastes originating in uncontaminated controlled areas outside of plutonium enclosures and process glove boxes, including radwastes associated with or originating in current types of nuclear

power reactors and wastes from plants or plant areas not processing or handling transuranium elements.

Wastes not clearly falling into the above categories should be classified on an individual basis after a careful review of plant operations to determine the likelihood of transuranic contamination.

It should be noted that, as yet, there has been no definition of the form of solid wastes that would be acceptable to the AEC, neither has any indication been given as to the costs associated with the AEC management and disposal of such wastes, nor has the site to which such materials are to be delivered yet been named. In the absence of such information, the proposed amendments are considered premature.

It is most urgent that waste form specifications, packaging requirements, and charges for services be stated in a complete and consistent form at the earliest possible date and certainly prior to the adoption of any such amendments. Such specifications, requirements and charges should be set forth in the proposed amendments and not left to future notices.

Sincerely,

Ralph W. Deuster

Ralph W. Deuster
Chairman

RWD:cl

Attachment

ATTACHMENT

Atomic Industrial Forum

Subcommittee on Radioactive Waste

of the

Nuclear Fuel Cycle Services Committee

* * * * * * * * * * * * * * * * * * * *

Ralph W. Deuster	Nuclear Fuel Services, Inc., Chairman
Emanuel Gordon	Atomic Industrial Forum, Secretary
S. J. Beard	Exxon Nuclear Company
Gary R. Bray	Allied General Nuclear Services
Irving Knudsen	Westinghouse Electric Corporation
James H. Leonard	Nuclear Engineering Company
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Edmond C. Tarnuzzer	Yankee Atomic Electric
Peter T. Tuite	Hittman Nuclear & Development Corporation
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10/25/74

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October 28, 1974

U.S. Atomic Energy Commission
Washington, D. C. 20545

Attention: Deputy Director for Fuels and Materials
Directorate of Licensing-Regulation

Subject: Comments on Draft, "The Generic Environmental Statement on the Use of Recycle Plutonium in Mixed Oxide Fuel in LWR's"(WASH-1327)

Dear Sir:

The attached comments have been developed by an Ad Hoc Plutonium Recycle Task Force of the Atomic Industrial Forum's Committee on Nuclear Fuel Cycle Services. A list of the Task Force membership is also attached.

The Task Force commends the AEC for the staff effort and care reflected in the draft GESMO and believes that the statement will contribute important support to the ultimate recycle of plutonium-bearing fuels in light water reactors. The Task Force also commends the AEC for seeking the comments of the nuclear industry and other interested parties on the draft statement.

The comments are submitted with the objective of strengthening the draft statement and address the following five general areas: cost-benefit analysis, limitations of scope, safeguards, health and safety, and format. Additional comments of a more detailed nature, derived from a page-by-page review of the draft statement are presented separately.

The Task Force's detailed comments seek to correct certain inaccuracies, address additional topics and clarify points that appear to have been based on incomplete or obsolete data. They are offered with the hope that they will shorten review of the statement during the hearing that is to be held. For the most part, the exceptions taken by the Task Force to certain of the proposals set forth in the draft GESMO are attributable to the Task Force's belief that there is a greater need to quantify environmental impacts insofar as possible through cost-benefit analyses. This is especially true in those sections of the statement treating on safeguards.

The Task Force appreciates this opportunity to review the draft statement and hopes its comments will facilitate early issuance and adoption of the final statement.

Sincerely,

Ralph W. Deuster

Ralph W. Deuster, Chairman
Nuclear Fuel Cycle Services Committee

RWD/jmc
Attachments

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General Comments on the GESMO

Cost-Benefit Analysis

It is generally known throughout the industry that the capital costs enumerated in Table S-14, "Capital Invested (Millions of 1974 Dollars about 1990)" are outdated. Table S-14 cost estimates overall are low by about 20%. Selected areas, such as reprocessing and mixed oxide fabrication are perhaps low by several hundred percent. Similarly, the operating cost assumptions for materials and services in Table S-15, "Projected Costs for Materials and Services in 1990 (Millions of 1974 Dollars)" are generally low by varying amounts.

Using more recent estimates of capital and operating costs, the differential annual cost for the year 1990 to the users of LWR's generated electrical energy, if plutonium is not recycled, is approximately 0.8 mil/KWH (compared to 0.4 mills/KWH in Table S-4), or about $2 billion cost penalty compared to the $1 billion penalty indicated in GESMO. If neither plutonium nor uranium is recycled, the cost penalty for the year 1990 will likely be in excess of $2.5 billion. It should be emphasized that the economics for a single future year case are not nearly indicative of the overall magnitude of potential cost savings attributable to plutonium recycle in LWR's. For the year 1980 through the year 2000, the users of LWR's generated electrical energy will pay a cumulative total penalty of nearly $50 billion if plutonium is not used in light water reactors, and nearly $60 billion if neither plutonium nor uranium is recycled. This cumulative penalty to society through the year 2000, which is in 1974 dollars, is more than the total capital investment that will be needed to support the LWR fuel cycle.

In the overall evaluation of plutonium recycle, the most realistic analysis would assume some delays in the schedules as outlined in GESMO. Certainly some slippage in almost all schedules is inevitable without solid commitments to key milestones from the AEC and its licensing and regulatory agencies, from the nuclear industry, from the Government in its energy policies, and from the general public at large. It would be appropriate in GESMO to analyze the impact of schedule slippages on the cost-benefit of plutonium recycle. The initial delays in reprocessing should be addressed. Also, an alternative case analysis which should be included in any further studies on the sensitivity of schedules is that case which considers a slippage in the breeder (FBR's) schedule of 5-10 years. Under these circumstances, a comparison should be made between the alternatives of LWR plutonium recycle through the year 2000 and uranium utilization only. This approach would provide the proper perspective on which to judge the merits of various fuel cycles. Furthermore, this comparison should be carried out on a cumulative basis since the true impact occurs over the number of years the program is implemented.

A critical issue in the consideration of the GESMO assumptions and alternate case studies is the fact that without plutonium recycle in LWR's, the growth of a breeder industry will be slowed considerably. Experience gained with handling large amounts of plutonium through 1990 and beyond is essential to the growth of the industry and will provide the framework for licensing and public acceptance. Under this basis, four of the six cases evaluated by the Commission would no longer be considered viable options for the breeder concept.

Finally, in GESMO, the impact of plutonium recycle on the price elasticity of yellowcake is assumed to be negligible or non-existent. This assumption must be challenged on the basis that the demands placed on U_3O_8 without plutonium recycle are likely to far exceed by a considerable margin the values projected in GESMO.

Limitations of Scope

As we interpret the GESMO, there are severe scope limitations which either restrict the applicability of the GESMO, or imply that operations outside of the GESMO scope will not be permitted.

Manufacturing Facilities

The report would have greater credibility and usefulness if it also covered the period of time when the MOX fuel cycle industry is evolving and growing (1975-1990) as well as when it reaches maturity (estimated - 1990). As the report now exists, it relates only to the wide scale use of Pu in MOX fuels for LWR's in the year 1990. At that time (1990) an estimated 6-8 MOX fuel fabrication plants of approximately 200-300 MT/yr. capacity would be required, the inference of the report being that these MOX fuel fabrication plants, which do not now exist, would be new and would meet the concepts and requirements of an upgraded safeguards program yet to be defined. No consideration is given to the five pilot-development MOX fuel fabrication facilities now existing and which could be viable for the interim period between 1975 and 1985, provided they are not required to meet 1990 safeguards and other standards during the interim period. (See "Manufacturing" section under "Health & Safety"). These existing plants are needed for developing both LWR and Breeder fuel.

When evaluated in relation to the upgraded safeguards concepts, it is obvious that these existing pilot facilities will be obsolete by 1990 standards. However, it is not clear that the same measures needed under the heavy throughputs of 1990, are needed while throughputs are still very low and adequately controlled by existing safeguards methods. Since there will be a need for these pilot facilities between 1975 and 1990 an environmental assessment and cost-benefit analysis should be made to determine the

extent to which existing plants should be operated, partially upgraded and perhaps even expanded without adversely affecting the environment or detracting from an adequate safeguards program. Inasmuch as the AEC actively encouraged each of the companies operating pilot MOX fuel fabrication facilities to get into the plutonium business, every effort should be made to enable the existing facilities to be gainfully used and fully depreciated in a safe and prudent manner before such facilities are declared obsolete under 1990 standards. As already mentioned, this analysis should consider the small capacities of the existing MOX fuel fabrication plants, and the fact that the facilities have already been upgraded to meet current AEC safeguards requirements.

Limits on Recycle Amounts

Detailed discussion in GESMO relative to the model LWR indicates that the 1.15 self generated recycle (SGR) value used is an average calculated from operating experience with existing LWR's. The report summary, however, goes one step further and implies limiting Pu recycle to the 1.15 SGR level. Since one might expect improved operating performance in all LWR's by 1990 it would seem more appropriate for the report to evaluate the impact on the environment of the highest Pu recycle technically possible for LWR's and to allow each reactor to recycle all the Pu it generates under equilibrium conditions.

In like manner, the report uses an upper limit of 5% Pu in uranium and mentions only natural uranium as the carrier. Some reactors may require slightly higher Pu concentrations than 5% and could economically use depleted on slightly enriched uranium rather than natural uranium as a carrier. These alternatives should be considered by the GESMO report.

Statement of Purpose

It would be most useful if the stated purpose of the GESMO could be enlarged to make it clear that environmental considerations covered by the report need not be duplicated for inclusion in environmental statements submitted by LWR operators, reprocessing plants and mixed oxide fuel fabrication plants when Pu is ultimately recycled or new facilities are constructed. If this is not allowed there seems to be little use for GESMO except as a starting point for more discussion and perhaps the basis for repetitive environmental statements.

Safeguards

We feel that GESMO should emphasize the fact that considering the existing supply of plutonium and its current utilization, the current safeguards

system, as recently promulgated by the Commission, provides reasonable assurance that the health and safety of the public will be protected. We, therefore, concur with the Commission that the active safeguards system should be continued including the ongoing assessment of changing considerations. It is recognized that as safeguards are reassessed, upgrading may be necessary in the future. Future upgrading, particularly in areas of the government's responsibility, was addressed recently (October 9, 1974) in a speech by the Forum's President Carl Walske. His speech is attached for your information.

The GESMO in its present form presents no real cost-benefit analysis with respect to upgraded safeguards programs vs. status-quo programs. The report also seems to imply there are no alternatives to the concepts proposed (although we do not believe this to be the actual intent). Since definitive safeguards programs will not be issued for at least another year, some thought should be given to separating the detailed discussions of safeguards proposals from the GESMO and treating these as a separate issue at a later date.

Of those concepts which have been identified by the Commission as a means to improve safeguards significantly, we consider co-location as having a very long-range potential rather than being a viable near-term alternative. On the negative side, co-location could impose commercial difficulties which would affect the ability of fuel service suppliers to respond in a timely manner to the needs of fuel users.

With respect to the transportation aspects of co-location, we believe that adequate transportation safeguards can be provided within the present system and commensurate with the type, form and amount of the nuclear materials involved. Therefore, there is no absolute requirement to eliminate transportation in any segment of the fuel cycle. In any case, it must be recognized that transportation could not be eliminated altogether. The Commission has indicated as one of the advantages of an integrated fuel cycle facility that it would make use of onsite protection measures more efficient. But on balance, considering the small portion of the total fuel cycle costs which would be incurred for safeguards even with possible improvements, the benefit of any added efficiency gained by reducing transportation or by integrating facilities could not offset the added costs associated with co-location.

We suggest that the concepts involving spiked Pu or debilitating gases be discarded. Considering the fact that there are other reasonable means available which can be employed to attain the Commission's objectives, these schemes are quite unattractive. It is difficult to see how the benefit could outweigh the increased hazard created.

In conclusion, we believe that the present system of safeguards is generally adequate for the current state of the industry and such improvements as are desirable can be made in an orderly evolutionary way. We are convinced that much of the concern being expressed today is based upon situations which may have existed at certain facilities prior to the implementation of the present safeguards system and upon an inadequate understanding of the technological and other improvements that are now incorporated in the present system.

Health and Safety

Environmental Radiation

The radiation doses in the environs from reactors using mixed oxide fuel are calculated using as a basis WASH-1258 "Final Environmental Statement Concerning Proposed Rule Making Action: . . .'As Low As Practicable' . . . Nuclear Power Reactor Effluents". The GESMO evaluation, therefore, contains the same problems of overconservative assumptions and overconservative methods of calculation of doses as that document. In fact, the GESMO evaluation fails to utilize several of the improvements made in calculational techniques and assumptions made by the AEC. Several specific examples are offered to illustrate the nature of overconservatism in Attachment A to the comments.

"Hot Particle" Problem

Possible effects of the so called "hot particle" problem should be discussed in more detail in the final GESMO. As long as the Commission has not developed a final position on this subject, a possibility exists that it will be necessary to reduce the allowable airborne concentrations of plutonium by significant factors. A discussion of the impact of such a potential reduction should be included in the final GESMO.

Manufacturing

The GESMO addresses only hardened manufacturing facilities designed, built, and operated according to some combination of the GESMO assumptions and new regulations which apply to plutonium in the fuel cycle. If mixed oxide fabrication loads are less than projected in the GESMO there may be a need to use existing facilities during the period addressed in the GESMO. The existing facilities will, therefore, have to be modified to meet some interim regulatory safety requirements. As a result, occupational safety and environmental safety impacts of the interim facilities may not be consistent with the GESMO. The final GESMO should present an analysis of this eventuality.

The final GESMO should include additional analysis of the consequences of accidents in the manufacturing facilities. The consequences of loss of confinement and loss of shielding are more severe than in the UO_2 fabrication plant where the uranium has much less radiotoxicity and external radiation exposure is of little concern. In order to reduce the risk of accidents to acceptable levels, design, construction and operation of recycle fuel manufacturing facilities will result in greater capital and operating expenses. The factor of 1.5 greater than the cost of uranium facilities used in GESMO appears to be low.

Format

The following comments are presented as a means of clarifying the GESMO through some changes in format:

> Although Volume I contains a good summary of the information presented in GESMO, it is often difficult to locate the detailed discussions in the later volumes which are related to the general statements and tables in Volume I. To clarify these statements and tables, it is recommended that chapter and section numbers of the applicable detailed discussions be referenced in Volume I.
>
> A rather detailed table of contents is provided for the report. However, it would be very helpful if a subject index were also included. The same specific subjects are discussed in several locations throughout the report. Therefore, it is difficult for someone studying a particular aspect to find all of the separate related discussions.
>
> The report, and in particular Volume I, is quite repetitious. The value of a brief summary at the beginning is recognized. However, in reading through the report, one wastes time in covering the same ground several times.
>
> If the data were expanded and all technical inaccuracies corrected, the Volume 3 technical data would be useful with regard to the out-of-reactor portion of the licensing process. The Volume would be extremely useful to industry with regard to the reactor portion of the licensing process if it contained a table for indicating the impact of Pu recycle as was provided by the Commission with respect to the impact of the uranium fuel cycle. This may have been the Commission's intent judging from the titles of the Tables IV A-7 and IV A-8 listed in the Table of Contents, however, these tables of GESMO are missing.

The paragraph designations used in GESMO are confusing, consider the use of a straight number system. With the number system, the reader could easily determine what main section and subsections a specific paragraph is contained in. For example, paragraph I.b.(1).(a) of Chapter IV, Section E could be straightforwardly designated as 1.2.1.1 of Chapter IV, Section E or Paragraph 4.5.1.2.1.1.

Numerous general statements are made in GESMO which should be further clarified by placing them in context. For example, it is stated that the immediate recycling of plutonium would reduce the requirements for uranium mining by about 9% around 1990. It would be beneficial to add what fraction of the total benefit (in dollars) this reduction represents. This type of clarification would make GESMO much easier to understand and it would strengthen many of the arguments presented.

The purpose of the GESMO seems to get lost in the words (page S-13). It should be possible to state the objectives more clearly and then to equate the conclusions to them.

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Attachment 2 of 4

Detailed Comments on the GESMO

DETAILED COMMENTS

Page

S-2 Paragraph 4. This paragraph states that "accidents in the mixed-oxide fuel fabrication plant, a facility that does not occur in the UO_2 fuel cycle, are similar in consequence to accidents at UO_2 fuel cycle facilities. . .". This is only so if plutonium fabrication plants are designed and built like reprocessing plants. If this is the implication, it should be more clearly stated or the paragraph revised.

S-3 Table S-1. It would help if there was a footnote indicating the size of the 1990 LWR industry and what fraction of the fissile material is plutonium. It is also not clear if the Kr-85 is released or removed from the effluent streams.

S-4 Paragraph 3. The definition of self-generated quantities of recycle is somewhat ambiguous. Does this refer to total amount of plutonium available or equilibrium amounts? Although the choice of 1.15 times self-generated recycle for the reference case is reasonable some statement should be made about the relative effect of larger quantities of plutonium in recycle fuel (up to 200%). In view of the delays in start-ups of spent fuel reprocessing plants it may be necessary or desirable for the industry to recycle larger than self-generated quantities of plutonium in order to work off the backlog of reprocessed plutonium which will develop after a number of reprocessing plants have begun operation. Thus, the report should also consider the relative effects of significantly larger than 115% self-generated plutonium recycle.

S-4 Last Paragraph. The GESMO seems to place unnecessarily heavy reliance on a situation "already dominated" by other strategic SNM materials. There is considerable uncertainty in the timing of the LMFBR and the HTGR programs. Furthermore, it is suggested the amounts of special nuclear material projected for the HTGR and LMFBR programs be more specifically identified. It is not obvious whether Pu for military uses is included in the "other" category.

This paragraph also seems inconsistent with later statements since it indicates that plutonium recycle will not significantly affect required safeguards since other SNM dominates the shipping picture. Later, however, on pages S-6 and S-7, the statement is made that the current safeguards provisions are inadequate and further work is being undertaken to study methods of upgrading them.

S-5 Table S-2. Is the bottom line SNM without the plutonium recycle program or SNM less recycle plutonium? Is the top line additional SNM due to plutonium recycle? Also, it is not clear if the quantities are total plutonium or fissile plutonium.

Page

S-7 Paragraph 1. Some reference to the timing for the co-location concept is believed to be important. The concept, if viable, becomes more important as the number of fuel fabrication and reprocessing plants increases. It is not a very important or effective method of improving safeguards while the number of plants are very few. Furthermore, the opportunities of co-locating with any of the partially constructed reprocessing plants are difficult to access so that it is not clear that co-location can be a practical solution for use in time for the first additions of fabrication capacity.

S-7 Concept 6. Some mention of the fact that "spiking" is likely to be the most expensive of all the alternatives should be made.

S-7 Paragraph 7. Although this paragraph implies that the above are only concepts which are under study, it is recommended that the Commission make this more positive. It should be clear that the six listed concepts are merely examples and that the Commission is not now locked into any of these, and that many alternatives will be investigated before firm determinations are made.

S-7 Paragraph 8. Upgrading of safeguards about one year after issuance of the final GESMO is likely to delay decisions on the construction of any manufacturing facilities for mixed oxide fuel. Since the use of additional safeguards seems to be a rather firm conclusion, it would seem more advisable to recognize that evaluation of the alternative safeguards methods will proceed in parallel with the GESMO. The timing on release of upgraded safeguards regulations should not be tied to the timing of the final GESMO but rather proceed as expeditiously as possible.

S-8 Paragraph 9. The conclusion that "alternative 4. ranks best" cannot be made directly from the data presented in Table S-3 (page S-9). Based on that table, alternative 3. is the best.

S-9 Table S-3. Depending on the manner of safeguard upgrading, the whole body radiation exposure for alternative 3. and 4. may not be identical ("spiking" may greatly increase the exposure).

The value under whole body radiation exposure "plus 21%" should be "minus 21%".

The ability to calculate the cost differential between Cases III and IV is highly questionable considering the vast differences between the costs of the six subcases considered in Item 4.

What is the time basis for this table? (Annual?)

Page

S-10 Paragraph 3. "1955" should be "1995".

S-10 Paragraph 4. Clarification is required. This paragraph first implies that some LWR plutonium will feed LMFBR's and then states "the only potential use of Pu" is LWR recycle.

S-10 Paragraph 5. Alternative 5. which involves permanent storage of plutonium is claimed to present a reduced safeguards threat compared to the base case. It is not immediately apparent that having a large stockpile of plutonium involves less of a hazard than smaller amounts in recycle.

S-11 Table S-4 (and preceding text). There is no indication whether the costs presented are based on current dollars or costs escalated to the 1990 comparison date. Also, Table S-4 indicates that costs include upgraded safeguards but does not state which safeguards are included (although it seems apparent that the costs of the various safeguards proposals will vary widely).

S-12 Paragraph 6. In the conclusion to approve plutonium recycle, (and in a number of other places in the report), the implication is that the approval of more than 1.15 SGR would not be given. It would be unfortunate if this blanket limit was adopted without compelling reason and it would be much better to rely on a case-by-case analysis. Some reactors will very likely have greater recycle capabilities and needs than others.

S-12 Conclusion 2.B. Remarks relative to timing of the decisions for upgrading safeguard measures should be omitted as discussed in the comment on Page S-7, Paragraph 8.

S-12 Conclusion 2.C. Some expansion of the statement to identify those safeguard measures which will be promptly implemented would be helpful.

S-13 Paragraph 1. This should be reworded to indicate that plutonium recycle constitutes a federal action which potentially affects the quality of the environment.

S-14 Paragraph 2. The manner in which this paragraph is worded opens up the question as to just what purpose the GESMO does serve. It is recommended that the paragraph be written in a more positive vein, indicating the purposes the GESMO serves, and its limitations.

S-14 Paragraph 3. The uranium prices are too low and need to be updated.

Page

S-15 Paragraph 3. Should ^{238}Pu be ^{239}Pu?

S-15 Paragraph 4. The stated concern for ^{241}Am conflicts in basic approach to the consideration using "spiked" plutonium to improve safeguards.

It does not appear that the costs and effects of plutonium repurification to remove Am have been included in the evaluation of alternatives. In particular, there should be a cost savings for alternatives 3. and 4. (immediate Pu recycle) as opposed to alternative 1 (base case). Undoubtedly the costs are relatively small but they should not be ignored.

S-15 Footnote. Does "other isotopes, e.g., ^{236}Pu" include ^{238}Pu? If so, the statement is incorrect. ^{238}Pu is not an important fissile material but is extremely important to evaluating overall environmental impact, including cost benefit analysis.

S-16 Paragraph 5. This should specify that MOX spent fuel contains larger quantities of Pu and transplutonium isotopes.

S-18 Paragraph 2. In contrast to the judgment made in the GESMO, dissolution of mixed oxide fuels may well present significant difficulties to the reprocessor. Complete dissolution of plutonium will probably require the addition of fluoride in quantities sufficient to cause corrosion in the stainless steels used throughout most head-end processes. Major modifications to flow sheet and equipment will, therefore, be necessary in all existing reprocessing plants.

S-20 Paragraph 2. "TWR" should be "LWR".

S-21 Paragraph 4. Relating plutonium inventory to FBR fuel requirements seems meaningless since FBR requirements increase approximately five times between 1990 and 1995 and approximately twenty times between 1990 and 2000.

S-22,23 Figures S-1, S-2, S-3. Are the amounts in the figures annual or cumulative?

S-27,28 Are the amounts in the tables annual or cumulative?

S-28 Table S-6. The use of fossil fuel should be clarified. What percentage of the energy requirements for the cycle are assumed to be supplied by fossil fuel?

Page

S-31 Table S-7. Assuming that Table S-7 represents the worldwide effects of the U.S. LWR industry, the title of the table should read, ". . .FROM THE U.S. LWR INDUSTRY."

S-35 Paragraph 4. Quantity of 2×10^{16} Btu needs a time dimension (per year?).

S-35 Paragraph 6. Is the "residual heat" the total heat value of the waste from 10 years decay to infinity? The term should be defined or clarified.

The size and capacity of the waste canister (1' Ø x 10' L, 3.2 MT fuel at 2 ft^3 waste/MT) or a reference to Page IV H-12 should be shown in paragraph 6.

S-35 Last sentence, bottom of page. This sentence should be changed to read, "Since the quantity of waste is small and since the waste is stored and not released to the environment, there would be minimal environmental impact."

S-36 Paragraph 3. Change the first sentence to read, ". . .0.27 and 0.18 cases per year respectively".

S-40 Table S-9. An attempt to quantify the radiological effects of transportation accidents should be made. The term "small" is indefinite.

Footnote. The last two sentences in the footnote should be omitted. A reference to Page S-36 might be desirable.

S-43 Table S-10. The estimates of Pu_f utilization in commercial LWR recycle fuel shown in Table S-10 should be updated to reflect the availability of reprocessing facilities. In particular, it appears that there will be no recycle plutonium in 1976 and something less than 2400 kgs Pu in 1977.

S-44 Paragraph 5. A reference should be made to the recommendations of Willrich and Taylor as stated on page V-37.

In the third sentence of Paragraph 5., "ompliment" should be "implement".

S-45 Paragraphs 1. & 2. The element of cost has been omitted from the discussion of safeguards in the first two paragraphs. Any increase or tightening of safeguards measures should consider the cost and cost benefit to be derived from such changes.

Page

S-45 Concept 1. It should be noted that with Integrated Fuel Cycle Facilities (minimization of Pu shipping) the utility might be forced into using the specific fabrication facility which is on the reprocessing plant site (or vice versa).

S-45 Concept 6. It should be noted that the use of "spiked" plutonium might prove to be impractical or uneconomical due to the cost of processing such material in the PuO_2 conversion and fuel fabrication operations. One of the purposes of reprocessing is to minimize fission product content so that semi-remote handling is possible.

S-46 Paragraph 2. This paragraph expresses a time relationship between the issuance of the final GESMO statement and the decisions on safeguards upgrading. This relationship appears to be contrary to the ultimate purpose of GESMO. Several of the concepts under study could have a significant impact upon the environment and the cost benefit of plutonium recycle. For this reason, decisions on upgrading of safeguards requirements need to be made as soon as possible regardless of the date of the final GESMO statement.

In addition, Pu conversion, storage, and MOX fabrication facilities are being designed and/or constructed today. Postponement of safeguards decisions will only lead to inefficient backfitting and costly construction and operational delays. A statement should be made in paragraph 2. acknowledging the existence of present-day MOX fuel fab plants.

S-46 F. Paragraph 3. The statement: "Spent 1.15 SGR fuels would contain about 16% more tritrium and 11% less ^{85}Kr than spent UO_2 fuels" should be referenced.

S-47 Paragraph 3. This paragraph should mention the proposed disposition of the transuranics after separation.

S-47 Paragraph 5. The various safeguards concepts being considered have been detailed earlier and it appears too restrictive to single out one of the concepts in Paragraph 5. It is, therefore, suggested that the second sentence be omitted and the third sentence be restructured.

S-51 Figure S-7. Alternative 1 in this figure should show a Pu Storage "box" (without asterisk) similar to the box in Alternative 5.

S-52 Table S-11. Under Alternative 2, the Whole Body Radiation Exposure should be negative (-21%).

Page

S-53 Table S-12. Under Alternative 6, the number of Transportation Shipments should be "-2500".

The 77,900 MT SWU base case enrichment quantity should be footnoted to the effect that it includes 44% (or 30,000 MT SWU) of foreign enrichment requirements. This note will make Table S-12 consistent with the separative work units discussed on page S-61.

S-54 Last paragraph. Table number should be S-13.

S-55 Table S-13. Under Alternative 6, the kgs. of Pu_f accumulated in storage through 1990 should be "-309,200".

S-57 Paragraph 5. Sentence 4 should read, "Those operations where additional safeguards measures should be considered over Alternative 1. . .". A need or requirement has not been established; reference the wording and intent of the second paragraph on page S-42.

S-58 Paragraph 2. The last sentence speaks of ". . .the AEC's need to upgrade the safeguards program." Again, this need has not been established, and the sentence should probably read, ". . .the AEC's decisions on an upgraded safeguards program."

The paragraph entitled Capital Investments should state that costs are calculated in 1974 dollars and that Table S-14 represents total accumulated capital investment to 1990 (if that, in fact, is the case).

The paragraph entitled Materials and Services Costs should state that costs are calculated in 1974 dollars and that Table S-15 represents annual expenditures in 1990 (if that, in fact, is the case).

S-59 Table S-14. Under Alternative 6 and in the supporting data in Volume 4, the reason for a $70 million capital cost differential above the base case for "Spent Fuel Transportation" is not clear. Increased mileage accounts for the operating cost differential in Table S-15 (pg. S-60) but the reason for the capital cost differential is not apparent.

S-60 Table S-15. The differential changes in "Mining-Milling" costs between the alternatives in Table S-15 do not appear to be consistent. Table S-12 on page S-53 shows that the increase in mining-milling quantities for Alternatives 2 and 6 is approximately equal to the quantity decrease in Alternatives 3 and 4 (e.g., milling is +11,900 tons U_3O_8 in Alternatives 2 and 6 versus -10,000 tons

Page

S-60 (Cont'd) U_3O_8 in Alternatives 3 and 4). The operating cost figures in Table S-15, however, show a significant dollar change (+$670 million for Alternatives 2 and 6 versus - $300 million for Alternatives 3 and 4). If these figures are correct, some explanation should be given either in this summary section or in Volume 4. It appears that footnote "d" should also apply to the "Waste Management" item since the previous table (S-14) indicated that waste management capital costs were absorbed by the federal government.

S-61 Paragraph 2. The enrichment cost of $48.90/kg SWU for Alternatives 3 and 4 shown in the last line of paragraph 2 appears to be incorrect. Table XI-12 on page XI-35 indicates a figure of $55.06/kg SWU. This latter figure is also consistent with the -$400 million enrichment cost differential for Alternatives 3 and 4 shown in Table S-15. Use of the $48.90/kg SWU cost would yield a differential of about -$600 million.

I-2 Section A. It would be beneficial if the purpose of GESMO should be more simply stated.

I-3 Paragraph 2. Next to last sentence beginning with, "for comparison, . . .". This seems out of place. Makes the whole paragraph sound defensive.

I-3 Section B, 1st sentence. Need to define central station.

I-7 The out-of-reactor fuel cycle operations are presented. Subsequently plutonium and radioactive wastes are discussed. There is a need to establish what is done with "tails".

I-8 Figure 1-3. Need to define acronyms and use consistent units. Show depleted "tails" stream from enrichment. The whole balance is difficult to follow.

I-9 Does projected cost of yellowcake include escalation?

I-10 Figure 1-4. Consistent units should be used - define acronyms.

I-12 Figure 1-6. Is plutonium storage/inventory cumulative to 1990? The depleted U - "tails" - stream should be shown as part of balance. Whole balance is hard to follow.

I-14 Paragraph 1, second sentence. Beginning with "thus, it would be . . ." is very difficult to follow.

Page	
I-14	Paragraphs 2 and 3. This seems to establish a firm limit on quantity of plutonium charged in MOX. Is this the intent? MOX should be defined.
I-17	What is the time basis of values in Table I-3.2? Are these annual or cumulative?
II-2	Paragraph 1. "Estimates of nuclear power generation capacity. . ." Where is this shown? A reference should be provided.
II-3	2nd Line from top. . . ."ingested significant amounts of plutonium . . .". What is significant? This should be related to MPC_a.
II-3	Paragraph 2, 2nd sentence. . . ."under the defense in depth design . . .". is not clear.
II-4	Page II-4 and Table II-3 seem to imply an optimistic schedule for spent fuel recovery operations in U.S. (and, therefore, earlier than expected plutonium availability). Start-up date for the plants on Page II-25 is not achievable. This fact is implied in the definition of Case I (Base Case) for the cost/benefit calculations, but may make alternatives 3, 4 and 5 unrealistic. Perhaps more information could be presented on effects of delays in implementation of recycle and on effects of various cost parameters (storage costs, capital investment costs) on the results.
II-5	Paragraph 4, last sentence. Delete "The chart below,".
II-5	Paragraph 5, last sentence. This sentence should reference Table II-2.
II-12	Figure II-4. The cost/unit on right side of chart is confusing.
II-14	Table II-3. This schedule is probably not realistic as noted above (Page II-4 comment).
II-20	Table II-7. Half life of Pu-241 given as 13.2 years. IV C-58 lists the value as 14 years. The currently accepted value is ∿15 years (consistent with Volume I S-15).
II-24	Paragraph 2, 1st sentence. correct spelling of "about".
II-24	Paragraph 2. With regard to the coefficients of reactivity "larger" should be "more negative".
	The discussion on calculational uncertainties is inconsistent with a subsequent passage (Volume 3, IV. C-59) on the same subject.

Page	
II-25	1st sentence. Need a period after parenthesis.
II-25	Paragraph 1. Since cores containing mixed oxide assemblies are more stable GESMO indicates that "part length fuel rods" may be eliminated. The reference should be to part length control rods.
II-25	Last paragraph. The start-up dates for existing or planned reprocessing plants should be updated.
II-26	Paragraph 3, 1st sentence. Delete "very".
II-27	Paragraph 5. No mention is made of the hazards of plutonium nitrate.
II-27	Paragraph 5. Neutrons due to subcritical multiplication can also be very significant.
II-28	Section b. The beta contribution from Pu-241 is not discussed.
II-29	Section c and d. It is not clear whether this section is still restricted to plutonium oxide. Also, there is a statement that plutonium absorbed through the skin deposits in the bone which seem to contradict section a. on page II-28.
Appendix	In the Appendix to Chapter II, dealing with criticality accidents in chemical processing, it is recommended that the material recently published by Olsen, Hooper, Uotinen and Brown on "Empirical Estimation of Number of Fissions from Accidental Criticality in Uranium or Plutonium Systems" (ANS Transactions, winter meeting, 1974) be included. This work is not merely a compilation of data on miscellaneous accidents, but presents an empirical means of estimating the energy release from various criticality accidents.
II-32	Paragraph 3. 3×10^{4} should be 3×10^{-14}.
II-35	Paragraph 3. ". . ., the fuel fabricators designed their LWR fuel facilities to produce. . .".
II-38	Paragraph 2. There are redundant phrases concerning burn-up and linear heat ratings. Clarification is required.
II-40	Paragraph 1. Statement on cladding material of construction needs clarification.
II-40	It is not clearly stated what type of reactor Saxton was. (PWR)
II-48	Table II-12. No value given for hole size; footnote implies values given for % dishing are hole sizes.

Page	
II-52	Table II-15. "Pu concentration, % ± .10 "is not clear (is this on the ratio or a percentage?).
II-62	Paragraph 4. Mixed oxide reprocessing may require additional capacity in the plutonium purification facilities, not additions.
II-64	Paragraph 1. "In all transuranium elements certain small losses. . .". Statement needs clarification. 30% heat gen[illegible]rease lasts over what time period?
II-64	Paragraph 3. 4.5 microcuries per pound.
II-65	Paragraph 1. "Present plans are to hold. . .". Statement needs clarification.
III-4-7	Figures III-1,2,3. Shouldn't ordinate scale be labeled "10^3 Megawatts" instead of megawatts x 10^3?
III-8,9	Figures III-4A & B are unnecessary. The same information is provided in Table III-1.
III-1	The number of fuel reprocessing plants and mine-mill complexes may not be attainable in the period specified.
IV A-2	Paragraph 1. Reference in the first paragraph to "1/3 of the total power" is confusing, since power is an instantaneous measure. Is the word "energy" meant instead of "power"? This same confusion exists on other pages (e.g. IV B-2).
IV A-5	Figure IV A-2. No stream is shown in this figure for spent recycled plutonium or uranium, which have negligible value. It appears that continuous mixing with newly produced recycled material would not be economical. Also, no tails stream is shown from the enrichment plant on this figure or figure IV A-1 and similar figures in Section 3.
IV A-6	Table IV A-1. What is the basis of values in this table, annual?
IV A-7	Table IV A-2. Units in Table IV A-2 need clarification. ^3H & ^{85}Kr in millions Ci per year?
IV A-8	Table IV A-4. Same comment.
IV B-7	Paragraph 1. Regarding the last sentence of the first paragraph under 2.a., did [illegible] consider the added costs at reactors recycling Pu? This sta[illegible] implies they did not; in cost/benefit analysis it should be [illegible]dered.

Page	
IV C-2	Paragraph 1. Is "equivalent plutonium" total Pu or fissile Pu?
IV C-3	Under "Accidents" the first sentence seems to be more appropriate to "Normal Operation". This should be clarified.
IV C-3	Is the GESMO serving any purpose if each request for licensing mixed-oxide assemblies must be evaluated on a case-by-case basis? Also line 3 "normaly" should be "normal". At the end of this paragraph, the phrase "just as each new type. . ." could be placed at the end of the second to last sentence, if this is the actual intent. Third line from bottom change "basically" to "initially".
IV C-4	Last paragraph. The last paragraph refers to both 63 rods and 64 rods in a BWR assembly. Actually there are 63 fuel bearing rods plus one non-fuel bearing rod (water-hole rod).
IV C-8	Some figures (such as Figure IV C-4) are out of date and do not match text discussion (e.g., Figure IV C-11).
IV C-13	Paragraph 5. 100 tons - standard or metric? PWR core was expressed in pounds. Also, this description applies to the design of only one of three vendors.
IV C-20	Paragraph 2, line 8. Add "IV" before "C-15".
IV C-24	Second sentence. The intent of the second sentence on this page is unclear. Was 1974 used only to compute the values of isotopic abundance shown in Table IV C-1? If so is this conservative or not?
IV C-28	Paragraph 2, 3.a. Suggest the following wording changes: in line 2 change "changes are" to "differences is" and add "which" after "isotope." in line 3 change "and the" to "causes a". At the end of 3.a. do "thermal-hydraulic consideration" include fuel temperature, fission gas release, etc? If so the statement is not accurate as discussed later in GESMO.
IV C-29	Paragraph 3. Should specify that Saxton and San Onofre were PWR's.
IV C-32	Paragraph 2. Is there an error in the first sentence in the second paragraph under Control Rod Worth, regarding the thermal flux level being "only half"? It is certainly reduced but not by a factor of two. The argument following this statement still stands, however.

Page

IV C-33 Paragraph 5. The fifth paragraph is weak since it implies a difference between UO_2 and MOX. Could it be changed as follows: "The worst-stuck-rod control requirement may be unchanged and is affected by fuel loading patterns."?

Paragraph 7. The meaning of the last sentence in this paragraph is unclear.

Paragraph 8, line 2. Between "in" and "mixed" add "core containing".

IV C-34 Line 5. In line 5 replace "necessity of" with "need for" since it is difficult to imagine reducing a necessity.

Paragraph 3, line 1. Change "effect" to "affect".

At the bottom of page are words "above in Chapter V" correct? If Chapter V is the correct reference, "above" should be "below".

IV C-35 Why are Gd, Xe and Sm cross sections shown?

IV C-38 After first paragraph, there should be two conclusions. From reading the text that follows it is not clear what they are.

Paragraph 2, line 3. Change "since" to "and as a result".

IV C-39 At the bottom of page change "is generally true" to "may be".

IV C-43 First line. Change "would" to "could". No evidence is provided supporting this conclusion. Last sentence in second paragraph is a preferred approach in this area also.

IV C-55 The statement that "these increases are largely offset by the reduction in control. . .of mixed oxides" is not clear as to meaning. What may be meant is that "these increases are largely offset by the lower initial reactivity of mixed oxide fuels."

What is meant by "the required volume of coolant becomes excessive"?

What is referred to at the end of the first paragraph; i.e., "beneficial effect" on what?

IV C-58 Line 2. Change "results in" to "produces".

h., line 2. add "is" after "natural uranium" and in line 3 change "and" to "an".

Page	
IV C-59	Should another "bullet" be added stating to the effect that "less experimental data is available for normalization"?
IV C-61	The next to last paragraph should be more fully explained.
IV C-64	Label is missing on ordinate of graph (%M.O.).
IV C-71	Reference 1: ". . .The Big Rock Point. . .".
IV C-72	Item (6). Change "Creaction" to "Creation".
IV C-100	Paragraph 1. The syntax of the first sentence is incorrect.
IV C-100	Paragraph 2. The syntax of the second sentence is incorrect.
IV C-104	Table IV C-22. The dose from direct and scattered radiation should be "Total Body" rather than "GI Tract".
IV C-112	Table IV C-33. Heading should read Man-Rem/Year.
IV C-113	Paragraph 2. It is stated that "The most significant difference in man-rem does occur as a result of water ingestion for river-sited boiling water reactors." While water ingestion shows the largest percentage change, differences in dose from other exposure pathways are more significant, even though the percentage change may be smaller.
IV C-113	Paragraph 5. First sentence should read "The transportation of fresh fuel. . .".
IV C-114	Paragraph 2. A more typical effluent cleanup system should be employed so that infant thyroid doses are typical of that normally expected.
IV C-115	Paragraph 3. The statement that "At worst, some SGR fuels exhibit as much as a 14% increase in the iodine thyroid dose source. . . more typically. . .a 10% increase" is not consistent with Table IV C-36, which shows a maximum increase of 8% and typically no increase in iodine dose source.
IV C-116	Paragraph 1. The last sentence should refer to Table C-37.
IV C-117	Table IV C-37. This table is confusing because of the comparison of different plutonium types at differing exposures. Are the Pu-2 - 3 and Pu-1 - 2 cases selected for the calculation of the element dose ratios the most limiting cases?

Page

IV C-120 Table IV C-40 and IV C-41. In view of the difference in inventory ratios (Table IV C-37), why are the radiological consequences of postulated accidents identical both with and without plutonium recycle.

IV D Chapter IV-D assumes that glove-box type operations will continue to be the design basis for MOX fabrication facilities. The accuracy of this is questioned in that higher radiation and neutron fields are anticipated in the future with the use of plutonium containing higher percentages of the heavier isotopes.

IV D-3 GESMO assumes that eight fabrication plants are operated in 1990 while only five would be required. While there is likely to be some overbuilding, the greater than 50% excess capacity seems large.

IV D-3 Paragraph 4. The 1990 release should be specified as the annual release. Do annual dose commitments include Beta dose from Pu-241?

IV D-4 Are Beta doses included?

IV D-6 Paragraph 1. The enrichment of PuO_2 fuel may be greater than 5%, and the diluent may be depleted or slightly enriched uranium rather than natural UO_2.

IV D-9 Paragraph 6. The production of MO_2 fuel rods by a combination of chemical and mechanical operations would seem to be independent of the installation of equipment at reprocessing plants to convert plutonium nitrate to a solid.

IV D-13 Paragraph 3. Depleted or slightly enriched uranium may also be used in place of natural UO_2.

IV D-17 Paragraph 4. Enrichment of PuO_2 may be greater than 5%. The first sentence should read ". . .enough fuel for about 25 reactors operating at the 15% SGR loading.

IV D-20 Paragraph 5. Slightly enriched uranium may also be employed.

IV D-21 Paragraph 2. Error in syntax.

IV D-26 Paragraph 2. Proven technology may exist for solidifying Purex wastes, but AEC burial and transportation requirements have not been formulated.

IV D-26 Paragraph 7. 9×10^{-6} μCi (∝)/sec

IV D-31 Paragraph 2. Isn't 1 rem/yr used in the AEC for interpreting "as-low-as practicable" limits for personnel exposure?

Page	
IV D-32	Paragraph 6. What is the basis for estimating airborne releases of plutonium? Why are releases expressed in alpha curies only; 30-50% of dose from LWR plutonium comes from beta of Pu-241.
IV D-33	Table IV D-8 also indicates alpha curies only. Do estimated doses include beta effects of Pu-241?
IV D-37	Fabrication of MOX fuel may require some operations in remotely-operated cells.
IV D-38	Is the beta dose included in Table IV D-11?
IV D-39	Paragraph 2. The value stated for filter efficiency (10^{-9}) is in error; This is the transmission factor. The basis or reference for this value should be indicated.
IV D-39	Paragraph 1. Basis for filtration efficiency and air loading should be given.
IV E-2	Paragraph 1. Specify "Annual requirements in the year. . .".
IV E-5	The paragraphs on reprocessing facilities are outdated and should be revised.
IV E-7	Paragraph 3. Mixer-settlers are used extensively; centrifugal mixer-settlers aren't.
IV E-14, 15,16	It appears that iodine removal should be discussed. Iodine removal is indicated in Figure IV E-6.
IV E-16	Paragraph 2. Last statement unclear; throughput instead of throughout?
IV E-25	Table IV E-12. The annual dose commitments appear to be high compared to similar numbers in earlier environmental statement submittals and the EPA Environmental Analysis Report, EPA-520/9-73-003D.
IV E-26	Paragraph 4. What is the basis for the statement "the isotopic composition of uranium isotopes is somewhat less biologically hazardous with Pu recycle than without. . ."?
IV E-30	Paragraph 1. Why is the criticality excursion 10 times worse in fuel reprocessing than in the fabrication process (10^{19} vs. 10^{18} fissions)? No justification is given for the difference.

Page	
IV E-31	Paragraph 2. Syntax error in second sentence.
IV F-2	Paragraph 2. What is the basis for the statement "These values (9 and 11% reduction in uranium mining and enrichment demand) are significantly less than the theoretical 15% reduction in uranium consumption. . ."?
IV F-6	U_3O_8 Costs in Table IV F-3 should be $/lb. Although the footnote of Table IV F-3 notes that these costs are the costs at which uranium could be produced, rather than the sales price, greater emphasis should be given to this distinction since the sales price may be 50-100% higher.
IV F-15	Paragraph 1. The decrease in facilities (175 underground mines and 13 open pit mines) is not consistent with Table IV F-4 (total decrease of 180 facilities).
IV F-29	Paragraph 4. ". . .studied including: (1) Phase. . . .".
IV F-32	Table IV F-6. Are the total electrical power needs for added capacity supplied by gas centrifuge plants in addition to or in place of the requirements for gaseous diffusion plants. Why aren't the "Δneeds" for diffusion and centrifuge plants in the ratio of ten assumed in the basis given in the footnote?
IV F-33	Paragraph 7. The reference to Table IV F-5 is incorrect; the reference should be to Table IV V-6 or 7. The minimum range of electrical energy required (75 million megawatt hours) seems low and cannot be obtained from either Table IV F-6 or 7. The quoted values of coal consumption (44.8 and 39.9 million metric tons without and with recycle respectively) are not consistent with Table IV F-7.
IV F-34	Paragraph 4. The next to last sentence should read "Small radiological releases from the diffusion complexes, consisting only of uranium and uranium daughter products, . . .".
IV F-36	Paragraph 1. The quoted reduction of particulates and oxides of nitrogen by about 65,000 metric tonnes each is not consistent with Table IV F-7 which shows a 50,000 MT reduction. The 1.6% reduction in chemical effluents is not consistent with the 1.5% reduction in coal combustion quoted on page IV F-35.
IV F(A)-1	The total for no Pu recycle of the water discharged to ground should read 108,000.

Page

IV G-9 Paragraph 6. Depleted or slightly enriched uranium may also be employed.

IV G-10 Table IV G-3 shows a 30% increase in dose to transport workers and a 47% increase in dose to the general public for transportation of PuO_2 to storage with Pu recycle; in view of the order of magnitude reduction of the quantity of plutonium going into storage, this increase seems unlikely.

IV G-12 Paragraph 4. Depleted or slightly enriched uranium may also be employed.

IV G-13 Paragraph 3. Since the reduction of transportation steps prior to uranium fuel fabrication could have easily been factored into the analysis, why was this conservative simplification made.

IV G-23 Paragraphs 4 and 5. Depleted or slightly enriched uranium may also be employed.

IV G-24 Alpha waste associated with obsolete equipment or decommissioning-related rubble (masonry, structurals, etc.) which will not fit into drums will have to be specially crated and sealed to prevent dispersal of radioactivity. This type of container may be unsuitable for ultimate disposal, but will be required for many years of interim operations.

IV G-30 Line 4, Paragraph 2 should include sorption, followed by shipment to a central facility for incineration, and chemical destruction of organic bulk followed by recovery of Pu from residues or burial.

IV G-39 A more comprehensive analysis of risk may show that PuO_2 shipments in certain areas can be safeguarded more effectively by point-to-point aircraft shipment, using either rotary or fixed-wing equipment rather than by road shipment. This statement is made with full recognition of recent federal legislation to ban all aircraft shipments of Pu.

IV G-42 First sentence. Modify to show dose if half of fuel shipments are made by truck.

Page

IV G-44 Performance of PuO_2 (and Pu nitrate) shipping containers during transportation accidents should reference more recent papers by U.S. (BNWL) and French (CEA) authors, in Sessions 12A and 11 of the Fourth International Symposium on Packaging and Transportation of Radioactive Materials (Sept. 22-27) 1974. AEC-sponsored work at BNWL showed that the Pu transportation risks are three orders magnitude less than for meteorite hits, if current-day fireproof packaging is used. Prior evaluations should be re-ranked and these new findings be incorporated in Table IV-G-9 to give proper perspective to the low risk of shipping Pu nitrate (if correctly packaged). Overseas processors are expected to continue shipping Pu nitrate because of equivalency of risk compared to PuO_2. See author's final manuscripts as presented at September 22-27 meeting in addition to CONF-740991.

IV G-48 Actual data on package closure from an AEC-sponsored survey should be referenced and used. See reference above.

IV G-54 In paragraph 3., use of qualitative phrases such as "very small", "highly unlikely", etc. should be supplanted by probability ranges like 10^6 to 10^7 per year where assessments have already been published.

IV G-54 Item (e), Paragraph 1, last sentence should say "oxide or other form shown to be of equal or lower safeguards and transportation risk". AEC criteria for oxide vs. nitrate shipment need to be re-examined in the light of recent findings coupled with safeguards impact.

IV G-55 Accident risk statements, such as last sentence of item f. are not sufficient unless the phrase "in the vicinity of" are made clear by example. Isotope dispersal by waterways from a "major impact" site could be geographically far-reaching. Also amplify results of local confinement and cleanup opportunities if a "major impact" accident occurs.

IV G-56 Last paragraph under "Routing". The railroad associations have passed recent regulations and recommendations which affect the routing of rail cask trains. These details should be explained in the GESMO if AEC and industry perceive them to be long-lasting and relevant to the routing issue.

IV G-59 Line 4 suggests rewording as follows:. . ."assemblies, and limit the shipment of separated plutonium to only that quantity which is needed to balance the manufacturing loads (peak and valley effects) within the network of fabrication and reprocessing facilities." Delete statement referring to "elimination of need to ship separated Pu" because this idealistic condition could not be maintained at all times. Even if idealized IFCF siting could be achieved in 20 years, the transition period would require interplant shipment of plutonium.

Page

IV H-2 Paragraph 1--insertion in line 4 "to increase the total transuranium alpha activity sent to burial by a factor of five. Emphasis in subsequent statements should be on safe long-term alpha management, not just on heat generation and handling.

IV H-2 Paragraph 4 and IV H-10, Paragraph 5. In order to keep the volume down to estimated levels in GESMO report, current proposed AEC rulemaking must be changed to redefine exempt low-level alpha wastes by a new operationally-acceptable criterion (a) because 10 nanocurie per gram level is not practical to measure and administer and (b) because AEC recommendation to include all waste generated in "controlled areas" would inflate the burial volume and cost out of proportion to the benefit, especially considering $100 per cu. ft., projection for transportation and long-term management.

IV H-3 60 megacurie difference in hull burial is explained on Page IV H-20, but long-lived alpha buried with hulls changes in opposite dirrection from activation products, therefore, actinide curie comparison should be given in separate line.

IV H-4 No explanation is given for the maximum credible accident and why it involves only one waste canister. This section is too brief. The accident safety issues are not adequately covered.

IV H-15 Table IV H-3 should show separate subtotals for long-lived alpha and beta activity.

IV H-21 Footnote** should be reworded to state the end result required, i.e., quantitative leachability and devitrification stability of "glass" and then discuss generic aspects of one or more preferred solidification process routes, rather than deferring the analysis.

IV H-41 See note on IV H-21, also. The conversion to glass would require opening and emptying of the RSSF canisters or total fusion of canister plus contents. Discarded canisters disposal is not mentioned.

In last paragraph and on Page IV H-42, line 6, statements on shielding at RSSF do not seem consistent with high neutron and gamma streaming in storage cask configuration shown on Page IV H-36. A different air duct configuration would be needed to reduce surface dose to 2 mr/hr.

IV H-43 Paragraph 5 "milligrams" and "millicuries" require specific definitions. If this level of alpha release is meant, then it is high relative to MOX fabrication plant normal stack release.

Page

IV H-46 & 47 — What is the environmental effect of meltdown in a canister? Can the discharges be controlled. Which concept for RSSF is the safest. Which is most tamper-proof and fail-safe? Such sondierations when left to the imagination of the public reader, are likely to lead to confusion.

Statements made in WASH-1539 "Environmental Statement - Management of Commercial High Level and Transuranium-Contaminated Radioactive Waste" page 2.5-2 indicate that RSSF design includes protection against man-made intervention, assumed to mean with malicious intent. What is actually provided to prevent dispersal by sabotage?

IV H-57 — The concept of storing all plutonium waste at remote RSSF's with central incinerators should consider at least one eastern site to serve the fuel fabrication and reprocessing operations in this region of the U.S.

IV H-59 — Last paragraph. Volume reduction should be changed to 3 to 4 because field experience survey shows secondary scrap generation (filters, refractory, etc.) affects net volume reduction, especially with incineration.

IV H-61 — Paragraph 1. Rationale for considering only remote desert region is not clear for Pu waste RSSF.

IV I-4 — Suggest deleting paragraph 3 in its entirety since soft gamma contribution from Am-241 is a minor factor, considering that the new generation of fabrication plants have no choice except to be well-shielded and the Am-241 problem will be taken in stride.

IV I-5 — Line 1. After criticality prevention add "high accuracy inventory measurements for safeguards compliance".

III C — Change the word "when" to "if" in line 1 of the last paragraph.

IV I-6 — The storage inventory without recycle should be changed to show buildup starting in 1978 not 1976 since there will be no reprocessing carryout until about 1978.

IV J-6 — Improvements in control of occupational exposure during uranium mining and milling have not been listed as to effect on fifty year dose commitment. This information should be added for balance. Likewise, the impact of several inadvertent releases from reprocessing plants or mixed oxide fabrication plants have not been assessed and listed in the fifty year dose commitment.

Page	
IV J-7	Item C, Line 7. Plutonium fallout of 320 kilocuries ratioed to the area of the United States should be given in addition to the worldwide fallout. Paragraph 4. After reference 2 the text should indicate an analysis by C. R. Richmond which was published in 1974 following the Second Annual Life Sciences Symposium at Los Alamos during May.
IV J-16	Transportation accidents should be included in this table.
IV J(a)-4	Most resuspension data have been based on experiments in arid terrain. There is a lack of useful data in heavily vegetated areas such as the Middle Atlantic Region. Resuspension data with uranium shown on Page IV J(a)-6 may indeed be conservative but considering that the bulk of the population is located in the eastern half of the country, more realistic data should be made available.
IV J(c)-7	Item 2. 1974 publication by C. R. Richmond, LASL, should be listed as a primary reference since it deals with the hot particle problem.
IV J(c)-9-17	The text is silent as to the toxicity of plutonium when combined with uranium in a mixed oxide compound. To date there have been no studies on the radiotoxicity of various mixtures of plutonium with uranium. Although only a small percentage perhaps 5-15% of the total tonnage of mixed oxide being processed in the year 1990 represent solid solution mixed oxide in the finely divided processing stages, if this combined form followed a pathway which resulted in adverse effects in regard to either bone or other critical organs, it should be identified at an earlier enough date to appropriately adjust the models. To our knowledge there are no animal experiments currently funded in the United States which will evaluate the effect of the mixed oxide particle itself. Uranium and plutonium would be expected to disproportionate in the body fluids and the results may be more complex to interpret and apply than for PuO_2 or other 100% plutonium compounds.
V-6	Second paragraph. Improved statistical treatments should probably be included as one of the means of improving safeguards systems.
V-6	Last paragraph. While it is stated that "a early evaluation of the concept is necessary" GESMO should recognize that the decision is already late. One manufacturer is currently faced with siting a mixed oxide fuel plant requiring "large capital investments" for which considerable engineering has been done. Perhaps there should be an acknowledgment that earlier plants may not be co-located, but that as the industry matures co-location would improve the overall safeguards. This would put the concept into proper perspective; it should not be a "go--no go" situation.

Page

V-7 Section 6. This does not appear to acknowledge the considerably increased difficulty of making fuel with "spiked" plutonium.

V-28 Bottom of page. Here and in other sections of the GESMO the entire approach seems to be based on hardened manufacturing facilities. It would be highly beneficial (and probably a necessity) to address the problem of existing facilities.

V-39 Last paragraph. A similar listing of the disadvantages would seem to put things in better balance.

V-40 Paragraph 3. The weight of shipping containers for LWR plutonium oxide will probably range from 2500 to 5000 pounds due to shielding and confinement requirements.

V-41 Last paragraph. Some estimate of the probable costs of these systems would be appropriate.

V-44 Paragraph 6. This approach (incomplete separation) is not consistent with previous statements which imply conversion would have to be done at the reprocessor due to the ban on plutonium solution shipment.

V-44 Paragraph 7. The implication is that only additional shielding is required for fabrication of spiked fuel. In fact, entire new processes would have to be designed and QA activities would be greatly complicated. It is entirely conceivable that there may be no practical way to fabricate fuel under these conditions.

V-45 Paragraph 1. It seems much more likely that the fuel fabricator would be more concerned with health effects than a bomb builder. The population exposure as related to manufacturing personnel should be taken into consideration.

V-45 Paragraph 2. An increase in fabrication cost of $500/kilogram (which is probably not at all unrealistic) would likely render plutonium recycle uneconomic. Also, the effects decreasing fuel reliability (consequently enhancing population exposure due to fuel failures) because of decreases in the effectiveness of the quality assurance programs is not addressed.

VII-2 Paragraph 1. The lead sentence indicates that not all differential effects are adverse. However, the discussion is limited to only those effects which are adverse to plutonium recycle. Although such an approach is undoubtedly conservative, it serves to weaken the overall impact statement in that it fails to identify both favorable and adverse effects. It is believed this chapter should be expanded to identify both the favorable and adverse unavoidable environmental effects assignable to plutonium recycle as they differ from uranium fuel.

Page

VII-12 Paragraph 4. This indicates "additional measure to further limit any adverse effects may be possible. . .". However, the specific need for implementation of each approach is not justified in the report. Such quantification is believed essential for the final impact statement. Specifically, citing criteria for recycle plutonium facilities, guidelines on "as low as practical" releases for the facilities, improved safeguards, additional spent fuel shipment cask safety design criteria, long term waste management criteria, and possibly other items must be prudently developed and established prior to the accurate assignment of cost benefits to the various alternatives considered.

VII-14 Paragraph 6. The meaning of "action levels" is unclear.

VII-15 Last paragraph. "Fuel melt down" probably refers to clad melting.

VIII-8 Paragraph 4. Spent fuel transportation plus reprocessing cost of approximately $35/kilogram are undoubtedly too low.

VIII-13 Paragraph 3. Under the alternative of reprocessing spent fuel immediately and storing for later use, the build-up of Am in the recovered plutonium during storage and its associated impact seems to be ignored. Americium builds up in the recovered products through the decay of ^{241}Pu and in turn decays with a very strong alpha emission. The concentration of americium in the stored plutonium is dependent on the elapsed time since reprocessing and the isotopic concentration of ^{241}Pu in the plutonium. Typical plutonium recovered from reprocessing LWR fuel which is stored much in excess of one year prior to fabrication no longer can meet the current industry's specifications on americium concentration for recovered plutonium. The presence of americium in the plutonium and its associated strong alpha emission, imposes a significant radiological handling problem to the mixed oxide fabricator. Consequently, the need for chemical separation of the americium from the plutonium is required prior to mixed oxide fabrication. The major disadvantages of this additional separation step are:

(1) the production of additional plutonium bearing waste.

(2) the potential of introducing additional chemical impurities in the plutonium effluent.

(3) the need to reconstitute the plutonium back to its original oxide form for either shipping or uranium blending requirements.

(4) the major economic impact of the additional separation step.

Page

VIII-13 (Cont'd) When assessing this alternative in the final impact statement, both the cost benefit analysis and the environmental consequences of this additional requirement should be considered.

VIII-16 Paragraph 3. The use of depleted uranium as a carrier for the plutonium should be addressed. Utilization of tails assay materials, currently an unused waste from the uranium enriching process, should result in the significant benefits to this alternative.

VIII-16 Paragraph 4. This alternative would also have the same potential benefits of using depleted uranium as a carrier.

VIII-17 Paragraph 2. Alternative 6 seems to be discussed in paragraph i. not j.

VIII-21 Paragraph 1. A mixed oxide cost of twice uranium fuel fabrication is probably too low even considering current regulations, and is likely to increase rather than decrease as additional regulations are implemented. A cost of three times uranium fuel, over the entire time period (a surcharge of two times) should be subject to less argument. (The recent public bid openings at TVA and LADWP provide more concrete information on current pricing.)

VIII-21 Paragraph 2. The $35/kilogram number for reprocessing and spent fuel transportation needs to be updated.

VIII-33 Paragraph 4. The long term plutonium storage costs appear to be exceedingly low. The reason for this is not immediately clear and is recommended that the bases for the estimates be further explained.

VIII-37 There is some question as to the reasonableness of the estimated value of plutonium. Perhaps AEC could indicate the basis on which these estimates were made. Also, it would be desirable to include a statement on the sensitivity to a plus or minus change of $1/gram.

VIII-48 Paragraph 2. See comments under VIII-21, Paragraph 1.

Page

VIII-65 Paragraph 1. The unit costs of separative work, U_3O_8, and other factors used in the calculation of plutonium value need to be reviewed and revised to correspond with recent changes in the industry. Refer to other comments related to unit costs, escalation, and sensitivity to a plus or minus range when estimates are used.

VIII-65 Paragraph 2. The fabrication cost differential discussed in this paragraph does not relate to earlier parts of the GESMO that mention up to $500/Kg increase for safeguards concepts, such as spiking the plutonium. It would be desirable to track all cost-related items through the entire report to assure consistency.

VIII-69 Section C. This paragraph is confusing. It is suggested that it be rewritten to relate more closely with the other paragraphs discussing integrated fuel cycle facilities.

VIII-73 Section D. The cost to protect against theft of fresh fuel and the cost of additional hardening of barriers against theft of plutonium, each estimated at $1,000,000 for each reprocessing plant and for each mixed oxide fuel fabrication plant, is suspect. It is suggested that the discussion be expanded to indicate how these figures were derived.

VIII-75 Section N. The first sentence of this paragraph is not consistent with earlier parts of the GESMO, which indicated that costs would more than double when using "spiked" plutonium. It is suggested that the report be reviewed for consistency in matters of this sort.

XI - General The capital cost of facilities generally looks low. Since the major contributor to the benefits of Alternatives 3 and 4 are the savings in investment in Enrichment and Mining-Milling facilities, this modification will not affect the results.

One item open to question is the capital investment needed at a nuclear power plant to receive, store, and use Pu recycle fuel. It is not clear where this has been included. If one assumes it could add $5 million to the cost of each reactor recycling plutonium, the added costs to reactors is $600 million. If this figure is appropriate, the impact is small but is indicative of hidden costs which may need to be further investigated as licensing regulations evolve. Credibility of the report will be enhanced if all such cost items are identified.

XI-22 The conclusion paragraph should be expanded to discuss the apparent inability of the nuclear industry to get reprocessing and manufacturing facilities constructed. The problem areas should be outlined.

Page

XI-24 Table XI-10. The 1990 $12.83 figure for the U_3O_8 price in the terms of unescalated 1974 dollars is low and will distort the economic comparisons. This is indicative of the low cost numbers used in the report. It is recognized that there has been a dramatic increase in costs related to various components in the fuel cycle during this last year. For this reasons, all cost numbers and related economics should be updated.

XI-29 Table XI-11. The previous comment also applies to this table. All U_3O_8 cost projections used in the report need to be updated in order to enhance the credibility of the economic conclusions.

XI-44 Paragraph 3. Please expand the discussion to point out why the plutonium storage facilities would be similar to high-level waste disposal facilities.

ATTACHMENT A

Examples of Overconservatism in Dose Calculations

1. The use of the semi-infinite cloud model for gamma dose may approach being correct at some great distance from the point of release, but it is not correct at distance of usual interest. The resulting degree of conservatism depends on whether the release is from a stack, a roof vent, or a lower elevation. The correct model to use is the finite cloud gamma model. (p. IV J-(A)-2)

2. The X/Q values used are based on ground level release assumptions. Recent tests have shown that roof vent diffusion is much better than previously assumed by the AEC. (p. IV C-95)

3. The submersion total body dose from noble gases calculation was applied to GI tract, thyroid and bone. The revised Appendix I (2/20/74) does not apply submersion dose to individual organs. (p. IV C-103)

4. Details of iodine inhalation dose calculations are not evident and need to be reviewed. They apparently include assumption of out-door exposure at fence post all year. (p. IV C-103)

5. The iodine milk doses include all the overestimates which were shown to be objectionable at the ALAP hearings, namely (p. IV C-103):

   a. Iodine chemical form-overestimate by a factor of 2

   b. Roof vent diffusion-overestimate by factor of 10

   c. High iodine deposition factor-overestimate by factor of 2

   d. High transfer; grass to milk, overestimate by factor of 2

   e. Assumption of fence post cow and baby factor of 2 to 100 depending on actual cow location and milk usage. (The AEC abandoned fence post cow concept on 2/20/74.)

SAFEGUARDS—THE INDUSTRY'S ROLE AND VIEWS

128

Carl Walske
President
Atomic Industrial Forum, Inc.

The U.S. nuclear industry, or nuclear energy community—whatever we may call it—consists of hundreds of companies and other organizations interested in commercial applications of nuclear energy. Most, if not all, of them are members of the Atomic Industrial Forum—some 625 as of today. Their opinions naturally vary on any issue which affects the development of nuclear energy, though oftentimes there is a general consensus view. So it is with the matter of safeguarding nuclear material of weapons grade—or special nuclear material.

While the Forum has not polled its membership on safeguards questions we on the staff have had a number of discussions with a good sample of responsible people from our member organizations. These include people from fuel reprocessors and fabricators, utilities, reactor manufacturers and transportation companies. On the basis of these discussions I have some feeling for what "the industry" is thinking about safeguards. As I talk I shall also mix in my own views, identifying them where they may be special to my own experience.

First of all, the industry is proud of the record to date. There have been no diversions. There has been no sabotage. There have been a few cranks, or other malicious persons, who have made threats. Most of these, unfortunately, probably were inspired by the publicity which has been given the subject. In the view of many of us, the publicity was unfortunate, but that's water over the dam now and we have to deal with the situation as it is.

I said that the record to date is perfect and that's true. Of course, the quantities of plutonium and highly enriched uranium handled in the industry have been miniscule by comparison with what lies ahead as we move toward the eighties. The industry knows this and fully appreciates that strengthened controls are necessary to deal with the large amounts of special nuclear materials which we anticipate.

Now, is it possible to protect special nuclear material sufficiently so that reasonable people will agree that any risk from diversion or sabotage is negligible? I believe that it is and at a cost which, although high, need not be so high as to cripple the economics of nuclear power.

The current safeguards system, as spelled out in new AEC regulations, is a clearly strengthened one as compared to what we had just a year ago. I believe it goes a long way towards what we need. At the same time there are certain aspects of this safeguards system which can be further improved. Some are appropriate to the industry's area of responsibility, some to the government's area. The balance of this paper discusses these possible improvements. They are, I believe, supported generally by the nuclear industry

I shall be talking about the security personnel with the special nuclear material, physical protection, accounting and monitoring of special nuclear material in plants, communications, the command function, reinforcements and intelligence information All these are necessary and complementary in building a first-class protective system for anything—whether it's gold bullion or special nuclear materials. They are necessary for special nuclear material at a fixed installation or in transit.

Guard forces and physical protection with special nuclear material can provide a first line of defense. It is not necessary that this line be impregnable, provided it is backed up with a reliable communications system which can be used to call up adequate reinforcements from a friendly command. Accounting for and monitoring of special nuclear material, ideally on a current basis, can signal departures from normal conditions, that is, sound a warning that something has gone wrong. Intelligence information, when available, is even better; it can signal in advance that something is about to go wrong.

Let's talk now about guard forces. First of all, most people in the industry would prefer to manage their own, other things being equal, but there is a problem. AEC regulations call for the use of armed force, if necessary, to prevent diversion or sabotage of special nuclear materials. In my own view this is appropriate, but in the civilian nuclear industry it is essentially unprecedented. It brings with it a responsibility beyond the experience of most commercial organizations and one which threatens with a morass of legal liabilities. However, there is a compromise on the question of who should provide and manage guard forces. The compromise approach is to divide functions between those requiring the use of armed forces and all others. The former should be performed by governmental forces; the latter by security personnel directed by the company responsible for the special nuclear material.

For example, at fixed installations, monitoring and searching, if necessary, of plant personnel; materials accounting and monitoring; and maintenance and testing of physical security systems can all be done perfectly well by personnel under the plant management. In fact, they can be done with less upset to plant operations and to plant personnel—insiders dealing with insiders.

However, should the situation call for the use, or threatened use, of firearms to deal with a security problem—attempted diversion or sabotage—properly authorized public law enforcement forces should be brought into play. Such forces may be stationed at or near the fixed installation, or they may be on call from their normal station nearby. Obviously, they must be in a position where they can provide a timely reaction. For most fixed installations local police units may prove to be the most satisfactory.

Guards accompanying special nuclear material in transit must be able to meet force with force. Local police forces, in general, will not be able to respond rapidly enough to deal with attempted diversion and sabotage. Largely for this reason many in the industry feel that such guards must be under governmental control and must be authorized to act in emergencies under governmental orders. This might be done by using a special, governmentally organized force, or by civilian guards under contract to the government.

In all cases—material at fixed installations or in transit—guard forces should be well trained and required to exceed minimum physical and mental qualifications. They should be requalified by government inspectors on a periodic basis. Most importantly, guards should be given clearly defined authorities to govern their actions in the various emergency situations that could arise.

Physical protection of special nuclear material may include fences, lighting, vaults, and detection and alarm systems at fixed installations; and for material in transit it may include heavy containers or armored vehicles. These complement the assigned guard personnel. In general, the industry has accepted and agreed with AEC requirements for physical protection. There should, however, be a continuing review of these requirements, on the one hand, to see that no "Achilles' heels" are left in the protection systems and, on the other hand, to eliminate costly features which make only marginal additions to security.

AEC regulations currently permit shipment of special nuclear material—as defined in 10 CFR Part 73—either in a conventional truck with an armed escort vehicle manned by two armed guards, or in a specially designed truck or trailer without an armed escort. The design of such a special truck or trailer must include a capability for immobilization of the vehicle and must provide armor and other deterents to physical penetration. In a properly designed overall protective system the deterence to physical penetration will allow sufficient time for reinforcements to arrive at the scene of a diversion attempt.

In general, the industry is sympathetic with the armored vehicle approach when it is applied to special nuclear materials in a sensitive form suited to easy movement and direct usage in nuclear explosives, that is, separated highly enriched uranium or plutonium in the metallic or oxide form. However, when either of these fuels is contained in a fabricated fuel element, they are awkward to transport and they must be separated chemically or physically in order to be used as ingredients in a nuclear explosive. Thus, the industry's feeling is that for truck shipments of separated or concentrated special nuclear material, we should phase over, as practical, to the use of the armored vehicles. Until this is achieved and while conventional trucks are still in use, I believe that more than one armed escort vehicle should accompany shipments and each escort vehicle should have at least two armed guards.

Shipments by air, where possible, can generally be made the most secure. I noticed recently that the JCAE's Conway Committee has recommended against plutonium shipments by air, except in cases involving national security. This appears to me to be unfortunate. The risk of extensive aerial dispersion in a plane crash is certainly minimal. Careful choice of flight paths and special packaging could reduce even this small risk. It seems to me wrong to give up our most secure means of transporting plutonium.

Shipments abroad of special nuclear material must provide for adequate protection until a shipment is safely in the hands of its intended recipient. It goes without saying that precautions must be taken against hijacking and also that recipients must be capable of protecting material in their custody.

Reliable personnel are an absolute must if we are to have good security. Although security-type clearances are foreign to the civilian industry, nevertheless a clearance program appears appropriate. It would apply to all personnel having access to significant quantities of special nuclear materials. The AEC has now obtained legislation necessary for such a program. I believe the industry, in general, understands the need for this and supports it.

Such personnel clearances should certainly reduce the concern of those—such as the author of the Rosenbaum report—who postulate that "insiders", including senior management and operating personnel working within a facility or transportation company, could be involved in sabotage or diversion.

Furthermore, such cleared employees of licensees need be searched only exceptionally on entering or leaving protected areas containing special nuclear materials. Monitoring with instruments should suffice, with spot check searches only infrequently. As I said earlier, any such physical monitoring or searching should be the responsibility of personnel employed by the plant management.

At the same time I must say that security-type clearances are not to be taken lightly. It is most important that our society carefully preserve the rights of its members. Security clearances can obviously be abused. It will be up to all of us to guard vigilantly against any such abuse.

Much effort and much expense have gone into accounting and monitoring systems for special nuclear materials "in process" in a plant. Presently available techniques suffer from two great faults: First, their accuracy is such as to leave sizeable quantities of special nuclear material in a doubtful status; and, second, they report on losses only after they have happened, not as they are happening. All the same, the industry generally supports the rational application of the present techniques. There is, however, a strong feeling that it is illogical to incur greatly increased costs by shutting down plants frequently for overall inventories and by reducing allowed inaccuracies beyond what is straightforward. Unfortunately, the answers from the present system will be inaccurate, whatever the effort expended. Therefore it is sensible to use the present system only for what it is capable of doing—that is, detecting gross losses or diversions.

Beyond the present system, we may hope to have real time and accurate accounting someday. I don't know how achievable this may be, but it is certainly the right objective. Even now we can use special precautions whenever there are inter-area transfers at a plant. These could include independent weighings, checks of seal integrity, and other routine accounting actions and measuring actions to aid in the prompt detection of diversion.

Let us turn now to the question of communication systems. As I said earlier such systems serve the purpose of permitting local guard forces at a fixed installation or with a shipment to call for assistance, that is, to call for reinforcements. Obviously, such a purpose will only be met if the communications are highly reliable and if reinforcement forces are available for timely reaction from authorities having such forces at their disposal.

The AEC presently requires a licensee to maintain communications between his so-called control point and the guard forces at his installation or with shipments containing special nuclear materials. Carriers must make advance arrangements to assure support from law enforcement agencies. For shipments the present system relies on (1) the use of radio-telephones which are not effective in large areas of the United States, although they are working well in present operating areas; (2) local or state law enforcement agencies for reinforcements; and (3) support arrangements as can be made between such law enforcement agencies and the licensee.

There are several important improvements that should be made to the present system. First, the communications should be based on a federally operated, high frequency network. Such a network has proven highly reliable in maintaining radio contact with virtually all areas of the U.S. Second, a federal command center, perhaps supported by regional centers, should be established. It would receive and act promptly on reports of attempted diversion or sabotage involving special nuclear materials. Such a communications system and command center would be for both fixed installations and shipments.

The federal agency responsible for operating the federal command center should be responsible for consummating agreements with local and state police, the national guard and federal armed forces for provision of reinforcements. As mentioned previously, effective local law enforcement agencies are particularly well suited for responding rapidly to incidents at fixed facilities. Generally, state and federal forces will be more effective for incidents affecting material in transit. The agreements will certainly involve state governors for state police and the national guard; they will involve the President for federal armed forces. New legislation may be necessary to implement these arrangements. It is my impression that this area of federal communications, a federal command center and authority and implementing agreements, is the single most important task facing us as we move to improve the protective system. You will note that this, as I have presented it, is a task requiring the initiative and leadership of the federal government.

A special type of reinforcement capability would be needed if a diversion attempt were to prove successful, that is, if a diverter were to escape the first line of defense. In this event retrieval of the special nuclear material would be our objective. A retrieval operation would logically use nationwide intelligence information and therefore would best be handled by using a federal force under federal direction. This might be basically an FBI operation under the Attorney General.

Intelligence information available to the FBI, Treasury Department, CIA, Department of Defense, AEC, and state and local law enforcement agencies will never be sufficient to forecast all threats that may be developing. However, the totality of information available to these agencies can be very helpful in reducing risks. It is not clear to me that a good mechanism now exists for the prompt reporting of such information to a central, responsible command authority of the type previously mentioned and, also, the prompt dessemination of such information to law enforcement agencies. If it is not being done well, as I suspect, it should be corrected.

I have discussed a number of improvements that would strengthen our present safeguards system. The major new tasks are in the area of governmental responsibility, although I have mentioned some additional tasks for the industry. These would not, in my view, involve an appreciable increase in present safeguards costs. In fact, the AEC's new regulations—in effect since December 6, 1973, and now being implemented—went a long way to provide the necessary measures required of the industry

As we look on ahead to the future, the nuclear industry will continue to work with the AEC to employ more stringent methods and procedures. Safeguards cannot be static as the nature of the problem changes. Both industry and government must move forward together to meet their vital responsibilities in this area.

My main points in this paper, aimed at strengthening our safeguards system are, I believe, generally acceptable to the nuclear industry. These points are:

1. Local guard forces and physical security measures should be sufficient to detect, report and delay attempted sabotage or diversion until reinforcements arrive.
2. Guard and security forces at fixed installations should be under the supervision of the plant management, except for those guards charged with the use of armed force. These last should be governmental forces, or at least governmentally organized and supervised guards.
3. Guards accompanying special nuclear material in transit should be under governmental control and should be authorized to act under governmental orders in emergencies. They may, thus, be government employees or contract guards under government orders.
4. Moreover the federal government should be directly and fully responsible for security of special nuclear materials in transit, coordinating and making use of local, state and federal resources.
5. For shipments of concentrated special nuclear material phasing over of conventional truck transportation should be undertaken, as practical, to the use of armored vehicles with immobilizing features. The design of the transport vehicle should include a strong barrier against penetration, which will allow sufficient time for reinforcements to arrive.
6. Physical protective features for special nuclear materials should complement guard forces in such a way that no "Achilles' heels" are left, but also so that costly features providing marginal additions to security are eliminated.
7. Agreements should be consummated, as necessary, between the responsible federal agency and local, state and federal officials for the prompt use of their forces when necessary. These agreements should include arrangements for operations by a federal retrieval force and for exchanging threat information with law enforcement and other agencies.
8. A federal communication system and command center should be created to support and coordinate the response of local, state and federal security forces in the event of attempted sabotage or diversion attempts at fixed installations or during transport.
9. Improved real time accounting procedures should be developed and implemented, at which time the dependence on MUF and LEMUF for detection of diversion should be greatly reduced.
10. An employee clearance program should be established for licensee personnel who have accesss to significant quantities of special nuclear material.

I regret that adequate safeguards require so much government involvement, particularly by the federal government. It would certainly be preferable if the industry could handle this problem entirely "in-house". Unfortunately, that does not seem to be a practical way to reach our objective of providing proper protection to special nuclear materials. We must, it appears, proceed with an industry-government partnership with each carrying out its role where it can do the best job.

In conclusion, I want to re-emphasize that the nuclear industry recognizes the importance of protecting nuclear facilities and special nuclear materials at fixed sites and in transit We are confident that potential risks will be held at such a low level that they will be acceptable in the judgment of reasonable people.

Attachment 4 of 4

Ad Hoc Plutonium Recycle Task Force
of the
Nuclear Fuel Cycle Services Committee

D. R. de Halas (Chairman)	The Babcock & Wilcox Company
Emanuel Gordon (Secretary)	Atomic Industrial Forum
Richard L. Booth	Nuclear Fuel Services, Inc.
Colin S. Caldwell	Nuclear Materials & Equipment Co.
Bernard H. Cherry	General Public Utilities Service Corp.
Joseph Cupo	Westinghouse Electric Corp.
George Darmohray	General Electric Co.
Christopher Fowler	Allied-General Nuclear Services
Rudolph Grube	Yankee Atomic Electric Company
William Macnabb	NUS Corporation
Harvey Price	Atomic Industrial Forum
Raymond Robinson	Exxon Nuclear Company
Norton Shapiro	Combustion Engineering, Inc.
Thomas Snead	Duke Power Company
Wallace Sumner	Allied-General Nuclear Services
Robert Tallman	Bonneville Power Administration
William Utnage	Kerr-McGee Nuclear Corporation
Albert Watson	Carolina Power & Light Company

10/28/74

I wonder if the members of the Atomic Industrial Forum would care to come up to the front, and perhaps we could ask the questions from up here. It would be much easier.

I have a few questions I would like to ask.

Dr. Sagan, I am impressed with your emissions tax proposal. One of the questions I had as I understood it, you said in a sparsely populated area, a tax would be different from what it would be in a densely populated area.

Would this in some way imply an inequity in the risk to the population? Would there be more material going out?

Dr. Sagan: I think there should be some balance between the risk to the individuals and total risk to the population.

The way I would visualize that, and I must admit I have not given great thought to how this would be implemented, I would suppose that one would begin by estimating a dollar cost per man-rem. This is done many times for radiation as a whole.

I would guess that that dollar cost per man-rem for plutonium exposure would be less than for total body exposure. That is to say, the estimates for total body exposure range from $10.00 up to $500.00.

I would think the man-rem cost for plutonium would be lower than that, simply because fewer organs are exposed. Then, what I am suggesting in my talk is that that cost, whatever might be arrived at, might then be adjusted upwards or downwards depending on how many people were exposed to such a plutonium release.

For example, if that release were in the middle of New York City, I would think there should be greater penalties attached to it than if it were released in the center of the Nevada Desert.

Dr. Mills: Thank you. I have a question for Dr. Goldman.

Many times it is proposed that we put our radiation standard into perspective. We often use the perspective of natural background.

Would you care to comment on how you visualize this perspective being put to use; that is, are we really talking about natural background rather than a threshold level for an effect, or are we talking about proposing releases in addition to natural background, that these releases are so small that they are within the noise level and therefore the effects are simply indistinguishable from the normal occurrence?

I am just trying to seek your comments as to how you visualize this.

Dr. Goldman: If I understand your question correctly, I introduced the topic of natural background just to remind us that it is composed of a variety of radiations, including alpha emitting particles with varying propensity to become diffused.

We do not start out with zero. I do not believe that on the basis of laboratory information I have seen that there are radiation effects derived from background. That is really beyond biomedical science, that minor differences in radiation background could produce effects.

The reason for this is in the bulk of the radionuclide studies that I have been familiar with, it is only when one gets to factors of

a thousand times above background, something like three to ten thousand times the background radiation rate, with animal experimentation that I have seen, be it a linear or sigmoidal or threshold type of response, that I have seen increases in the effects under study.

I do not know whether we will ever be able to quantify, whether what I have said is 3,000 or 10,000. I am merely saying that on the basis of my assessment, that is the kind of thing I see.

In the case of things like radium, or perhaps even plutonium, the dose rate to the critical organ gets up into the range of hundreds of millirem per day, to find whatever quality factor you want, to get from rads to rems, but it is at that point that the biomedical effects data start to arise.

What is rather fascinating is one need only go another order of magnitude higher when you get complete 100% type effects. When one gets beyond that, we get into wasted radiation and inefficient utilization, computing risks and all that.

My concern has been to concentrate on that region. These effects wander between the 80 percent and 5 percent level of effect. I think we can learn much about the nature of response for radionuclides where the dose rate is rather low, although the cumulative total may appear large.

It would appear that something akin to what Mr. Parker said with regard to a signoidal type response exists.

I think what I am trying to say is that I do not believe there is a risk associated with the levels of radiation that we call natural background.

Dr. Mills: But you would agree that any assessment, any models we use to assess the effects of plutonium, that those same models there is no uniqueness to plutonium toxicity, should be used in the assessment of what natural background might contribute?

Dr. Goldman: You are then asking me to say that some fraction of the background health effects might be attributed to the contribution from background radiation.

If there were a magnet that could eliminate background at the spontaneous rate of condition A, B or C, that might be reduced. Is that the sense of your question?

Dr. Mills: No. I am not really asking you that. What I am saying is, in terms of putting radiation in perspective, we have viewed that quite often, would you agree that models that one uses to make the assessment, those radionuclides which are added to the environment, that those same models, where they are compatible -- would those same models be used for the naturally occurring radionuclides?

Dr. Goldman: I think that is one approach, yes.

Dr. Garner: Would you agree, this procedure would be fine for comparative purposes. Maybe you would not agree if you were talking about absolute risk. Would that be a distinction in this use of models for natural background?

Dr. Goldman: I feel a bit more comfortable in considering things on a relative scale rather than on an absolute scale.

Dr. Garner: I have a question. I do not know quite to whom to address it. It is the question of plutonium recycling.

I would like to try to find out, if some one of you can answer it, to what extent this recycling would reduce the amount of the present risk. One of the major concerns of the general public is, of course, the hazard from long term storage of waste which we are told will be dangerous for millions of years.

If in some way we could reduce the amounts of this hazardous material present in waste, I should think we should try.

Is plutonium recycling, or the efficiency of recycling of a transuranic, is it going to be effective in reducing the amount present in the waste to be diposed of?

Mr. Deuster: If one reprocesses, which is what you are presuming, the normal reprocessing plant will remove about 99 percent of the plutonium from the fuel. There is something like a half of one percent to one percent of plutonium that was originally in the spent fuel that does go with the high level waste when they are separated.

All of the plutonium, then, that is separated will be recycled back into the reactor. Thus, that will be taken out of the waste stream.

In other words, if you did not reprocess spent fuel and you elected to store or dispose of spent fuel, then all the plutonium

would remain in that spent fuel assembly.

Dr. Garner: Yes. The question I am asking is, you said it would be economical to recycle plutonium. Is this economy such that there are better separations techniques in trying to extract plutonium in recyclable materials; disposing of them with a fission problem, because we know there is much more of a problem with storing of fission products than with transuranics.

Mr. Deuster: We have no plans to improve on the extraction process. I believe the extraction efficiency of plutonium from the spent fuel in our facility is essentially the same as that for the other facility that is expecting to go into commercial operation, the Allied General Nuclear Services Facility.

I do not know whether Dr. Wolfe is still here, but I believe the efficiency of the plan for Morris operation was similar to that of West Valley.

Dr. Garner: So it makes very little difference?

Mr. Deuster: I am not a chemical engineer. But the discussions I have had on this particular subject are such that, yes, it is possible to improve on that abstraction efficiency by some small amount, perhaps a half percent, by redesign of a plan to add another separation stage, perhaps take it down to a .2 percent, but this is still a rather small change and, on an economic basis, unjustified.

Dr. Garner: I have another question to address to Dr. Goldman. I would agree with you until a few moments ago that the main health hazard from plutonium was the question of suspended material. I think

this is what you concentrated on.

Dr. Goldman: I did not say it was the main question. It is what has gotten the greatest publicity.

Dr. Garner: In fact, aging material may become more biologically available so that a very small percentage could be absorbed in the body and might be increased by aging material. Would you like to comment on that?

Dr. Goldman: As I said, I think there is going to be a profusion of technical comments made on some of this by the people who actually generated this type of data you are referring to.

I am a firm believer, though, in the fact that whether it be by ingestion or inhalation, it is the absorbed radiation dose that is of primary concern to me, and that the nature of the response in the critical organ is not too disparately different.

If one wants to postulate on a linear scale what the environmental consequences are on this, that, or the other, I in my own assessment found it necessary to include a fraction that might be ingested rather than inhaled. The fact that the intestinal tract is so efficient in barring against the uptake of this has a conservatism built into it that may not exist with respect to inhalation. So there are going to be additional considerations there.

Dr. Garner: Following up this question, relating to Dr. Parker's statement, when we talk about the transuranics we talk quite frequently about plutonium, meaning plutonium 239 as being perhaps in some of our minds the most toxic of these materials.

To some, I believe that americium 241 is considered to be perhaps the most toxic componant transuranic.

Would you like to comment on that?

Dr. Parker: Of the two, one would expect that the evaluation of americium could well be. In selected isotopes of plutonium such as 239, we would make the point that what is our real definition of toxicity.

I found out the other day, as a health physicist, I do not really know. I hope the agency knows.

Expressing things in terms of mass per gram of the contaminating substance, as mentioned in the British reference that I quoted, the transuranium elements are not even in the first 50 elements that you could come up with as being toxic, on that very arbitrary basis.

What was the real toxicity, I do not know. 239 obviously is wasteful because if you had some cooperation in the body, you are going to be dead with most of that staying in; so therefore, a clear waste of radiation, looking at it from the enemy point of view.

So you want something that does its darndest while entirely within the body. What that is in terms of the raw substances, I would hestitate to say, only that it be looked at very carefully.

Dr. Garner: I entirely agree with the statement that you made that we should review it from time to time. We fall into somewhat of a trap, continually using the linear non-threshold model, perhaps in a context it should not be used in.

Have you any solutions to offer if we abandon that model and start looking at animal data and decide there is a threshold, sigmoid, or

something of this kind?

What solutions shall I offer to my colleagues in the radiation programs, for example, who are faced with predicting the long-term consequences of exposure to these materials?

Dr. Parker: I would hope that the next stage, rather than having to assume a linear relationship, as a prudent method, we would, say in one decade from now, begin to have some data that would show a dose relationship to effect as A times dose plus B times dose squared something of that nature, in which you never have a precise value, but a reasonable estimate on what the values of A and B are.

Jumping the gun in terms of thinking that we know some of those, for example, from some of the data in Dr. Chuck Mays, you would probably come to the conclusion that at the environmental level, which I am assuming is very low, in activity scale you could safely say that the nose count of alleged cancer death is lower by, say, a factor of 100 than is derived on the linear model.

I believe, sir, if we had that data in hand and I am sure we do not have it today, this will be a real advance in comfort of what you might ask others to accept at the very low levels involved in the environment.

Is that responsive to your question?

Dr. Garner: Yes. It is responsive up to a point. You know as well as I do that abandoning this popular model is opening an enormous can of worms because we need to know the distribution, for example, of

the population or what have you.

It is all very well to talk about a dose square model, but then we have to know then exactly what these -- but then, we would not go into that.

Dr. Parker: I was not restricting this to plutonium. I have this hope in mind for the broader analysis of dose.

Dr. Garner: I would like to end with one very short comment that we should not talk ourselves into a state of complacency because, in fact, we have seen nothing in human exposure to plutonium.

There are about half a million curies of plutonium around the world. From tests, one could argue that we see nothing from this and why bother. But we know quite well that --

Dr. Radford: I would like to follow up on this dose response. I think Dr. Goldman made some statement to the effect that all the data he had seen showed no effect until, you conceded, about 3,000 to 10,000 times the background rate. Is that a fair statement of what you said?

Dr. Goldman: Yes, in terms of chronic radiation exposure. Dose rate from internal emitters is difficult to handle in terms of a unit dose, but rather one must keep in mind that it is a total dose derived over a longer period of time than in most of the human experience that has gone into the BEIR report.

In the case of animals, it has been over a decade, for example, a dose rate to the organs under exposure for that particular nuclide. You get up into the order of a hundred or more millirem per day,

that is when I see an increase in the incidence of tumors in that particular organ.

Dr. Radford: Let us deal with the dose of radium aspect first. I want to make it plain I am only talking about alpha emitters from here on out, only alpha emitters because these are essentially all the transuranic elements that are of importance here.

I will get to the question of which one in a minute. With respect to the effects of dose for rates of high radiation, what is your thinking about whether this rate has any effects on the risk factor for, say, cancer production?

Dr. Goldman: I feel that if the dose rate is sufficiently low particulates, that biologically it seems reasonable to me that the risk may not necessarily be unit proportional to that risk which might be more easily derived from a higher dose rate of the same kind of alpha particles, by virtue of the fact that -- maybe it sounds a bit simplistic -- but biologic systems are very dynamic.

If a sufficient amount of time intervenes, and if the alpha particles are sufficiently separated with respect to time as well as space, it is entirely conceivable to me that the effectiveness of those alpha particles is going to be far diminished over the kinds of data which is more easily derived.

You are going to have very high doses. Sometimes you call them incandescent experiments, in which very high levels do not permit whatever recovery or molecular repair events to occur. I can not really quantify or define it on a molecular basis.

Dr. Radford: Everything you seem to have said so far is just kind of a cerebration of the process based on some sort of model.

Dr. Goldman: It is not based on any model. It is based on an assessment of the response to radium, from alpha emitters, as well as emitting gammas and betas, over the lifespan of a variety of animal species, and when one corrects for the incident rate, the cause specific incident rates, and the amount of radiation dose, the response curves are not linear.

Dr. Radford: Which radium isotope are you talking about?

Dr. Goldman: 226, a long lived isotope which I think is more germane to the question you are raising.

Dr. Radford: Would you agree that radium 226 exposure in man has produced cancer when the radiation dose has been given over long periods of time?

Dr. Goldman: I did not say it did not. I am saying the nature of the response incurred is not linear, but even in the limited amount, in the lives of humans, we see excess doses of radium over a century. The current consensus is --

Dr. Radford: Are you quoting from the BEIR Report on that?

Dr. Goldman: I am quoting from the BEIR Report and some recent reports from the Argonne National Laboratories and Center for Radiobiology.

Dr. Radford: If I recall correctly, the BEIR Report said that while the data appeared to show non-linear relationships, a linear fit could not be ruled out. Is that a correct statement?

Dr. Goldman: That is a correct statement, and I have added to it the fact that when one adds animal experience to it, it is probably one of the few radionuclides for which we have that bridge.

People keep telling about how one extrapolates from animal information to human, that the nature of the response here does not vary qualitatively. There are differences, of course, in the way one scales time. The dose rate story that I told you about with respect to animals is not inconsistent with the pattern one sees in the data published in the BEIR Report, when one really connects data points rather than putting a line to it.

Dr. Radford: Now about radium 224?

Dr. Goldman: Radium 224 is very short lived and may indeed have a different dose distribution pattern, so one can not have low dose rate radium 224 studies with a nuclide that only lasts for a portion of a week.

Here one is dealing with what I consider acute radiation.

Dr. Radford: But it was shown by Mays and Speth that when the dose was protracted, the same total radiation exposure was given over a projected period of time, there appeared to be a higher cancer rate than when dose was given in relatively few injections.

Dr. Goldman: Then one has to make decisions about what kind of model to follow; in view of the absence of specific knowledge as to what happened, it would appear that the dose in terms of rads for the radium 224, might have had a lot of what Mr. Parker or someone mentioned

as wasted radiation in its effectiveness.

The difference between the 224 and the 226, if I recollect rightly, is within a factor of about two or three.

Dr. Radford: In terms of mean rad dose, it is much more than that.

Dr. Goldman: The same level of effect. The radiation doses, I do not think would have been different.

Dr. Radford: Do you recall what the lower dose received by any individual who developed cancer from the radium 224 injection is?

Dr. Goldman: I think that is subject to quite a bit of a problem in that the radiation estimate was retrofitted after the material had decayed. If I recollect, as Mr. Parker said, some tens of rads.

Dr. Radford: What about the lung cancer production, say in a mining population? How would you characterize the radiation exposure under those circumstances? Again, I am talking now in terms of dose rate.

Dr. Goldman: In terms of dose rate, the products that have been postulated to be responsbile for some of the excess lung cancer in these miners, I guess, would consider to be a chronic or fractionating exposure.

There may be some residual radionuclides in the lungs as well as the alpha emissions from the gaseous products, but that is continuous. I had some very serious problems with regard to quantifying that epidemiological information.

In fact, this is probably a problem in much of epidemiology when the dose is estimated. It is just that, just an estimation. It is not

a measurement. I do not know whether the people who have been reported to have this lung cancer had ever been mining, the conditions in which they worked.

One could get an accurate estimate of their exposure level; futhermore, it is my understanding that a goodly number of these people were heavy cigarette smokers.

We do not know enough about the epidemiology of lung cancer to be able to separate the role of their cigarette smoking history from the number of tumors that have been ascribed soley to radiation.

So there is dilemma there, especially in view of the fact that few non smokers have had comparable exposure. We do not know if such cases occurred. We may be dealing with a chemical synergism, but then again it is speculation as to model.

I have a problem in quantifying that.

Dr. Radford: To get that issue out of the way, the fact is that a number of cancers are now appearing in non smokers. It is historical,

What about the miners in Newfoundland? Would you characterize their dose estimate as inaccurate?

Dr. Goldman: I did not say inaccurate. I am just saying that one has precision problems in real life that are sometimes eliminated when one is in the laboratory, where there is specific control over all of that.

It is the precision, when one gets down to these levels and the small numbers of people involved, and the inaccuracies perhaps in the dose, still leave these open to question.

Dr. Radford: In essence, what you are saying is you do not believe the estimates had been made by the investigators. Therefore, you cannot really judge anything on the basis of this data. Is that essentially what you are saying?

Dr. Goldman: No. That is not what I am saying.

I am saying the dosage data exists. I have no reason not to accept it. It is the extrapolation beyond where the real data lies, that I have difficulty with because of the problems.

I think they have done an admirable job in estimating dose, but I know we have some problems, and especially in converting it down to three orders of magnitude lower dose.

Dr. Radford: Apropos of the three orders of magnitude lower dose, it seems to me one of the fundamental issues we are here to discuss, whether in fact it is three orders of magnitude lower dose.

I would ask anyone on the panel to answer.

Would you agree with Dr. Bair and his colleagues that a single alpha particle can be considered to have 500 rem exposure, one alpha track, when ingraded over only that, that it passes through about 500 rems?

Dr. Goldman: That is a physically measurable quantity.

Dr. Radford: So the hot particle issue, isn't it, gentlemen, that you have a single source of alpha radiation which when integrated over the volume to which it is distributed may lead to hundreds of thousands of rems, is that not over perhaps x period of time?

Isn't that what we are here talking about? High dose effects from a single particle?

Dr. Goldman: That is one part of the problem. I attempted to say very superficially in my few remarks that on the basis of empirical observation, using those types of particle that the animal experimentation does not raise the order to a uniquely different risk. That might be estimated on the basis of just adding up the number in that microscopic volume.

When describing the alpha particle on the basis of just toxological information, it is very unpractical to push this approach very far.

Dr. Radford: I would like to raise a couple of other questions. I believe it was Mr. Parker who mentioned the U. S. Transuranium Registry. Could you explain what that Registry is?

Dr. Parker: Yes, I would be glad to, Dr. Radford.

It is an operation that functions out of my headquarters in Richland. It is currently operated by the Hanford Environmental Health Foundation.

It briefly consists in an attempt to sign up those workers who are presumably exposed to plutonium to permit access to autopsy samples, prefereably as was done with many uranium cases, on whole willed bodies in the hope that eventually from this source, by being aware of the health conditions of these men and making presumably eventually reliable determination of their residual plutonium, we will get some real relationship between available plutonium in the body and deleterious effects, whether they be cancer or otherwise.

I would like, if I may, to go back parenthetically to Loren's closing remark which I suppose Dr. Goldman and I both thought the other was going to answer.

I am afraid the record will show that Dr. Garner brought up the issue of saying I hope we are not complacent and it drew a total silence from us.

I hope we are not complacent, too. None of our statements to you this morning, gentlemen, reflect that. I think my personal emphasis on the value of the Registry reflects that this is virtually the sole logical source of human data.

I will perhaps say I am not a little suprised that we have not seen deleterious effects among the some hundreds of workers who have measurable depositions of plutonium, which Dr. Garner says is always the issue of latency.

But eventually, that has to disappear because some of the more seriously exposed people were those in the early days of the project when conditions were not as favorable as they are now.

Some 30 years have gone by and in another decade, we will know a lot more. I do not want to project how the curve goes, but it is vital to the nation, as I see it, Dr. Radford, to do the best we can to acquire all the possible human data.

Dr. Radford: Apropos of just that point, you state that the Registry is an attempt to sign up workers who have been exposed to plutonium with particular emphasis, because you mentioned it in your next sentence, on willing their bodies for whole body analysis.

How many workers have you signed up so far?

Dr. Parker: I do not have that answer. I could ascertain it and submit it for the record from the head of the Registry, or possibly from some member of the Commission who may have it here.

I do not know the answer, sir.

Dr. Radford: Well, is it five?

Dr. Parker: No. It is more than that.

It is a number which varies very much between the principal sources of which plutonium has been used. My basic familiarity has been with the Hanford experience. I have no personal knowledge from memory of numbers.

As I say, I can obtain these numbers very easily.

Dr. Radford: You said you were in charge of the Transuranium Registry?

Dr. Parker: No, sir. I am a member, one undistinguished member of a large advisory committee. If I were that, I would hope I would be better informed, sir.

Dr. Radford: I want to come back to this time factor in terms of exposure. I really think this is a general question that I hope we can focus on and get out of the way once and for all.

It is somewhat germane to some of the points Dr. Garner made earlier; that is, what elements are we talking about here?

Is there anyone in this group, for example, who knows what mix of isotopes we are talking about? You mentioned, for example, mixed isotopes. What isotopes?

Dr. Parker: This is an engineering determination of the exposure. We have to determine what fuels are going to be used in the next 20 years and determine what exposures are most advantageous. I think it is rather elementary to work out those compositions.

I am suggesting my notes, which were made very brief, that you could possibly pick two representative conditions. I had a report some time ago with a similar theme which picks three. It depends on how many dollars you want to put into different compositions.

A required number of compositions would lie somewhere between two and infinity, if you had no limit of dollars to put into it.

Dr. Radford: Let us not get into the experimental design. I just would like to know does anyone on this panel know which isotopes we are talking about?

Mr. Deuster: The plutonium that is produced in the water reactors varies on the reactor type. The PWR will produce a slightly different composition than a BWR because of the spectrum in the reactor.

Typically, if we are reprocessing normally radiated fuel in the range of 25,000 to 30,000 megawatt-days per ton, the plutonium 239 content would be perhaps around a 70 percentile.

Then, plutonium 240 and 241, and some 242; perhaps, 240 at 15 percent or 18 percent; 241 at nominal 10 percent; a percent or two of 242. Then when we mix that material with some uranium, it may be natural uranium; it may be, some people propose using the tail uranium --

Dr. Radford: I was mainly concerned with the -- But that is through a fuel processing plant?

Mr. Deuster: Typically, but it will vary.

Dr. Radford: Those are mass percentages, right.

Mr. Deuster: Yes. But they are not that accurate, in any case.

Dr. Parker: I can read three accurate compositions into the record, if it will be helpful, or give it to you later.

Dr. Radford: No. I have the numbers. I am just trying to find out whether we are talking about the same thing.

I am referring specifically to the ORNL report 4451 on Fuel Reprocessing that gives as a topic, compositions as a function of time after removal from the reactor for a 30 day holdup time for radioactive decay and so on.

The significant point to me is that plutonium 238 is much higher in concentration by activity. This is in the waste stream assuming 25 percent, so it comes up on an activity basis.

We are talking about, say, 300, I think, curies per ton throughput, curies per metric ton; and plutonium 239, only 17.7 curies.

Now, are we talking about plutonium 238 or are we talking about plutonium 239?

Mr. Deuster: The plutonium just comes out, and it is all mixed. We have little control over what its isotopic content is.

Dr. Radford: But the dose rates from a single micron particle of plutonium 238 is extremely irregular, from that of 239, is that correct?

So in terms of dose rate influences, you need to know whether you are talking about one or the other, or a mixture.

Dr. Goldman: I think we were talking in terms of rads. That does not require specifying any specific activity, sorting out particles. I forget what the number is; I think it is something like 250 difference in mass; the same activity between the 239 and 238 isotope.

But a microcurie is a microcurie. The energies of 238 and 239 are essentially the same.

Dr. Radford: But when we were talking about radium 224, you emphasized the rate distribution would be different from the radium 226.

I am suggesting simply the rate distribution would be different.

Dr. Goldman: There are very different magnitudes here. The physical decay rate for 238 is eighty-eight years; for 239; it is some 24,000 years. The decay rate for radium 226 is intermediate 1600 years, but that for the 224 relative to the life of a cell or tissue in man is only measured in hours, 3.5 days, I believe.

There is a gross difference as far as the human body is concerned. I might suggest that with regard to decay rates, the 238 and 239 are essentially the same. Both of these are quite long relative to a lifetime.

Dr. Radford: One final question on this, or two quick ones.

If you have a particle escaping from the fuel reprocessing program, is it likely to be a mixture of plutonium isotopes as well perhaps of americium, curium, maybe some Californium or would they be separated in the reprocessing essentially?

Mr. Deuster: The transplutonics are separated from the plutonium and they would go into the high level waste stream initially, so that

if particulates evolved from the plant, they would naturally be from plutonium or the mixed uranium plutonium parts.

Dr. Parker: May I elaborate on that? Some of them, however, will grow in again whether you like it or not, so there will be americium derived from each plutonium 241, nothing to be done about that once you have left go of your actual separation process.

Dr. Radford: Of the transuranics that we are talking about here, at least one of them anyway, and maybe more that you know about, have spontaneous fission rates which are, while not high, still definite.

Is there any possibility that one could sequester a portion of the fuel reprocessing, enough spontaneous fissions to give a neutron flux that would be significant as far as inducing fission?

Mr. Deuster: Yes. That is one of the design factors taken into account in a mixed oxide fuel fabrication facility.

It is also one of the factors taken into account in the design of shipping costs, the neutron dose does evolve from spontaneous fission.

Dr. Mills: Let me ask for a comment from the NRDC? What is the latest that you can get on? I know that you want to get on this morning, and we will try to do everything that we can.

So, will you bear with us? I apologize for having put you off.

Mr. Speth: I think we can postpone it until this afternoon, since people are getting hungry.

Dr. Mills: In deference to you, Mr. Speth. perhaps we can put you on now or within five minutes or wait until after lunch. I will leave it to you.

I apologize for the delay. What is your preference?

Mr. Speth: My preference is to go now.

Dr. Mills: Let me just get a couple of brief questions from Dr. Taylor and Dr. First.

Dr. Taylor: What I have really is more of a comment than a question.

As Dr. Parker mentioned, the desirability of a five year review plan, the fact is standards for internal emitters have been under study and review for the last 15 years.

They have come up with a new number every few years. Over this length of time, the number has not fluctuated by more than a small amount, less than one order of magnitude, I would say, as far as I am aware.

Dr. Parker: I think that is only a partial answer, though, Dr. Taylor. After all, the standards are characteristically found wearing white hats. There are some legitimate responders in this who are entered as wearing the black hats.

I believe very firmly their voice should be heard in these five year reviews, is what I am saying. Until such time that we can convince them that we were right, which of course we knew all the time, but that is not the way this thing should be done.

Dr. Taylor: I do not disagree with that. My real point, though, is as far as I am aware with whatever studies we have made on this, we are not expecting to see anything more than an order of magnitude off of where it has been for some time.

You suggested it might be a rational number in any case.

Dr. Parker: Yes. I agree, but we have to reserve the right to be wrong, since we do not know all the facts.

Dr. Taylor: I could not agree or disagree with you more.

Dr. First: I would like to clarify a couple of items in the disucssion which we have had so far. We have heard a good deal of talk about background values and also about plutonium and transuranic exposure.

I have the impression, which may be quite wrong, and I would like a comment, that we are comparing the dose of these particular materials with general background radiation from all sources, and that we are not saying specifically that the background that we are comparing the exposures from processing, background respirable particles, is this correct or incorrect?

Dr. Parker: Strangely enough, both.

Dr. First: Could you please straighten it out?

Dr. Parker: I think people do make comparisons with both. I would say it is profitable to do so, in the intellectual sense; possibly, that which pertains to alpha particle bearing substances in the atmosphere being inevitably taken into the lung, is possibly the more relevant for some of the species of arguments in which we are involved here.

Let me relate that, in fact, to what you did not ask me, but asked everybody else, about the lowest practicable level.

Let me say that if we are trying to reduce plutonium to the

lowest practical level in the environment, this will increasingly spiral the dollars from the millions to the billions.

At some stage, we could in theory improve the health of the citizen of the United States more effectively by removing the natural radiation.

People sit back and say we cannot do anything about that. It is nonsense. All it happens to take is more money than we have, but there is some stage at which it would be far more useful to attempt that than take away the last plutonium atom, as I see it, sir.

Does that answer properly the question you had in mind?

Dr. First: I think it alerts me to ask this question. When we start getting comparisons as the hearing goes on, to define it, but your last comment brought me to another question which I had.

This relates, I believe, to Dr. Goldman's comments about the weathering of plutonium particles in the environment. There was no quantitative aspects in your comments. If these particles do weather, what time scale are we talking about, and ultimately, can one derive from such numbers a safe level of emission to the environment that we can hope that natural processes will continue to keep up with the depositions so that we will maintain a constant level?

Dr. Goldman: I think I am going to defer the specific quantification on that to some people that I believe studied this more intensively than I. I was speaking as a biologist. I leave the mysterious ways of geology and atmospheric sciences.

I was observing the increase of time. I am talking about decades rather than days or weeks.

Dr. First: That is not going to be any help to me personally.

Dr. Goldman: It will be a help to somebody, that the material appeared to migrate downward more deeply and aggregate in such a way that the fraction per unit volume is biologically less potent.

Dr. First: I was thinking about geological time in the point I was trying to get at.

Dr. Goldman: I think I am talking in terms of decades.

Dr. First: Perhaps another question I had, and I will try to make this brief, is more up your line. Dr. Wolfe mentioned the fact and I can quote him quite specifically, that he was interested in more information on real pathways of plutonium.

We had a lot of comment from you and others concerning the fact that animal data and man data should be quite comparable, and I thought you said that we could depend, Dr. Parker, that we could depend quite reliably on animal data.

Is this a difference of opinion here? Just how reliable are the animal data to our human exposures?

Dr. Goldman: The real pathways can be described in fraction rate quality of material from whatever the source is, say from the nostril or intestinal tract, as it were.

That is my view of what the pathway situation is. What is real or unreal about it may be the fact that we can not quantify over the long time span, the exact contribution of the air borne suspension,

water borne, dietary borne, the grow in of other nuclides.

We can model the consequences, though, of a given unit absorbed, regardless of the pathway that it took to get there, whether it is a skeletal dose; it could be the soluble fraction of that in the lung; it could be something injected intravenously; or a fraction absorbed through the intestinal tract.

The assessment is how much activity is there? How was it distributed? And what kind of dose?

It is kind of an independent factor perhaps, in that sense, as to what environmental impact it may have, part of the overall path.

Dr. First: I am not sure whether I understand whether you are in agreement or disagreement with Dr. Wolfe on this point.

I am not trying to generate an argument between the two of you, but I am confused by what appears to me to be a difference.

I get the impression that Dr. Wolfe is saying we do not know enough about the real human pathways to be able to judge the situation adequately.

Dr. Goldman: I do not disagree with what he said. I said that I feel a lot more comfortable about the assessment. I guess as you pointed out I feel qualitatively somewhat comfortable about the real pathways, but I suspect from his point of view he would like greater quantification.

But I do not think we are in disagreement.

Dr. First: The question is do we have enough information to make judgments? One never has enough information, obviously, to do all we would like.

Dr. Parker: I think an ultimate solution of the total ecological web is really out of the question. It depends on our intelligence in identifying the main signalling paths which in the case of plutonium all seem to be rather small, compared with the experience we have had. Right now, we certainly do not have enough data, I think, defined.

The volume by Dr. Stannard and colleagues has a chapter on the environmental knowledge assessed at about two years, that defines what it is.

From memory, I think he leaves off the chapter by saying we do not know enough.

In the research field, you always have to say that or you would not get money to work the next year, so that has to be put in its proper place.

What we have today is the knowledge of something approximating the knowledge of body burden that the United States population has from weapons plutonium.

This has been analyzed by various groups, and the results are in concord enough to give us that degree of transfer from which you might want to speculate. You have a first order of approximation to what may come from the nuclear industry as it increases its possible burden decade by decade.

Dr. First: You think then that we know enough about the subject at the present time to make standards relating to environmental exposures, or do we have to wait for a considerable body of new information, which is what I gathered from Dr. Wolfe's comment?

Dr. Parker: I have to give you what is a hedged, ambiguous answer. I think we know as much about this as we do in many other things in which we daily come forward with an alleged answer, and we would be foolish if we did not continue our vigilance in trying to prove that answer.

Dr. Mills: Let me suggest, if there are other questions for this panel, could we write to you and elicity answers to those?

Thank you very much.

We will reconvene at 1:30.

Again, let me thank NRDC for their patience.

(Whereupon, at 12:40 p.m., the hearing in the above matter was recessed, to reconvene at 1:30 the same day.)

AFTERNOON SESSION

Dr. Mills: Perhaps we can reconvene.

To start off this afternoon, we have the Natural Resources Defense Council, Dr. Cochran, Mr. Speth, and Dr. Tamplin.

Again, gentlemen, let me thank you for the patience you showed this morning, for this extended period of time.

With that, I turn it over to you.

Mr. Speth: My name is Gus Speth. This is Tom Cochran, who will speak after I do.

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NRDC Statement

at the

Environmental Protection Agency

Public Hearings

on

Plutonium and the Transuranium Elements

J. G. Speth

Arthur R. Tamplin

Thomas B. Cochran

December 10, 1974

We appreciate the opportunity to participate in these hearings. The nuclear industry's proposal to make plutonium into the principal nuclear reactor fuel in the years ahead has implications for our society that deserve the widest possible public airing. We hope these hearings will contribute to that goal.

Our presentation will be in two parts. Today we will discuss briefly the basic issue of the acceptability of plutonium as a commercial fuel. The key question here is whether the promised benefits of proceeding into what the Atomic Energy Commission (AEC) has called the "plutonium economy" are worth the tremendous risks to the health and safety of the public associated with such a course. We conclude, emphatically, that they are not.

Our presentation tomorrow will include a more detailed treatment of the "hot particle issue" -- the question whether minute, insoluble particles of plutonium have uniquely high cancer-producing potential. We raised this issue before the EPA and the AEC ten months ago when we petitioned that the radiation protection standards applicable to plutonium and other hot particles be tightened by a factor of about 100,000. Since our views on the hot particle issue have been published and available for some time, we hope that at the session tomorrow we can concentrate on responding to questions from the panel and to issues raised in the testimony of other speakers.

I. Introduction and Summary

First with the initiation of plutonium recycle and then with the introduction of the fast breeder reactor, the AEC and the nuclear industry hope to transform plutonium from its current status as a troublesome by-product of the fission process into the principal fuel for future nuclear power plants. If these plans are consummated, the commercial plutonium industry at the turn of the century could involve hundreds of reactors fueled with plutonium, a score of fuel reprocessing and fabricating plants, and perhaps thousands of interstate and international shipments containing hundreds of tons of plutonium.

To appreciate the implications of having one of our most important industries based upon plutonium, certain characteristics of the element must be understood. First, plutonium is one of the most toxic respiratory carcinogens known. Lung burdens on the order of one-millionth of a gram (the weight of a grain of pollen) have been shown capable of producing lung cancer in animals with virtual certainty. And one of the purposes of these hearings is to shed light on whether plutonium is several orders of magnitude more toxic than the AEC believed when it set current radiation exposure standards. Concern is amplified by the fact that plutonium-239, the principal isotope of the element, has a half-life of 24,000 years. Its radioactivity is undiminished within human time scales.

Such considerations led the International Commission on Radiological Protection to conclude that:

> "in terms of amounts available, projected usage, extent of anticipated accidental human exposure, and radiotoxicity, plutonium is the most formidable

radionuclide in the periodic table."[1]

This ICRP statement addresses the toxicity of plutonium. But plutonium's toxicity is only part of the problem; the least of its two evils many would suggest. An amount of plutonium the size of a softball is enough for a nuclear explosive capable of the destruction we witnessed in Nagasaki. Scientists now widely recognize that the design and manufacture of a crude nuclear explosive is no longer a difficult task technically, the only real obstacle being the availability of the plutonium itself. The successful theft of this material by organized crime or terrorists, as Willrich and Taylor note, "could enable a small group to threaten the lives of many people, the social order within a nation, and the security of the international community of nations."[2]

Given the facts about plutonium, the widespread reliance upon it contemplated by the industry and the AEC would give rise to three problems, each of the utmost gravity:

- A major public health problem. As we move into the plutonium economy, exposure of industry employees and members of the public to plutonium will become increasingly widespread. Experiences at existing plutonium facilities provide frightening examples of what the future holds.
- An unprecedented public safety problem. If plutonium is permitted to become a major commercial

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1/ ICRP Publication 19, The Metabolism of Compounds of Plutonium and Other Actinides, Pergamon Press, New York, (1972), p. 1.

2/ Willrich, Mason and Theodore B. Taylor, Nuclear Theft: Risks and Safeguards, a Report to the Energy Policy Project of The Ford Foundation, (Ballinger Publishing Co., Cambridge, Mass., (1974), p. 1.

fuel, current realities are such that plutonium will most likely be stolen, a plutonium black market will most likely appear, illicit nuclear bombs will most likely be made and used both here and abroad.

- An intractable civil liberties problem. The drastic nature of the nuclear terrorists' threat will be used to justify a drastic police response. Extensive intelligence gathering, security surveillance measures will most likely become commonplace since they are among the cheapest and easiest safeguards.

In sum, our judgment is that the proposed use of plutonium as a commercial fuel would give rise to unprecedented social risks and costs. We do not believe that a fully informed public would be willing to accept these risks, certainly not in light of the unconvincing benefits. Plutonium recycle, for example, would reduce light water reactor fuel costs by about 10-15%. But fuel costs represent less than 20% of the costs of nuclear power, and by 1985 nuclear power is expected to account for only about 15% of total domestic energy. In other words, plutonium recycle involves an economic savings of less than one-half of one percent.

In the longer term, the economic incentive to use plutonium may become substantial but only if one assumes a high and sustained reliance upon nuclear fission, a prospect which is increasingly uncertain. Developments in solar, geothermal and fusion energy, in more efficient and clean means of consuming fossil fuels and in energy conservation generally suggest that alternatives to prolonged reliance upon increasingly controversial fission-based power do

exist. A major part of the problem of assuring the timely availability of these alternatives to plutonium is the fact that the AEC's fast breeder reactor development program continues to drain off a major share of federal energy R&D funding. This is a classic case of misplaced priorities.

It is imperative that our society develop the ability to say no to technologies that are too risky and too demanding. We can no longer assume that each new innovation accompanied by major financial backing should be permitted to proceed, even with regulation. Some should simply be halted for the reason that their advantages bear no reasonable relationship to the possibility of tremendous social harm they present. The use of plutonium fuel falls into this category. There is something fundamentally insane about the widespread commercial use of a material which is both fiendishly toxic and capable of being easily fashioned into atomic weapons.

II. Dimensions of the Plutonium Economy

Plutonium is almost unknown in nature: the entire present-day inventory is man-made, produced in nuclear reactors.[3] Most of this inventory has been used to construct nuclear weapons for national defense purposes. Much lesser amounts have been used for civilian reactor research and development.

The fuel currently used in present-day commercial reactors is uranium. Unlike plutonium, this uranium fuel is not extremely toxic, and it is not sufficiently rich in the fissionable isotope uranium-235 to be fashioned into nuclear weapons.[4] While present-day reactors are operating, however, they are also producing as a by-product substantial amounts of plutonium, principally plutonium-239. A typical large reactor produces about 200 to 250 kilograms (400 to 500 pounds) of plutonium each year. Since this plutonium is easily fissioned, it can be used as reactor fuel.

Sometime in the coming year the new Nuclear Regulatory Commission (NRC) will decide whether to authorize "plutonium recycle" the use of this plutonium as a fuel in nuclear power plants around the country. The AEC Regulatory staff (which will constitute the NRC staff when it is formed) has recently prepared a draft environmental statement on plutonium recycle.[5] Its view is that "plutonium

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3/ Plutonium occurs in nature but in such small amounts that it does not constitute a practical source of the element. The ratio of the concentrations of plutonium-239 to uranium in ores varies from 4×10^{-13} to 1.5×10^{-11}. Katz, J.J., Chapter IV, The Chemistry of Actinide Elements, Methuen and Co., Ltd., London, (1957), pp. 239-330.

4/ Only with extremely sophisticated technology not available to the public, notably gaseous diffusion or gas centrifuge plants, can uranium be enriched to weapons grade.

5/ DRAFT GESMO: U.S. Atomic Energy Commission, "Draft Generic Environmental Statement Mixed Oxide Fuel (Recycle Plutonium in Light Water-Cooled Reactors)," WASH-1327 (August, 1974).

recycle would result in a small reduction in the already negligible radiological exposure to the general population from the present LWR [light-water reactor] industry," that "plutonium can be adequately safeguarded [from theft] in a plutonium recycle economy,"[6] and therefore that plutonium recycle should be authorized. NRDC has taken strong exception to the Regulatory staff's position in the appended report, "The Plutonium Decision: A Report on the Risks of Plutonium Recycle,"[7] and in NRDC's additional comments on DRAFT GESMO.[8]

The next escalation in the availability of plutonium is projected to come with the introduction of the fast breeder reactor. According to the AEC's schedule the breeder reactor will replace today's reactors after about 1990. The breeder reactor is designed to convert uranium to plutonium faster than the plutonium is consumed as fuel. In other words, the breeder reactor breeds more fuel than it burns.

A nominal size (1000-megawatts) breeder will contain two to four tons of plutonium at any given time. Annually, approximately one-half this amount, one to two tons, will be removed for reprocessing and will be circulated through the fuel cycle. The AEC has proposed that we build between 1987 and 2020 some 2,200,000 megawatts of breeder reactor capacity. Over the lifetimes of these plants, we can project

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6/ AEC Regulatory Staff Response to Questions on Pu Recycle, addressed to Senator Walter F. Mondale, signed by L. Manning Muntzing, Director of Regulation, U.S. Atomic Energy Commission (7 October 1974), p. 1.

7/ Speth, J.G., A.R. Tamplin and T.B. Cochran, "The Plutonium Decision: A Report on the Risks of Plutonium Recycle," Natural Resources Defense Council, Washington, D. C. (September 1974), printed in The Bulletin of the Atomic Scientists, Vol. XXX, No. 9, (November 1974), pp. 15-22.

8/ These comments were submitted to the AEC on October 30, 1974.

a cumulative flow of some 100,000 tons of plutonium through the nuclear fuel cycle. This would correspond to about 10^{17} (100 billion billion) lung cancer doses if the lower risk estimates are correct.[9] One hundred thousand tons of plutonium also corresponds to about 10 million atomic bombs of the size dropped on Nagasaki. We present these numbers not as a procedure for calculating risk, but only to show that the plutonium economy offers a potential for social harm that is truly awesome.

In order to appreciate the significance of the plutonium economy from a somewhat different perspective, we suggest that you consider what the public response would be if our government leaders proposed that we base our energy system on botulin toxin. There can be little doubt that the public would be properly skeptical of an energy strategy centered around using a biological warfare agent as a fuel in thousands of plants, each containing several tons of this material and each generating more of this material than it consumes. Certainly one would hope that we would consider the "botulin breeder" only as a last resort. However, an examination of our present energy strategy demonstrates that with our fast breeder reactor program, we are actively pursuing a course which in relevant respects closely parallels the botulin breeder.

9/ For reference purposes the AEC has estimated that of the plutonium activity released routinely, one can expect that one part in 10^5 to be inhaled into someone's lungs of which 15 to 25 percent would be deposited in the deep respiratory tissue.

III. The Present State of Affairs

Lest it be thought that our concerns are only for the future, we turn now to the present state of affairs with respect to plutonium safeguards and accidental exposures to plutonium.

A. Plutonium Safeguards

In the language of the nuclear industry, the various programs and techniques to prevent nuclear theft and recover stolen nuclear material are called "safeguards." There have been a series of major studies on the adequacy of the present safeguards program within the last year, including the study by Willrich and Taylor for the Ford Foundation Energy Policy Project,[10] the AEC's "Special Safeguards Study" (the Rosenbaum Report),[11] and a series of reports by the General Accounting Office.[12] All of these have concluded that our present safeguards program is totally inadequate. In fact, the most disturbing routine releases from the nuclear power industry are the continuous flows of documents pointing out the inadequacies of our present safeguards program. The AEC's own Rosenbaum Report states:

> "Even though safeguard regulations have just been revised, two factors have appeared in recent months which make necessary a new and fundamental look at the problem.

10/ Willrich and Taylor, op. cit.

11/ Rosenbaum, Dr. David M., et al., Special Safeguards Study, safeguards study made for the Atomic Energy Commission (1974), referred to herein as the "Rosenbaum Report."

12/ U.S. General Accounting Office, Improvements Needed in the Program for the Protection of Special Nuclear Material, Report to the Congress, B-164105 (November 7, 1973); Protecting Special Nuclear Material in Transit: Improvements Made in Existing Problems, Report of the Joint Committee on Atomic Energy, B-164105 (April 12, 1974); and Letter Report on Security Systems at Commercial Nuclear Power Plants, addressed to Dixy Lee Ray, Chairman, USAEC and signed by Henry Eschwege, Director, Resources and Economic Development Division, USGAO, B-164105 (October 16, 1974).

> The first of these is the widespread and increasing dissemination of precise and accurate instructions on how to make a nuclear weapon in your basement. While such information may have always been available in the unclassified literature it was masked by a great deal of irrelevant and incorrect information, also readily available. There is a slow but continuing movement of personnel into and out of the areas of weapons design and manufacturing. These moves are sometimes forced and can create very strong resentments in the people involved. As a result, larger and larger numbers of people with experience in processing special nuclear materials and with varying psychological attitudes are dispersed in the overall industrial community. In addition, the psychological effect on terrorist groups of widespread dissemination of such information should not be overlooked.
>
> "The second new factor is the recent start of political kidnappings within the United States. It is our opinion that the kidnapping of Patricia Hearst does not represent an isolated and passing incident, but is rather the precursor of a wave of such incidents. If not firmly and competently met, these kidnappings may lead to a risk of urban terrorist groups in this country of a sort without precedent in our history. These groups are likely to have available to them the sort of technical knowledge needed to use the now widely disseminated instructions for processing fissile materials and for building a nuclear weapon. They are also liable to be able to carry out reasonably sophisticated attacks on installations and transportation. We believe these new factors necessitate an immediate and far reaching change in the way we conduct our safeguards programs."[13]

In "The Plutonium Decision" (appended hereto), we reviewed the steps the AEC suggests might be taken to correct present safeguards inadequacies. We discussed why an "adequate" system of safeguards may be impossible to achieve and why such a system would probably be unacceptable. One of the recommendations of the AEC's Rosenbaum Report gives us a flavor of the type of corrective measures required of an adequate system:

13/ Rosenbaum, Dr. David M., et al., op. cit., pp. 2-3.

"The Need for Better Intelligence"

> "The first and one of the most important lines of defense, against groups which might attempt to illegally acquire special nuclear materials to make a weapon, is timely and in-depth intelligence. Such intelligence may involve electronic and other means of surveillance, but its most important aspect is infiltration of the groups themselves. It is not the AEC's business to conduct this sort of intelligence, but it is the AEC's business to see that those agencies of the United States Government which have intelligence gathering responsibilities including the FBI, CIA, and NSA, focus their attention upon this particular threat to our national defense and security."[14]

This is not the Houston Plan, rather it is part of the "Blueprint for Plutonium Recycle."

In reply to a recent letter from Senators Mondale and Hart questioning the wisdom of a commitment to plutonium recycle at this time, the AEC's Director of Regulations wrote:[15]

> "The AEC safeguards program has as its objective achieving a level of protection against such acts [as unauthorized possession and sabotage of nuclear facilities] to insure against significant increases in the overall risk of death, injury, or property damage to the public from other causes beyond the control of the individual." [emphasis added]

and elsewhere:

> ". . . studies are required to determine the additional specific safeguards measures or combinations thereof that will be required to meet the Commission's safeguard objective. Until these are completed the Commission will not be in a position to judge the exact nature of the measures that should be established to protect plutonium and other special nuclear materials."

In other words, not only are the present safeguards inadequate, the AEC staff has not even developed an adequate program on paper.

Moreover, the nuclear industry is not even complying with the currently inadequate safeguards regulations. On October 31, 1974,

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14/ Ibid.

15/ Letter of Regulatory Staff Response to Questions on Pu Recycle, op. cit.

the AEC announced it was fining the General Electric Company (plants at Vallecitos, California) and Nuclear Fuel Services (West Valley facility) $12,500 and $4,000, respectively, for safeguards violations involving failure to have required intrusion monitoring and alarm systems and physical barriers to protect against industrial sabotage.[16]

B. Plutonium Exposure

Occupational as well as public exposure to plutonium has already become commonplace. Robert Gillette, in the first of a three part series in Science, describes the present state of the industry:

> "Increasingly, and with a frequency that seems disproportionately high, incidents of plutonium inhalation are being recorded from a small group of privately owned and operated facilities engaged not in weapons work but in reclaiming plutonium from reactor fuel and recycling it in new reactor fuel. . . .
>
> "The record reveals a dismal repetition of leaks in glove boxes; of inoperative radiation monitors; of employees who failed to follow instructions; of managers accused by the AEC of ineptness and failing to provide safety supervision or training to employees; of numerous violations of federal regulations and license requirements; of plutonium spills tracked through corridors, and, in half a dozen cases, beyond plant boundaries to automobiles, homes, at least one restaurant, and in one instance to a country sheriff's office in New YOrk."[17]

In recent months in two separate incidences production workers have come to Washington to complain to AEC officials about the health and safety practices at the fuel fabircation facilities where they worked. These workers were accompanied by officials of their union, the Oil, Chemical and Atomic Workers (OCAW). The first case involved a meeting on August 13, 1974, with workers from

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16/ AEC News Releases, November 6, 1974, p. 2.

17/ Gillette, Robert, Science 185 (20 September 1974), pp. 1030-1031.

the Nuclear Fuel Services' (NFS) Erwin, Tennessee facility;[18] the second meeting on September 27, 1974, involved employees of Kerr-McGee's Cimarron Facility near Crescent, Oklahoma.

The employees from the NFS-Erwin facility had five areas of specific concern, the following three of which were verified by subsequent AEC inspections.[19]

- The company has failed to reduce exposures to meet the "as low as practicable" (ALAP) requirement expressed in the AEC regulations.
- The company has failed to provide adequate radiation surveys.
- The company has failed to perform adequate biological monitoring, i.e., determination of uptake of radioactive materials by workers.

18/ This facility is presently fabricating enriched uranium fuel rods and has not fabricated any plutonium fuel in the past 18 months. However, the allegations and subsequent violations cited by the AEC involved practices occurring both during and prior to the last 18 months.

19/ Internal memorandum to N.C. Moseley, Director, Region II from John G. Davis, Deputy Director for Field Operations, "Allegations Against NFS, Erwin -- Meeting with OCAW Representatives," with attached Note to Files, "Nuclear Fuel Services, Erwin, Tennessee, License No. 70-143 -- Meeting with Representatives of the Oil, Chemical, and Atomic Workers International Union," dated August 29, 1974.

Letter to Mr. William Manser, Jr., Plant Manager, Erwin, Tennessee from N.C. Moseley, Director, Directorate of Regulatory Operations, U.S. AEC [RO:II:FJL 70-143/74-01] dated October 11, 1974.

Letter to Mr. William Manser from N.C. Moseley, U.S. AEC [RO:II:FJL 70-143/74-01] dated October 18, 1974.

Two allegations of willfulness were not verified but are still indispute. These include: a) The company has failed to permit OCAW representatives to accompany AEC inspectors as required by 10 CFR 19; and b) The company has failed to notify workers of overexposures as required by AEC regulations.

The following is a sample of the information presented in support of the employee concerns cited above:

Failure of the company to meet ALAP.

° Lunchrooms. The company provides two lunchrooms. Workers are permitted to enter the lunchroom after washing hands and donning shoe covers over shoes worn in the production area. The clothing worn in the production area is worn in the lunchroom. A monitor is provided for use by the workers. The sink provided for washing hands also is used to wash parts from vending machines. Workers state that these parts have shown contamination. One of the lunchrooms is immediately adjacent to a production area. A taped closed door serves as a wall. The workers contend that radiation, i.e., radioactive material, enters the lunchroom as evidenced by contamination on food dispensing machines. The workers state that up to 40,000 dpm have been measured on a beverage vending machine. In excess of 20,000 dpm were measured inside the machine. Several vending machines were removed from service and replaced because of contamination. The current location of the machines was not known.

Failure to provide adequate radiation surveys.

° With regard to surveys for removable contamination, there are no instructions on how this is to be done and no established frequency for surveys.

- Previously, there had been routine surveys of workers by health physics technicians. Those no longer are performed.

A complete summary of the NFS-Erwin allegations is contained in an AEC "Note to Files," dated August 29, 1974,[20] which is appended to our testimony. After investigating these allegations, the AEC cited NFS for two licensing violations which required immediate action and subsequently cited NFS for five licensing violations.[21] The letters reflecting these citations are also appended here.

The employees from the Kerr-McGee Cimarron facility alleged among other things that:

- Employees were not educated as to the hazards of plutonium. One employee, Karen Silkwood, related that she had worked at the facility one and one-half years before learning that pltuonium exposure could cause cancer. She also said that she never received a respirator that fit her face which was narrow, although the company had promised to order her respirator that fit over a year earlier.
- Employees coming on board were often sent directly to production work before receiving classroom health

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20/ Internal memorandum to N.C. Moseley, Director, Region II from John G. Davis, Deputy Director for Field Operations, "Allegations Against NFS, Erwin -- Meeting with OCAW Representatives," with attached Note to Files, "Nuclear Fuel Services, Erwin, Tennessee, License No. 70-143 --"Meeting with Representatives of the Oil, Chemical, and Atomic Workers International Union," dated August 29, 1974.

21/ Letter to Mr. William Manser, Jr., Plant Manager, Erwin, Tennessee, from N.C. Moseley, Director, Directorate of Regulatory Operations, U. S. AEC [RO:II:FJL 70-143/74-01] dated October 11, 1974. Letter to Mr. William Manser, Jr., Plant Manager, Erwin, Tennessee from N.C. Moseley, Director, Directorate of Regulatory Operations, U.S. AEC [RO:II:FJL 70-143/74-01] dated October 18, 1974, Enclosure 1.

and safety training. One worker, unaware of the hazards of plutonium exposure, was purportedly badly contaminated, and quit work the next day before he received any health and safety training.

- o Production workers have been required to wear respirators for an entire week due to high activity air concentration levels (above MPC) in the production area, the emphasis being on meeting production schedules as opposed to locating the source of contamination.
- o Plutonium was stored in unapproved areas (e.g., desk drawers).
- o There was no routine procedure for changing filters on respirators.

These are but some of the allegations still being investigated by the AEC, and as of this date the AEC has not issued a report or cited the company for licensing violations pertaining to these allegations.

On November 7, 1974, some five weeks after meeting with the AEC officials, Karen Silkwood, upon reporting to work at the Kerr-McGee facility, was found to be externally contaminated with plutonium. Plutonium alpha contamination levels up to several thousand disintegrations per minute were found on her clothing and body.[22] Subsequently, her roommate, also a Kerr-McGee employee, and their apartment were found to be contaminated. Isolated areas

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22/ Directorate of Regulatory Operations Notification of an Incident or Occurrence, at Facility: Kerr-McGee Nuclear Corporation - Crescent, Oklahoma Cimarron Plutonium Facility, License No. SNM-1174 Docket No. 70-1193, dated 11/11/74, No. 134.

of contamination ranging up to a few hundred thousand disintegrations per minute were found in the kitchen, bathroom and bedroom areas.[23] Less than two weeks later Ms. Silkwood was killed in an automobile accident on the way to a meeting with a union official and a New York Times reporter to provide background information in support of an allegation that the facility was manufacturing faulty plutonium fuel rods and falsifying quality assurance inspection reports. There have been several as yet unsubstantiated allegations pertaining to this incident, including that her death was the result of foul play,[24] and that she smuggled plutonium from the plant and deliberately contaminated herself.[25] The entire bizarre incident related to her exposure and death is still under investigation. It is known from fecal and urine samples taken when she was alive, and an autopsy after her death, that Ms. Silkwood ingested a very large amount of plutonium.

There have been several recent cases where members of the public have inadvertently been exposed to plutonium. Moreover, it is well known that the area east of the Rocky Flats plant in Colorado is contaminated with plutonium. Recently the Environmental Protection Agency indicated that cattle grazing in this area show

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23/ Ibid.

24/ The New York Times, November 19, 1974 and November 20, 1974.

25/ The Washington Post, December 8, 1974, p. A3. This same report stated: "Kerr-McGee sources say their internal investigation has determined that a fuel rod inspection report was falsified at least 20 times over the summer months by William Scott Dotter, a former employee. That prompted a search by Kerr-McGee and Westinghouse Corp., the contractor, for the affected rods, either in Oklahoma or at Richland.

"Dotter says he did nothing deliberately, although he may have included erroneous information in reports because he does not feel he was adequately trained for the job."

a high degree of plutonium in their lung.[26] The implication of this for humans in the area is obvious. These recent events follow a history of serious public exposure and offsite contamination, including but not limited to the exposure of Edward Gleason, a stevedore in a trucking terminal,[27] the fire and explosion at Gulf-United's plutonium facility in Pawling, New York,[28] the burnup of a SNAP reactor over the Indian Ocean, plutonium found at the bottom of the Erie Canal next to Mound Laboratory, and surface contamination near Palomares, Spain and Thule, Greenland resulting from the non-nuclear detonation of strategic weapons.

Aside from highlighting the deplorable state of affairs presently existing in the fledgling plutonium industry, these most recent plutonium exposures are evidence of the need to take urgent action to insure that the present radiation standards applicable to plutonium exposure are adequate. This brings us to the final chapter of our presentation -- the adequacy of the present plutonium exposure standards.

26/ The Washington Post, December 6, 1974, p. 3.

27/ Tamplin, A.R. and T.B. Cochran, "Radiation Standards for Hot Particles," op. cit., Appendix B.

28/ Gulf United Nuclear Fuels Corporation, "Report of Incident at Gulf United's Plutonium Facility at Pawling, New York," Elmsford, New York (January 19, 1973).

Hot Particle Petition

Beginning in 1969, the existing radiation exposure standards came under strong public criticism. As a consequence, an Advisory Committee on the Biological Effects of Ionizing Radiation (the BEIR Committee) of the National Academy of Sciences was convened to review the biological data on the effects of radiation as they relate to the exposure standards. In November, 1972, three years after the debate began, the committee issued its report and stated the existing standards were unnecessarily high.[29] It is now two years later and the EPA has not reduced these standards. While they may have seriously considered this matter, and perhaps even performed some additional studies, nevertheless the same discredited exposure standards are in the Code of Federal Regulations.

It was ten months ago that NRDC petitioned the EPA and AEC relative to the plutonium standards. Just recently EPA asked the BEIR Committee of the NAS to study the question. If history repeats itself, five years from now EPA will have done nothing about the plutonium standards.

In the meanwhile, nuclear industry employees and members of the public are being exposed to plutonium, many at or above the standards we have urged. We would hope that one of the strong recommendations of this panel is to tell EPA that it is time to take the steps that are required. EPA has a strong ethical and legal obligation to take action without delay on the hot particle issue. Given the immediacy

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29/ NAS-NRC, "The Effects on Populations of Exposure to Low Levels of Ionizing Radiation," (BEIR Report), NAS-NRC, Washington, D.C., November, 1972.

of the problem, the lapse of 10 months between the filing of our petition and the initiation of these hearings and the National Academy of Sciences review is simply deplorable.

THE bulletin OF THE ATOMIC SCIENTISTS

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Plutonium Recycle: The Fateful Step

Impending move to reprocess fuel would escalate the risks of nuclear power

I fear that when the history of this century is written, that the greatest debacle of our nation will be seen not to be our tragic involvement in Southeast Asia but our creation of vast armadas of plutonium, whose safe containment will represent a major precondition for human survival, not for a few decades or hundreds of years, but for thousands of years more than human civilization has so far existed.

James D. Watson
Nobel Laureate, Medicine

J. GUSTAVE SPETH, ARTHUR R. TAMPLIN and THOMAS B. COCHRAN

The Atomic Energy Commission, if unchecked, is about to sow the seeds of a national crisis. The Commission now proposes to authorize the nuclear power industry to proceed to use plutonium as fuel in commercial nuclear reactors around the country. The result of a decision approving this commercial use of plutonium will be the creation of a large civilian plutonium industry and a dramatic escalation in the risks posed by nuclear power.

This decision to launch what the AEC calls the plutonium economy is the conclusion of the AEC's recently released draft environmental impact statement for *plutonium recycle*: the recycling of plutonium as fuel in the present generation of light water reactors [1, 2]. The final version of the impact statement, which is expected to confirm the decision to authorize plutonium recycle, is due in a few months.

Plutonium is virtually unknown in nature; the entire present-day inventory is man-made, produced in nuclear reactors. Plutonium-239, the principal isotope of this element, has a half-life of 24,000 years, hence its radioactivity is undiminished within human time scales. It is perhaps the most toxic substance known. One millionth of a gram has been shown capable of producing cancer in animals [3]. Plutonium is also the material from which nuclear weapons are made. An amount the size of a softball is enough for a nuclear explosive capable of mass destruction. Scientists now widely recognize that the design and manufacture of a crude nuclear explosive is no longer a difficult task technically, the only real obstacle being the availability of the plutonium itself [4].

We believe that the commercialization of plutonium will place an intolerable strain on our society and its institutions. Our unrelenting nuclear technology has presented us with a possible new fuel which we are asked to accept because of its potential commercial value. But our technology has again outstripped our institutions, which are not prepared or suited to deal with plutonium. Those who have asked what changes in our institutions will be necessary to accommodate plutonium have come away from that enquiry profoundly concerned. And the AEC's environmental impact statement does not allay these concerns. It reinforces them.

The AEC concedes that the problems of plutonium toxicity and nuclear theft are far from solved and indicates that they may not be for some years. Yet it concludes, inexplicably, that we should proceed. Whether stemming from blind faith in the technology it has fostered or from callous promotion of the bureaucratic and industrial interests of the nuclear power complex, the AEC's proposal cannot be justified in light of what we know and, just as important, what we do not know.

The fuel now used in present-day reactors, the light water reactors, is uranium which has been enriched; the uranium-235 content is increased from 0.7 percent present in natural uranium to about 3 or 4 percent. Uranium-235 is a fissionable isotope of uranium, the remainder being non-fissile uranium-238. Unlike plutonium, uranium fuel is not extremely toxic, and it is not sufficiently rich in uranium-235 to be fashioned into nuclear weapons. The uranium

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The current AEC radiation protection standards governing the amount of plutonium to which members of the public can be exposed are roughly 100,000 times too lax.

can be enriched to weapons grade material only with extremely sophisticated technology which is not available to the public, notably gaseous diffusion plants.

While present-day reactors are operating, however, they are also producing as a by-product moderate amounts of plutonium, principally plutonium-239. A typical large reactor produces about 200 to 250 kilograms of plutonium each year. Since this plutonium is easily fissioned, it can be used as reactor fuel. Plutonium recycle is the nuclear industry-AEC proposal to recover the plutonium produced in light water reactors, process it and recycle it as fuel back into these reactors.

Several critical steps are involved in recycling this plutonium. First, the used or spent fuel from the reactor must be shipped to a fuel reprocessing plant where the plutonium is recovered from the spent fuel, converted to oxide form and shipped to the next fuel cycle stages—the fuel fabricating and assembly plants. At a fuel fabricating plant the plutonium oxide will be mixed with uranium oxide into mixed oxide fuel. This mixed oxide fuel will be fabricated into fuel pellets, the pellets will be placed in fuel rods, and these rods will be collected into fuel assemblies. These assemblies will then be sent to the reactors for use, thus completing the fuel cycle.

At this point plutonium recycle has not yet begun, and there is no major industrial commitment of resources to it [5]. No major commercial plutonium fuel fabricating plants are operating or under construction.* No commercial reprocessing plants are operating now.** Reprocessing plants, in addition to recovering plutonium and other fission products from the spent fuel, are supposed to solidify high-level wastes and ship them to a permanent AEC repository for perpetual management. As yet, however, the AEC has no such repository. Nor does the AEC know whether the technology and social institutions for isolating these high-level wastes for geologic periods can be made available.

If the plans of the AEC and the nuclear industry are permitted, however, a major plutonium industry will develop quickly. Some 140 tons of plutonium could be recovered from commercial reactors by 1985 and some 1,700 tons by the year 2000 [7]. A plutonium industry by the turn of the century could involve hundreds of light water reactors fueled with plutonium, perhaps a score of fuel reprocessing and fabricating plants, and thousands of interstate and international shipments containing hundreds of tons of plutonium.

Plutonium Toxicity

The most pernicious product of the nuclear industry is plutonium. Microgram quantities in skin wounds cause cancer, and in the body plutonium is a bone seeker where, once deposited, it can cause bone cancer. But plutonium is most dangerous when inhaled. Donald Geesaman explains this hazard:

> Under a number of probable conditions plutonium forms aerosols of micron-sized particulates. When lost into uncontrolled air these particulates can remain suspended for a significant time, and if inhaled they are preferentially deposited in the deep lung tissue, where their long residence time and high alpha activity can result in a locally intense tissue exposure. The lung cancer risk associated with these radiologically unique aerosols is unknown to orders of magnitude. Present plutonium standards are certainly irrelevant and probably not conservative. Even so, the fact that under present standards, the permissible air concentrations are about one part per million billion is a commentary on plutonium's potential as a pollutant [3].

To determine whether the AEC's radiation protection standards for plutonium are inadequate, as Geesaman suggests, two of the authors of this article undertook a review of the biological evidence for the Natural Resources Defense Council (NRDC). Their report, *Radiation Standards for Hot Particles* [9], concludes that plutonium particulates or hot particles are uniquely virulent carcinogens and that the current AEC radiation protection standards governing the amount of plutonium to which members of the public can be exposed are roughly 100,000 times too lax.

The lung cancer risk associated with hot particles of plutonium, as estimated by Tamplin and Cochran, is comparable to the lethal dose of botulin toxin, a biological warfare agent. Certainly one would hope that this nation would give careful consideration and pursue all alternatives before implementing an energy policy based on such toxic materials.

As a result of this study, NRDC formally petitioned the AEC and the Environmental Protection Agency to reduce the present maximum permissible exposure levels by 100,000. Neither the AEC nor the EPA have responded finally to NRDC's petition, but the petition is now being considered by National Council on Radiation Protection and Measurements, National Academy of Sciences, Biophysical Society and several AEC national laboratories. Moreover, EPA will

*There are, however, several small commercial facilities that process plutonium for research and development purposes

**The first commercial reprocessing plant built in the United States, Nuclear Fuel Services in West Valley, New York, was shut down in 1972 for repairs and enlargement. The Midwest Fuel Recovery Plant under construction near Morris, Illinois, has been declared an almost total loss due to faulty design and construction [6]. The Barnwell Nuclear Fuel Plant in South Carolina is 70 percent complete. Thus, since mid-1972, all spent fuel from light water reactors has been simply stored and not reprocessed.

shortly commence a series of hearings and other initiatives on plutonium-related issues, including the hot particle controversy.

Although the adequacy of the AEC's plutonium standards is thus a matter of considerable doubt and great controversy, the AEC's draft environmental impact statement for plutonium recycle simply assumes that the present standards are adequate. The entire risk analysis of the statement, as well as the ultimate decision to proceed with plutonium recycle, are based upon a premature and unexplained rejection of the hot particle hypothesis. Yet, the AEC is forced to concede that this hypothesis "is being given careful consideration in a separate proceeding" [2, chap. 4, pp. 5-7].

We submit that the AEC has no basis whatever to conclude that plutonium recycle will not cause undue risk to the public health and safety until it has either satisfactorily resolved the hot particle issue or calculated the impacts of plutonium recycle using the assumption that hot particles are uniquely carcinogenic. The AEC's draft environmental impact statement for plutonium recycle does neither. However, the more basic issue is whether we want our energy system based on a material of unprecedented toxicity.

Some plutonium contamination of the environment has already occurred, due principally to the atomic weapons program. The leakage of plutonium from contaminated oil at the AEC's plutonium weapons plant at Rocky Flats, 10 miles west of Denver, Colorado, led to an uncontrolled source of plutonium which was much larger than the integrated effluent loss during the 17 years of plant operation. Tens to hundreds of grams of plutonium went off-site, 10 miles upwind from Denver [3, p. 59].

The Nuclear Materials and Equipment Corporation (NUMEC) of Apollo, Pennsylvania, was recently fined $13,720 for a 16 count violation of AEC regulations ranging from failure to follow radiation monitoring procedures to failure to comply with certain safeguards requirements [9]. Production workers at Nuclear Fuel Services, Inc. in Erwin, Tenn., a fuel processing and fabricating facility, met with AEC inspectors on August 13, 1974 to complain about the absence of even the rudiments of accepted health physics practices at that plant. Occurrences such as these can reasonably be expected to multiply greatly if plutonium is made a major article of commerce.

Nuclear Theft

On May 18 of this year the world was made dramatically aware of the relationship between nuclear power and nuclear weapons when India exploded a nuclear device made from plutonium taken from a peaceful reactor built with Canadian assistance. The magnitude of the threat posed by the availability of plutonium from power reactors is set out by Willrich and Taylor in their book *Nuclear Theft: Risks and Safeguards:*

> As fuel for power reactors, nuclear weapon material will range in commercial value from $3,000 to $15,000 per kilogram—roughly comparable to the value of black market heroin. The same material might be hundreds of times more valuable to some group wanting a powerful means of destruction. Furthermore, the costs to society per kilogram of nuclear material used for destructive purposes would be immense. The dispersal of very small amounts of finely divided plutonium could necessitate evacuation and decontamination operations covering several square kilometers for long periods of time and costing tens or hundreds of millions of dollars. The damage could run to many millions of dollars per gram of plutonium used. A nuclear explosion with a yield of one kiloton could destroy a major industrial installation or several large office buildings costing hundreds of millions to billions of dollars The hundreds or thousands of people whose health might be severely damaged by dispersal of plutonium, or the tens of thousands of people who might be killed by a low-yield nuclear explosion in a densely populated area represent incalculable but immense costs to society [4, pp. 107-108].

In our troubled world, terrorist activity and other forms of anti-social violence are an almost daily occurrence. A recent AEC study identified more than 400 incidents of *international* terrorism carried out by small groups during the past six years [10]. In an age of bombs and bomb threats, of aircraft hijacking, of the ransom of diplomats and the murder of Olympic athletes, the risks of nuclear theft, blackmail and terrorism are not minimized even by some of the most ardent supporters of nuclear energy. Thus former Atomic Energy Commissioner Clarence Larson has described the evolution of a plutonium black market:

> Once special nuclear material is successfully stolen in small and possibly economically acceptable quantities, a supply-stimulated market for such illicit material is bound to develop. And such a market can surely be expected to grow once the source of supply has been identified As the market grows, the number and size of thefts can be expected to grow with it, and I fear such growth would be extremely rapid once it begins. . . .Such theft would quickly lead to serious economic burdens to the industry, and a threat to the national security [11].

The critical point here is that these tremendous risks will become real with the advent of plutonium recycle. Unless plutonium is reprocessed and recycled, the possibility that it will be stolen is small. If the plutonium has not been detoxified by separating it from the high-level wastes in the spent fuel at a reprocessing plant, it is very effectively protected from theft, at least for hundreds of years. Willrich and Taylor explain these relationships:

> In the light water reactor (LWR) fuel cycle without plutonium recycle, plutonium which is produced in a power reactor, if reprocessed, might be stolen at the

Is the American public willing to accept the risks of plutonium in exchange for the promised benefits?

output end of a reprocessing plant, during transit from the reprocessing plant to any separate storage facility used, and from a long-term plutonium storage facility. *Until irradiated fuel is reprocessed, the theft possibilities in the LWR fuel cycle are minimal.* (Emphasis added.)

In the LWR fuel cycle with plutonium recycle, in addition to possibilities without recycle, plutonium might be stolen during transit from any separate long-term storage facility, and from a fuel fabrication plant. Complete LWR fuel assemblies, each containing a significant quantity of plutonium might also be stolen during transit from a fuel fabrication plant to a power reactor, and at a power plant prior to loading into the reactor, although the weight of each assembly makes this difficult [4, p 168].

In sum, plutonium recycle will bring with it all the risks associated with nuclear theft that numerous authors have described [12]. Reasonable prudence dictates, therefore, that we have adequate answers to the problem of nuclear theft well in hand before we begin plutonium recycle.

Safeguards and the AEC

In the language of the nuclear industry, the various programs and techniques to prevent nuclear theft and recover stolen nuclear material are called 'safeguards.' There is now widespread agreement—at least among those outside the nuclear industry—that present safeguards against nuclear theft are woefully inadequate [13]. The AEC's Rosenbaum Report concluded:

> In recent years the factors which make safeguards a real, imminent and vital issue have changed rapidly for the worse. Terrorists groups have increased their professional skills, intelligence networks, finances and level of armaments throughout the world. . . .Not only do illicit nuclear weapons present a greater potential public hazard than the radiological dangers associated with power plant accidents, but. . .the relevant regulations are much less stringent [13].

The problem is not simply that the AEC has not implemented the necessary safeguards programs; rather the agency has not even developed an adequate program on paper.

On the subject of safeguards, the AEC's draft impact statement on plutonium recycle is a marvel of clouded reasoning and breezy optimism. The statement concedes that the objective of keeping the risk of nuclear theft small "will not be fully met for the recycle of plutonium by current safeguards measures" [2, pp. 5-6]. Steps which might be taken to correct current inadequacies are then summarized in the statement as follows:

> 1 Minimization or elimination of the transportation of plutonium from reprocessing plants to mixed oxide fuel fabrication facilities which is the operation most vulnerable to an attempted act of theft or sabotage. To the extent that such shipments are minimized or eliminated, the safeguarding of plutonium would be enhanced. This objective can be accomplished by locating mixed oxide fuel fabrication plants in close proximity to or adjacent to reprocessing plants in Integrated Fuel Cycle Facilities. . . .
>
> 2. Further protection of transportation functions by use of massive shipping containers, special escort or convoying measures, vehicle hardening against attack, improved communications and response capabilities.
>
> 3. Additional hardening of facilities through new barrier requirements, new surveillance instrumentation, new delaying capabilities (e.g., incapacitating gases).
>
> 4. Upgrading of operating and guard functions through the use of personnel security clearance procedures, a federally operated nuclear security system, more advanced systems for monitoring and searching of personnel, and closer liaison with law enforcement authorities.
>
> 5. Improving the timeliness and sensitivity of the system of internal control and accountability of plutonium.
>
> 6. Use of 'spiked' plutonium which would be less susceptible to theft and would be more difficult to manufacture into a nuclear explosive because of the required elaborate handling procedures [2, pp. 5-7].

Despite the facts that: (1) these proposals are preliminary and their content not well defined, (2) they are still being studied, some apparently for the first time, (3) some would require Congressional action, (4) some would necessitate substantial changes in the structure of the U.S. utility industry, and (5) a sophisticated safeguards program would pose a major threat to civil liberties and personal privacy—despite all these facts the draft impact statement nevertheless recommends that we proceed now with plutonium recycle because "the Commission has a high degree of confidence that through implementation of some combination of the above concepts the safeguards general objective set forth earlier can be met for plutonium recycle" [2, pp. 5-7]. The Commission's faith, unfortunately, is hardly reassuring.

The AEC's lead safeguards suggestion—the Integrated Fuel Cycle Facility concept—merits special comment. It actually represents a major watering down of a far more significant concept, that of nuclear power parks where reactors as well as fuel reprocessing and fabricating plants are all located at one site [14]. In our judgment, a safeguards system which does not require nuclear parks is not addressing the problem of theft during transportation in a serious and responsible way. Moreover, the nuclear industry's current plans, already well advanced, do not call for the implementation of even the Integrated Fuel Cycle Facilities concept.

Adequate Safeguards?

While it may be possible to devise an adequate safeguard system in theory, there is little reason to believe that such a system would be acceptable in practice [15]. This is true for several reasons.

First, the problem is immense. The illegal diversion of weapons material is only one type of antisocial behavior a safeguards program must protect against. Terrorist acts against the reactors, shipments of radioactive wastes, fuel reprocessing facilities and waste repositories can result in catastrophic releases of radioactivity. Such threats against nuclear facilities have already occurred [16]. Moreover, a safeguards system would have to exist on a vast, worldwide basis. Some 1,000 nuclear reactors are projected for the United States in the year 2000, with hundreds of shipments of radioactive materials daily. Hundreds of tons of plutonium will be in the commercial sector of our economy by that date.

To accommodate plutonium we shall have to move toward a more intimidated society with greatly reduced freedoms.

Abroad, American firms are constructing nuclear reactors in countries that have little political stability and in countries, such as Japan, who have not signed the Non-Proliferation Treaty. Safeguarding nuclear bomb material would ultimately require a restructuring of the socio-political institutions on a worldwide scale. The United Nations unfortunately gives us little reason to believe that this is a practical reality.

Second, safeguards measures are strongly opposed by the nuclear industry. The degree to which the industry is sensitive to the diversion hazards and is likely to be an effective partner in the enforcement and implementation of safeguards programs was apparent in the vociferous industry opposition to the modest strengthening of the AEC safeguards rules which were first published in the February 1, 1973, *Federal Register* [17].

Third, experience with present safeguards is hardly reassuring. Nuclear Materials and Equipment Corporation, over several years of operation, was unable to account for six percent (100 kilograms) of the weapons grade material that it handled. As noted previously, it was also fined by the AEC, in part, because of safeguards violations. At a safeguards symposium the director of the AEC's Office of Safeguards and Materials Management observed that "we have a long way to go to get into that happy land where one can measure scrap effluents, products, inputs and discards to a one percent accuracy" [3, p. 59]. This statement takes on particular significance when it is realized that only one-half of one percent of the plutonium utilized by the commercial sector in the year 2000 is enough to make hundreds of atomic bombs. The editors of the *Bulletin* have noted that the frequent 'misroutings' of shipments of weapons grade materials highlights a key safeguards problem —hijacking [18].

A spot-check by General Accounting Office investigators at three AEC-licensed contractors showed that in some cases access to easily portable quantities of special nuclear material could be gained in less than a minute using the simplest of tools. At two of the three plants checked, GAO found weak physical barriers, ineffective guard patrols, ineffective alarm systems, lack of automatic-detection devices, and the absence of an action plan should material be stolen or diverted. AEC's inspectors, however, were giving the same facilities good marks on virtually every security category [GAO, 13].

Fourth, and perhaps most basically, there is little reason to believe that safeguards will work when little else does. For example, the AEC supports the creation of a federal police force to provide an immediate federal presence whenever the use of force may be needed to protect these incredibly dangerous materials from falling into the hands of would-be saboteurs and blackmailers. But is there anyone who believes that police are effective at a level commensurate with the potential nuclear hazard? The New York City police department was proven incapable of maintaining security over confiscated heroin. Are similar losses of plutonium acceptable?

The general point here is that our safeguards system must be essentially infallible. It must maintain what Alvin Weinberg, former director of the Oak Ridge National Laboratory, has called "unaccustomed vigilance" and "a continuing tradition of meticulous attention to detail" [19]. Yet our human institutions are far from infallible. Our experience indicates that rather than sustaining a high degree of esprit, vigilance and meticulous attention to detail, our governmental bureaucracies instead become careless, rigid, defensive and, less frequently, corrupt. A basic question, then, is whether we want to entrust so demanding and unrelenting a technology as plutonium recycle to institutions which are negligent of their own responsibilities and insensitive to the rights of others and to technical fixes which are untried and unproven.

Threat to Civil Liberties

One principal reason for our believing that an adequate safeguards system would not be acceptable in practice is the tremendous social cost of such a system in terms of human freedom and privacy. Safeguards necessarily involve a large expansion of police powers. Some one million persons have been trained in the handling, moving and operation of nuclear weapons. The projected growth of the nuclear industry will give rise to a parallel and, ultimately, a much larger group of persons, in this case civilians, who will be subjected to security clearance and other security procedures now commonplace in the military weapons program. Indeed, the AEC makes the following disturbing statement in its draft environmental impact assessment of plutonium recycle:

> Security problems are much simplified when it can be established with high probability that the persons who are responsible for the handling of plutonium or implementing of related safeguards programs are trustworthy. Various court rulings in recent years have been favorable to the protection of individual privacy and of individual right-to-work. These rulings have made it difficult to make a personnel background check of an individual in commercial activities to assure with high probability that he is trustworthy and, hence, potentially acceptable as a steward for the protection of plutonium. The AEC has requested legislation which would allow background checks of individuals with access to plutonium and related material accountability records [2, chap. 5, p. 42].

The keeping of police dossiers will not be limited to nuclear industry personnel. The New York Times reported August 11 that Texas state police maintain files on nuclear power plant opponents. How much more government investigation into the private lives of individuals can be tolerated by a free society? Security and surveillance procedures at best infringe upon the privacy of families and their friends. At worst, they are the instruments of repression and reprisal.

A second AEC safeguards proposal is the creation of a federal police force for the protection of plutonium plants and shipments. The draft impact statement for plutonium recycle justifies such a federal force in the following terms:

> A federal security system would be less apt to have the variations in staff and capability that would be encountered in use of private security guards. In addition, it should be noted that the consequences of a successful theft or diversion of plutonium would undoubtedly have nationwide impacts and could best be handled by Federal authorities. certainly, with Federal participation, there is the potential for a larger force, more effective weapons, and better communications [2, chap 5, p. 42].

How large would such a force be? What standards should govern and restrain its operations? The Washington Post reported in October 1973 that the AEC issued shoot-to-kill orders to personnel directing the production, shipment and storage of atomic weapons at the height of the Yom Kippur War.

Once a significant theft of plutonium or other weapons material has occurred, how will it be recovered? To prevent traffic in heroin, police have asked for no-knock search laws. This infringes upon one of our most cherished freedoms. To live with plutonium we may have to abandon this freedom along with others. In the presence of nuclear blackmail threats, the institution of martial law seems inevitable. It has been said that the widespread availability of weapons material and terrorists targets in the nuclear fuel cycle will radically alter the power balance between large and small social units (De Nike [16]). It should be added that the threatened society will undoubtedly attempt to redress that balance through sophisticated and drastic police action.

In sum, to accommodate plutonium we shall have to move toward a more intimidated society with greatly reduced freedoms. In this respect the following passage from the report of the distinguished international group of scientists attending the 23rd Pugwash Conference on Science and World Affairs is instructive:

> The problem of theft of nuclear material by internal groups of individuals intent on sabotage, terrorism or blackmail was agreed to be a very serious one, although there was some sentiment expressed that the possibility of such activity was much smaller in socialist states.

We believe that sentiment to be true. It is also apparent that that is the direction in which we must move to accommodate the nuclear industry. After having spent billions of dollars for our nuclear deterrent, our civilian nuclear industry might well accomplish that which our defense system is trying to prevent.

Alvin Weinberg is one of the few persons closely associated with the nuclear power complex who has looked carefully at the political and regulatory institutions that will be necessary to support a plutonium-based nuclear power economy, and his views on this subject merit close attention [19]. Weinberg's basic premise is that nuclear power will place unprecedented strains on our society. In an unpublished paper circulated prior to a conference in June 1973 at the Woodrow Wilson International Center for Scholars in Washington, D.C., Weinberg set out his views on the type of new institutions required to cope with the plutonium economy:

> One suggestion (proposed by Sidney Siegel) that is relevant to the situation in the United States would be to establish a national corporation patterned after COMSAT to take charge of the *generation* of nuclear electricity. Such an organization would have technical resources that must exceed those available to even a large utility: and a high order of technical expertise in operating reactors and their sub-systems is essential to ensuring the continued integrity of these devices. [Here Dr. Weinberg suggests nationalization of the industry.]
>
> Each country now has its own AEC that sets standards or, in some cases, actually monitors or operates reactors. Perhaps this will be sufficient forever. Yet no government has lasted continuously for 1,000 years: only the Catholic Church has survived more or less continuously for 2,000 years or so. Our commitment to nuclear energy is assumed to last in perpetuity—can we think of a national entity that possesses the resiliency to remain alive for even a single half-life of plutonium-239? A *permanent* cadre of experts that will retain its continuity over immensely long times hardly seems feasible if the cadre is a national body.
>
> It may be that an International Authority, operating as an agent of the United Nations, could become the focus for this cadre of expertise. The experts themselves would remain under national auspices, but they would be part of a worldwide community of experts who are held together, are monitored, and are given long-term stability by the International Authority. The Catholic Church is the best example of what I have in mind: a *central authority* that *proclaims* and to a degree *enforces* doctrine, maintains its own long-term social stability, and has connections to every country's own Catholic Church. (Emphasis added.)

These are far-reaching concepts presented by Weinberg. The basic question they pose is: Will the plutonium economy raise socio-political problems of such magnitude that their resolution will be unacceptable to society? In attempting to do the impossible—live with plutonium—we may create the intolerable.

Super-Human Requirements

The commercialization of plutonium will bring with it a major escalation of the risks and problems already associated with nuclear power. Plutonium will further strain the already weakened regulatory fabric of the nuclear industry.

Hannes Alfven, Nobel laureate in physics, has described the regulatory imperatives applicable to the nuclear industry:

> Fission energy is safe only if a number of critical devices work as they should, if a number of people in key

positions follow all their instructions, if there is no sabotage, no hijacking of the transports, if no reactor fuel processing plant or reprocessing plant or repository anywhere in the world is situated in a region of riots or guerrilla activity, and no revolution or war—even a "conventional one"—takes place in these regions. The enormous quantities of extremely dangerous material must not get into the hands of ignorant people or desperados. No acts of God can be permitted [20].

Weinberg similarly stresses the need ". . . of creating a continuing tradition of meticulous attention to detail" and suggests that "what is required is a cadre that, from now on, can be counted upon to understand nuclear technology, to control it, to prevent accidents, to prevent diversion" [19].

The public and its decisionmakers must seriously question whether it will be possible to attract, train and motivate the personnel required for these functions. These must be highly qualified persons who will maintain a tradition of "meticulous attention to detail" even when the glamorous aspects of a new technology become the commonplace operations of an established industry. We suggest that it is beyond human capabilities to develop a cadre of sufficient size and expertise that can be counted upon to understand nuclear technology, to control it, and to prevent accidents and diversion over many generations.

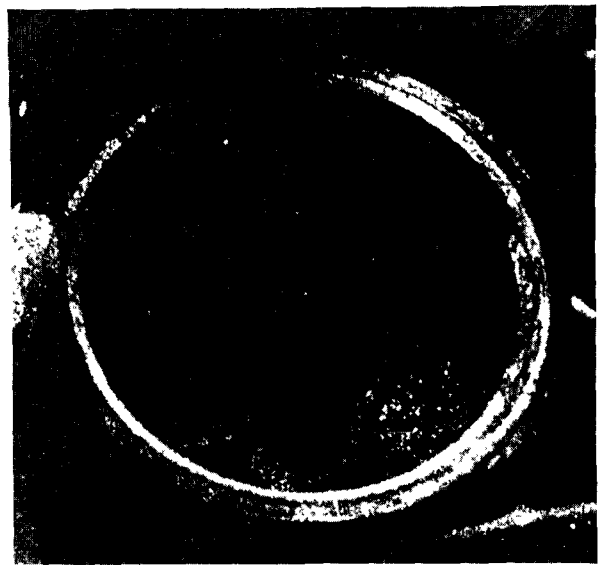
There is considerable evidence at the present time to suggest that the fledgling nuclear industry is already unmanageable. Consider, for example, that a previously secret AEC study released by Ralph Nader concluded that:

> The large number of reactor incidents [850 abnormal occurrences], coupled with the fact that many of them had real safety significance, were generic in nature, and were not identified during the normal design, fabrication, erection, and preoperational testing phases, raises a serious question regarding the current review and inspection practices both on the part of the nuclear industry and the AEC [21].

In addition, consider the tritium that recently appeared in the drinking water of Broomfield, Colorado. Consider the 115,000 gallons of high-level radioactive wastes that leaked from the tank at Hanford, Washington, over a period of 51 days while no one monitored the tank. Consider that the radioactive releases from the famed Shippingport reactor in Pennsylvania were higher than recorded. Consider that the executives of Consumers Power Corporation in Michigan failed to notify the AEC that their radioactive gas holdup system was not functioning. Consider that two reactors in Virginia were half completed before the AEC was informed that they were being constructed over an earthquake fault. Consider that the GAO found security at plutonium storage areas totally inadequate after the AEC inspectors had certified the facilities.

Considering all this, there is good reason to suggest, because of the meticulous attention to detail that will be required at every stage of plutonium recycle, that a decision to proceed with plutonium recycle will precipitate an already unmanageable situation into a national crisis.

Given that the risks of plutonium recycle are unacceptably high, particularly in light of the present uncertainties, a key question is what are our options? What are the alternatives to the AEC's proposal to proceed now with plutonium recycle? We believe that there are essentially three options, each of which is preferable to the AEC's announced plan.



Plutonium in cake form. This batch was produced at the AEC's Savannah River Plant near Aiken, S.C.

Alternatives to Plutonium Recycle

• We could phase out nuclear power reactors. There is mounting apprehension among knowledgeable persons concerning the human and societal hazards of fission reactors which would only be compounded by plutonium recycle. The 23rd Pugwash Conference on Science and World Affairs in September, 1963, concluded:

> 1. Owing to potentially grave and as yet unresolved problems related to waste management, diversion of fissionable material, and major radioactivity releases arising from accidents, natural disasters, sabotage, or acts of war, the wisdom of a commitment to nuclear fission as a principal energy source for mankind must be seriously questioned at the present time.
> 2. Accordingly, research and development on alternative energy sources—particularly solar, geothermal and fusion energy, and cleaner technologies for fossil fuels—should be greatly accelerated
> 3 Broadly based studies aimed at the assessment of the relation between genuine and sustainable energy needs, as opposed to projected demands, are required.

This third recommendation implies the implementation of energy conservation measures. It is important to recognize that energy conservation can be our major energy source between now and the year 2000. Conservation means using our present energy more efficiently; it need not mean a change in life styles. Coupled with the use of solar and geothermal energy, energy conservation could eliminate the need for new nuclear power stations.

• We could continue with the present generation of light water reactors but strictly prohibit plutonium recycle for the foreseeable future. Such a decision would be premised upon a judgment that plutonium

is too dangerous because of its toxicity and explosive potential to be allowed to become an article of commerce. Of course, we would still have plutonium to cope with because it is produced in present-day reactors. But without plutonium recycle there should be little incentive to reprocess the plutonium out of the spent fuel, so the plutonium could remain in the spent fuel where it is effectively protected from theft and, hopefully, confined and contained.

The benefits of plutonium recycle are small. Plutonium recycle would reduce the annual uranium requirements by about 10 to 15 percent and reduce the light water reactor fuel cycle cost by about the same amount. But the nuclear fuel cycle cost represents less than 20 percent of the total cost of power from nuclear plants, and nuclear plants by 1985 will represent less than 40 percent of the electric, or about 15 percent of the total, domestic energy supplied. In other words, plutonium recycle involves an economic savings of less than one-half of one percent.

Plutonium differs from the high-level wastes in the spent fuel in one critical respect: whereas the radioactivity of high-level wastes will continue for thousands of years, that of plutonium will continue for hundreds of thousands. Thus, while the problem of effectively storing both these materials and preventing their entering the environment are unprecedented in human history, plutonium must be contained for eons longer. For this reason, an argument can be made that, ultimately, the safest thing that can be done with plutonium is to burn or fission it in reactors, thus making it into high-level wastes rather than plutonium. But that is an activity that is best left for decades or even centuries hence—for a society more capable and less violent than today's.

- We could defer for several years the decision regarding plutonium recycle until present uncertainties regarding safeguards and plutonium toxicity are satisfactorily resolved and a basis has been laid for a more intelligent judgment regarding the risks and benefits of the commercialization of plutonium. We believe that this option must command general support. Too many questions, both technical and social, are unanswered today. And until these questions are answered it would be a grave error, we believe, to rush into the AEC's plutonium economy.

Is the American public willing to accept the risks of plutonium in exchange for the promised benefits? The national debate which must occur on this basic question has hardly begun.

NOTES

1. Glenn T. Seaborg, "The Plutonium Economy of the Future," Release No. S-33-70 (Washington, D.C.: Atomic Energy Commission, October 5, 1970).

2. Atomic Energy Commission, "Draft Generic Environmental Statement on the Use of Mixed Oxide Fuel," WASH-1327 (Washington, D.C.: The Commission, July 1974).

3. Donald P. Geesaman, "Plutonium and the Energy Decision," in *The Energy Crisis*, ed. R.S. Lewis and B.I. Spinrad (Chicago, Ill.: Bulletin of the Atomic Scientists, 1972), pp. 58-59.

4. Mason Willrich and Theodore B. Taylor, *Nuclear Theft: Risks and Safeguards* (Cambridge, Mass.: Ballinger, 1974).

5. The AEC's attempt to recycle plutonium into the Big Rock Point (Mich.) reactor was stopped by a lawsuit. *West Michigan Environmental Action Council v. AEC* (W. D. Mich. Dkt. No. G-58-73).

6. *Weekly Energy Report*, "GE Fuel Recovery Plant 'Inoperable,'" II (July 15, 1974), 1.

7. Atomic Energy Commission, "Nuclear Power Growth: 1974-2000," WASH-1139 (Washington, D.C.: The Commission, 1974), p. 34 (Case D projection). The year 2000 figure includes plutonium produced in liquid metal fast breeder reactors.

8. Arthur Tamplin and Thomas Cochran, *Radiation Standards of Hot Particles* (Washington, D.C.: Natural Resources Defense Council, Feb. 14, 1974). Copies of this report are available from NRDC (1710 N St., N.W., Washington, D.C. 20036) for $3 per copy.

9. Atomic Energy Commission, press release, August 14, 1974

10. W. C. Bartels and S. C. T. McDowell, quoted in *Nuclear News*, 17 (Aug. 1974), 46.

11. Clarence E. Larson, "Nuclear Materials Safeguards: A Joint Industry-Government Mission," in *Proceedings of AEC Symposium on Safeguards Research and Development*, Oct. 27-29, 1969, WASH 1147 (Washington, D.C.: The Commission, 1969); and Deborah Shapley, "Plutonium: Reactor Proliferation Threatens a Nuclear Black Market," *Science*, 172:3979 (April 9, 1971), 143.

12. See, for example, Bernard T. Feld, "The Menace of a Fission Power Economy," *Bulletin*, 30 (April 1974), 32-34; Lawrence Scheinman, "Safeguarding Nuclear Materials," *Bulletin*, 30 (April 1974), 34-36; David T. Rose, "Nuclear Electric Power," *Science*, 184:4134 (April 19, 1974), 351-359. See also Robert L. Heilbroner, *An Inquiry into the Human Prospect* (New York: W. W. Norton, 1974), pp. 40-43.

13. See, for example, Atomic Energy Commission, "The Threat of Nuclear Theft and Sabotage" (Rosenbaum Report), *Congressional Record*, April 30, 1974, p. S 6621; General Accounting Office, "Protecting Special Nuclear Material in Transit: Improvements Made and Existing Problems," B-164105 (Washington, D.C.: U. S. Government Printing Office, 1973).

14. Dean E. Abrahamson, "Energy: Nuclear Theft and Nuclear Parks," *Environment* (July/August, 1974), 5.

15. Taylor and Willrich believe that "a system of safeguards can be developed that will keep the risks of theft of nuclear weapon materials from the nuclear power industry at very low levels" [4, p. 171]. Yet they also emphasize that "regardless of its effectiveness, a nuclear safeguards system applicable to the nuclear power industry in this country cannot provide complete assurance that unannounced fission explosions will not occur in the United States in the future." They point out that "no future safeguards system that will be practical can offer 100 percent assurance against theft" [4, p. 123]. They never say what level of nuclear theft, or what size plutonium black market or how many unauthorized nuclear explosions are in fact acceptable to them.

16. L. Douglas DeNike, "Radioactive Malevolence," *Bulletin*, 30 (February 1974), 16. See also the story on the bomb threats that have occurred at the Zion nuclear power plant in northern Illinois reported in *Environment*, "Spectrum" (October 1974).

17. *Nuclear Industry*, "Industry Inundated by Proposed New Safeguards Rules" (February 1973), pp. 45-47.

18. R. S. Lewis and B. I. Spinrad, eds., *The Energy Crisis*, (Chicago, Ill.: Bulletin of the Atomic Scientists, 1972), p. 59.

19. Alvin Weinberg, "Social Institutions and Nuclear Energy," *Science*, 177:4043 (July 7, 1972), 32-34.

20. Hannes Alfven, "Energy and Environment," *Bulletin*, 29 (May 1972), 5.

21. AEC Task Force Report, dated October, 1973, page 16, released in testimony presented to the Joint Committee on Atomic Energy by Ralph Nader and the Union of Concerned Scientists, January 29, 1974.

UNITED STATES
ATOMIC ENERGY COMMISSION
WASHINGTON, D.C. 20545

August 29, 1974

N. C. Moseley, Director, Region II

ALLEGATIONS AGAINST NFS, ERWIN - MEETING WITH OCAW REPRESENTATIVES

Please note the attached information concerning items of concern expressed by OCAW representatives at a meeting in Headquarters on August 13. We believe these matters to be of priority concern. Please note that the allegations include two allegations of willfulness. Note also, that OCAW has specifically requested that an order be issued directing the licensee to perform whole body counting of workers.

In your investigation of this matter, please determine, specifically, the correctness of each allegation. In developing the specifics of the allegations you should contact the alleger - OCAW representatives in Erwin.

OCAW has requested to be allowed to be present at the management interview following this investigation. We will inform you of the position to be taken by you.

The brief history of NFS compiled by the OCAW attorney and the existing conditions at the plant (if as alleged) raise rational questions about the effectiveness of our enforcement actions against NFS, Erwin. Please comment on this.

I will appreciate from you, your estimated date for submittal of your report.

If you desire to discuss this, please contact me.

John G. Davis, Deputy Director
for Field Operations

Enclosure:
Note to Files dtd 8/29/74

194

UNITED STATES
ATOMIC ENERGY COMMISSION
WASHINGTON, D.C. 20545

August 29, 1974

Note to Files

NUCLEAR FUEL SERVICES, ERWIN, TENNESSEE, LICENSE NO. 70-143 - MEETING WITH REPRESENTATIVES OF THE OIL, CHEMICAL, AND ATOMIC WORKERS INTERNATIONAL UNION

In response to a telephone call from Steven Wodka, Legislative Assistant, Citizenship - Legislative Department, OCAW, a meeting was held on August 13, 1974, with representatives of the OCAW to discuss working conditions relative to radiation exposure at the NFS, Erwin facility. Attendees at this meeting are shown on Enclosure 1.

Wodka generally was the spokesman for the OCAW, although there was active - and, at times, emotional - participation by many of the OCAW contingent.

Wodka opened his presentation by remarking:

1. The OCAW was highly concerned with worker exposure at fuel cycle plants - both those unionized and those not unionized - and will devote effort to see that the exposures are reduced.

2. He had reviewed the file on NFS, Erwin, in the Public Document Room and had noted many instances of worker overexposures reported over the years.

3. His review of the file was incomplete since he had been unable to locate the basic license in the PDR and, consequently, could not accurately determine the requirements placed on the licensee.

4. The OCAW had, over the years, made several complaints on activities at NFS, Erwin to the AEC and, although the AEC looked into the complaints, OCAW was not satisfied that working conditions at NFS, Erwin had improved. Because of this, the OCAW concern was being elevated to OCAW International Headquarters level.

Note to Files

August 29, 1974

With regard to the specific situation at NFS, Erwin, Wodka stated the OCAW had five areas of specific concern:

1. The company has failed to reduce exposures to meet the "as low as practicable" requirement expressed in the AEC regulations.

2. The company has failed to permit OCAW representatives to accompany AEC inspectors as required by 10 CFR 19.

3. The company has failed to notify workers of overexposures as required by AEC regulations.

4. The company has failed to provide adequate monitoring.

5. The company has failed to perform adequate biological monitoring, i.e., determination of uptake of radioactive materials by workers.

The approximately two and a half hour meeting consisted of providing details supporting the five areas of concern. In the discussion, OCAW representatives specifically alleged that the licensee willfully failed to comply with requirements in two of these areas of concern:

1. Failure to permit worker representatives to accompany AEC inspectors.

2. Failure to notify individuals of exposures.

In addition, the OCAW specifically requested, due to continuing significant differences in bioassay and whole body counting results, that the AEC immediately order NFS, Erwin, to whole body count all workers for plutonium, thorium, uranium 235 and uranium 233.

The following is an account of the substance of the information and remarks presented by OCAW in support of the five areas of concern:

1. Failure of the company to meet ALAP.

a. Lunchrooms. The company provides two lunchrooms. Workers are permitted to enter the lunchroom after washing hands and donning shoe covers over shoes worn in the production area. The clothing worn in the production area is worn in the lunchroom. A monitor is provided for use by the workers. (The sink provided for washing hands also is used to wash parts from the vending machines.) Workers state that these parts have shown contamination.

One of the lunchrooms is immediately adjacent to a production area. A taped closed door serves as a wall. The workers contend that radiation, i.e., radioactive material, enters the lunchroom as evidenced by contamination on food dispensing machines. The workers state that up to 40,000 dpm have been measured on a beverage vending machine. In excess of 20,000 dpm were measured inside the machine. Several vending machines were removed from service and replaced because of contamination. The current location of the machines was not known.

The workers state that the smearable contamination limit is 500 dpm on eating table services. The only action required by the licensee is to decontaminate to below 500 dpm alpha. The opinion was expressed forcefully by Cochran, the health physics consultant, that he could not relate a 500 dpm limit, at a plant authorized to possess plutonium, with ALAP.

The OCAW representatives strongly expressed the opinion that the location of the lunchroom in proximity to the work area contributed in exposures to individuals that violated ALAP. This is evidenced by contamination detected in the lunchroom.

b. Exposures of people. Wodka stated that his review of the docket in the PDR showed, since 1969, there had been reported over-exposures of 53 individuals. In addition, whole body counting currently shows six individuals where the measurements indicate the uptakes are increasing although the licensee is supposed to have removed those workers from radiation work. Wodka stated, also, that the information on exposures in the PDR is very difficult to relate to specific exposures to individuals. These repeated instances of exposures show, according to OCAW, failure to meet ALAP.

c. Contamination. The company, according to OCAW, has shifted from a practice of some years ago of removing contamination to a practice of fixing - by paint - contamination. Fixed contamination on floor surfaces reading up to 500,000 dpm exist. In addition, shipments are made within containers showing 100,000 dpm fixed contamination.

d. Respiratory protection. Rather than provide confinement, respirators are routinely worn on some jobs to prevent over-exposure. OCAW alleged no program of control of the respirators. There is no program for changes of filtering elements or monitoring of the respirators. Training in the use of respirators is not formalized. The washing machine used for washing the respirators shows 20,000 dpm on the inside.

e. Confinement. OCAW alleges that there is general work area contamination in excess of that which would result from good practice. In general, the scrap recovery building has areas capable of confinement - and it would be practicable to do so - which are not now confined. In the plutonium line, bags leak.

f. Air effluents. Previously, the company monitored for particles on the roof. This no longer is done. Process areas operate with open building doors and with fans drawing air from the process work areas (not process lines) directly outside without filtering.

Stack sampling on the 302 and 303 buildings previously was performed daily, it now is performed weekly. A recently installed stack for process line air discharge is not sampled. It is filtered.

2. Failure to permit OCAW representative to accompany on AEC inspections.

After 10 CFR 19 became effective, OCAW alleges that in 1973 and 1974, two AEC inspections were conducted and Union representatives were denied, by the company, the right to accompany AEC inspectors. OCAW alleges that the company was fully aware of the 10 CFR 19 requirements - although the local OCAW representatives were not - and willfully denied OCAW representatives accompaniment rights. The OCAW is particularly disturbed regarding this since a local wildcat strike occurred which included this issue. OCAW states that it is the workers representative; has been so designated and recognized; and the company clearly understands the long standing desire on the part of the workers to be represented on AEC inspections; and that the local president is this workers representative.

OCAW requested that their representative be allowed to attend the management interview following the inspection as well as accompany during the performance of the inspection.

3. Failure to notify workers of exposures.

OCAW alleged that NFS, Erwin does not notify workers of exposures as required. For example, Franklin Tifton was exposed on August 23, 1973, and was only told the week of August 4, 1974, of the exposure. The notification was verbal. The company states that in the case of Gerald Webb, his exposure records have been lost. There are cases where there have been no notification. Where notification does occur, it may be as long as three to five months after the exposure. OCAW contends that this failure to notify employees of exposures is a willful act on the part of the licensee. OCAW alleges that this failure to notify applies to both notification of exposures in excess of limits and routine exposures.

Note to Files August 29, 1974

4. Failure to provide adequate monitoring.

   a. At one time, the company used trained health physics technicians to provide adequate monitoring of work areas. More recently, the company has moved into the practice of "self-monitoring". OCAW contends that this practice does not provide adequately trained personnel to evaluate exposures.

   b. OCAW contends that monitoring equipment is not adequately maintained.

   c. Work station air samplers are not located as to accurately measure the exposure of workers. Also, results of room air samples are averaged. Because of locations, this averaging produces results lower than the concentration level to which workers actually are exposed.

   d. The volumes used for calculations of air concentrations are not correct. Sample buildup severely changes the air flow through the filtering medium. Consequently, the reduced volume makes the concentration calculations erroneous in a non-conservative manner.

   e. Air samples, in some cases, are not changed for a period up to 48 hours. This permits excessive buildup on the sampling medium and renders inaccurate the results. Also, samplers are permitted to run the entire weekend without changing of samples. The long cycle of samples would permit small time periods of high concentrations without detection.

   f. With regard to surveys for removable contamination, there are no instructions on how this is to be done and no established frequency for surveys.

   g. Previously, there had been routine surveys of workers by health physics technicians. Those no longer are performed.

   h. When a criticality alarm sounds and evacuation occurs, there is no monitoring within the work areas prior to reentry to assure that actual criticality did not occur. On at least one occasion, workers have been ordered to reenter the plant with the alarm sounding. Difficulty had been experienced in resetting the alarm. Under this circumstance, if criticality had occurred, there would have been no alarm associated with the criticality event.

Note to Files August 29, 1974

5. Failure to provide adequate biological monitoring.

   a. OCAW expressed concern on the present method of urine sample collection - collected at employee's home and first collection on second day after exposure. The OCAW was concerned on lack of discipline in the method and about 10% of those who have been selected for sampling do not actually submit the samples.

   b. OCAW was concerned that cases exist where urinalysis does not show uptakes while a whole body count of the same individual does show an uptake. OCAW believes that the reliability of the NFS, Erwin urinalysis is doubtful. This lack of confidence is reinforced by the company practice of denying OCAW members assignment to perform, or assist in performing, analyses. OCAW contends that worker representatives should assist in the analysis or the samples should go to a disinterested outside supplier.

   c. OCAW is concerned, due to the differences in results, in the small number of employees whole body counted. Also, due to those differences in results, OCAW requests the AEC to order whole body counting for plutonium, thorium, uranium 235 and uranium 233 for all workers.

   d. Nasal smears, which formerly were taken ~~routinely~~, no longer are taken.

Other specific matters, outside the five areas of concern, discussed by OCAW representatives are:

1. NFS, Erwin apparently is aware of each AEC inspection and devotes considerable effort to preparing for each inspection. The AEC does not have the opportunity to inspect typical activities due to those preparation efforts.

2. Previously, during criticality alarm test evacuations, the employees evacuated through gates to areas distant from the plant. Now, they are not permitted to exit through those emergency gates. NFS, Erwin attributes this change to new AEC security regulations.

3. Employees use "Oven-off", an oven cleaner, as a means of removing contamination from their hands. The company supplies the "Oven-off" and has not objected to its use.

4. OCAW believes there is a beryllium hazard associated with a portion of work at NFS, Erwin. OCAW is unsure of the interface between AEC and OSHA on this matter.

Note to Files August 29, 1974

The OCAW representatives do not desire to have their identifies protected. They have no objection to these comments and allegations being specifically identified to NFS, Erwin as to source.

On August 27, this summary information was discussed by telephone with Mr. Wodka. He confirmed the substance expressed the OCAW concerns.

John G. Davis

Enclosure:
As Stated

Enclosure 1

Meeting with Oil, Chemical and Atomic Workers
International Union

Attendees, August 13, 1974

Atomic Energy Commission
Directorate of Regulatory Operations

J. G. Davis, Deputy Director for Field Operations
G. C. Gower, Regional Coordinator
G. H. Smith, Regional Coordinator
P. R. Guinn, Radiation Specialist, Region II
G. P. Coryell, Fuel Facilities Inspector, Region II

Oil, Chemical and Atomic Workers
International Union

S. Wodka, OCAW - Legal Department
T. Mazzocchi, OCAW (Rep., Int'l Pres.)
E. D. Swisher, Int'l V.P., OCAW-AFL-CIO
H. A. Adkinson, OCAW, Int'l. Rep.
T. Harris, OCAW, V.P. Local 3677, Erwin
J. Williams, OCAW Representative
E. Gesmer, OCAW
R. Lewis, NFS - Health Physics Technician
D. Masters, NFS - Operator
L. Tolley, NFS, Operator
T. B. Cochran, OCAW - Health Physics Consultant

202 UNITED STATES
ATOMIC ENERGY COMMISSION
DIRECTORATE OF REGULATORY OPERATIONS
REGION II - SUITE 818
230 PEACHTREE STREET, NORTHWEST
ATLANTA, GEORGIA 30303

TELEPHONE: (404) 526-4503

In Reply Refer To:
RO:II:FJL
70-143/74-01

OCT 11 1974

Nuclear Fuel Services, Inc.
ATTN: Mr. William Manser, Jr.
Plant Manager
Erwin, Tennessee 37650

Gentlemen:

This letter refers to the investigation conducted at your facility regarding alleged excessive contamination and unsafe working conditions. Two of the items substantiated by our inspectors are of more immediate concern to us.

The two items which are in violation of conditions of your license and which involve failure to meet the "As Low As Practical" criteria are:

1. Lunchroom Contamination:

   Lunchrooms continue to be contaminated in excess of limits established in Section 3.3.5 of the "Contamination Survey Program" procedures.

2. High Enriched Scrap Recovery Building

   The high enriched scrap recovery building continues to be contaminated in excess of the limits established in Section 3.3.5 of the "Contamination Survey Program" procedures.

Based on a telephone conversation between Mr. Long and Mr. Coryell of this office, and Mr. Manser on October 9, 1974, it is our understanding that immediate action is being taken to assure that contamination levels in the two areas of immediate concern are reduced and maintained at levels compatible with AEC requirements. Specifically, we understand that in addition to corrective actions already taken you will:

Nuclear Fuel Services, Inc. OCT 11 1974

1. Institute rigorous enforcement of the self-monitoring procedure for personnel entering the lunchroom.

2. Require that all personnel working in known or suspected contamination areas wear smocks over work clothes when in the lunchroom.

3. Increase the frequency of surveys in the high enriched scrap recovery building to assure prompt detection of contamination.

4. Perform immediate cleanup of contaminated areas.

5. Take high volume air samples during cleanup or when airborne contamination is suspected.

6. Require use of masks as a precautionary measure during periods of known or suspected airborne contamination.

7. Shutdown building operations if contamination levels remain above limits for prolonged periods.

8. Revise operating procedures to require use of protective covering around contaminated equipment or product containers prior to handling in open areas.

9. Expedite procurement of material and installation of planned engineering changes to improve containment and building ventilation.

If the above stated understandings are contrary to your actions regarding the two items, we should be informed promptly in writing. You may expect to hear further from us regarding the enforcement aspects of this matter. In addition, other matters identified to you previously regarding the investigation findings will be communicated to you by separate correspondence.

Very truly yours,

N. C. Moseley
Director

204

UNITED STATES
ATOMIC ENERGY COMMISSION
DIRECTORATE OF REGULATORY OPERATIONS
REGION II - SUITE 818
230 PEACHTREE STREET, NORTHWEST
ATLANTA, GEORGIA 30303

In Reply Refer To:
RO:II:FJL
70-143/74-01

OCT 18 1974

Nuclear Fuel Services, Inc.
ATTN: Mr. William Manser, Jr.
Plant Manager
Erwin, Tennessee 37650

Gentlemen:

This refers to the investigation conducted by Messrs. G. P. Coryell, J. H. Kahle, and P. R. Guinn of this office on September 17-20 and September 24-26, 1974, of activities authorized by AEC License No. SNM-124, for the NFS, Erwin facility, and to the discussion of our findings held by Messrs. Long, Coryell, Kahle and Guinn with Messrs. Manser, Idecker and Michel subsequent to the investigation on October 7, 1974.

Areas examined during the investigation included allegations of excessive radioactive contamination and unsafe working conditions. Within these areas, the investigation consisted of selective examination of procedures and representative records, interviews with personnel, and observations by the inspectors.

During the investigation, it was found that certain activities under your license appear to be in violation of AEC requirements. The violations and references to pertinent requirements are listed in Enclosure 1 of this letter.

This notice is sent to you pursuant to the provisions of Section 2.201 of the AEC's "Rules of Practice", Part 2, Title 10, Code of Federal Regulations. Section 2.201 requires you to submit to this office, within 20 days of your receipt of this notice, a written statement or explanation in reply including: (1) corrective steps which have been taken by you and the results achieved; (2) corrective steps which will be taken to avoid further violations; and (3) the date when full compliance will be achieved.

One item which remained unresolved at the conclusion of the investigation has been referred to Regulatory Operations Headquarters for further evaluation. The item is discussed in Enclosure 2 to this letter. We will inform you of the results of this evaluation when available.

Nuclear Fuel Services, Inc.

OCT 18 1974

If you have any question concerning this letter, we will be glad to discuss them with you.

Very truly yours,

N. C. Moseley
Director

Enclosures:
as stated

Enclosure (1)

RO Investigation Report No. 70-143/74-01

OCT 18 1974

NOTICE OF VIOLATIONS

Certain activities under your license appear to be in noncompliance with AEC and license requirements as indicated below.

The following violations are considered to be of Severity Category II:

1. 10 CFR 20.201(b) requires licensees to conduct such surveys as necessary to comply with the Regulations. NFS has chosen to employ urinalysis as a means of compliance with this requirement.

   Contrary to the above, the evaluation of urinalysis results was not adequate to determine compliance with 10 CFR 20.103.

2. License Condition No. 8 incorporating the license application dated June 3, 1963, Section 3.3.5 of procedures entitled "Contamination Survey Program," states in part, "....that smearable contamination less than 500 d/m is considered acceptable in certain areas."

   Contrary to the above, lunch room contamination surveys during the period July through September 1974, including surveys made in the presence of the AEC inspector, revealed contamination levels which exceeded the specified limit. Levels up to 4000 d/m were detected.

3. License condition No. 8 incorporating the license application dated June 3, 1963, Section 3.3.5 of procedures entitled "Contamination Survey Program" states in part, that "....in plant processing areas, smearable contamination to 5000 d/m is considered acceptable."

   Contrary to the above, contamination in the Building 233 processing area has exceeded the specified limit on a continuing basis during the period July through September 1974. Levels up to 30,000 d/m were detected.

4 License Condition No. 8 incorporating license application dated June 3, 1963, Section 3.3.2, "Respiratory Protection," requires in part, that "....employees wash their respirators at the end of each shift and that filters on the respirators be changed once each week or more frequently as determined by the Health and Safety Department."

   Contrary to the above, there was no evidence that respirators were cleaned daily and that respirator filters were changed once each week, prior to initiation of a revised mask and respirator protection program in August 1974.

5. License Condition No. 8 incorporating license application dated June 3, 1963, Section 3.0, "Health and Safety," paragraph 3.5, "Basic Health and Safety Rules and Regulations," item 15, states "Bioassay samples must be submitted by all laboratory, operating and maintenance personnel on designated dates."

   Contrary to the above, bioassay samples were not submitted by 68 persons including laboratory, operating and maintenance personnel. Delinquent periods ranged from three months to two years.

Enclosure (2)

OCT 18 1974

RO Investigation Report No. 70-143/74-01

ITEMS REFERRED TO REGULATORY OPERATIONS HEADQUARTERS FOR FURTHER EVALUATION

Air Sampling

Investigation findings confirm the allegation that air samples run the entire weekend without changing of samples, versus the normal workweek practice of changes each 24 hours. This weekend schedule has been in effect since initial plant startup. Investigation findings relating to the corollary allegation that the long (72 hour) cycle of samples would permit small time periods of high concentrations without detection is being referred to Regulatory Operations for further evaluation.

Dr. Mills: Thank you, Dr. Cochran, Mr. Speth.

The point that Mr. Speth made has to do with revising plutonium standards. Is it your concern that the safeguards program or a failure in non-compliance exists as they are today, that any release of the plutonium because of non-compliance or breakdown of the safeguards program should be such that there should be no public health -- risks to public health, I guess, is the word I speak of.

Is that the focus of the discussion on the non-compliance, the failure of compliance?

I am trying to tie in, in terms of establishing standards, the safeguards program and the incidents that you talked about of failure to comply that the AEC found out.

Is what you are proposing to address in terms of the standard itself such that those releases would not be of public health risk?

Mr. Speth: We are not sure we understand the question. But one thing you may be asking is why we did discuss the safeguards problem in this particular format.

I think the answer is that we do not feel you can make an artificial separation between those issues. When we consider plutonium, we have got to consider the whole fuel cycle and its implication.

Obviously, there are certain jurisdictional things that EPA cannot do, but it is also true, you have got to make a basic societal judgment about the desirability of moving into what the AEC has called the plutonium economy, large scale reliance on plutonium as a fuel.

When we make that judgment, we would better know all the facts

and be aware of both sides, all of the problems that are associated, not just the plutonium toxicity problem.

Dr. Mills: My point was, in the establishment of an environmental ban, the standard, I do not see how it could insure against failures of non-compliance.

Dr. Cochran: One standard you might consider is to not use this material.

Returning to the question of safeguards, there has been some discussion earlier and one of the points in the Federal Register is with respect to the costs versus benefits of use of this material. You cannot just weigh the benefits against part of the cost and eliminate the safeguards aspect. There was even some suggestion here earlier this morning that we should weigh the cost against the cost, that is, the effects of releases of plutonium weighed against the effects of natural background radiation.

The point we would make with respect to the safeguards is that it is one of the principal, if not the principal, cost items in this weighing. These two issues, the safeguards and the toxicity are of principal concern to us. When we look at these and the benefits we do not see why there would be any commercial plutonium recycled at this time. On the benefit side, we made the statement here earlier in Mr. Speth's presentation that plutonium recycle reduces light water costs by 10 or 15 percent. That is really the AEC statement, not ours. I would submit that the cost of reprocessing and fabricating mixed oxide fuels has gone up so drastically in recent years, there is

a very good chance that there is no economic incentive, forgetting about safeguards for plutonium recycling at this time.

Some of your evidence for this is in the materials presented in our comments on GESMO, the material presented by the intervenors in the licensing proceedings going on at NFS, West Valley, and also in a recent G.E. report on nuclear energy parks.

Dr. Mills: Do you agree, then, that in establishing a standard we have to look at the benefit of the activity as well as the health impact? Can I interpret that correctly?

Dr. Tamplin: Yes. I think that is true. Also, that we addressed our comments here to most of the items that were listed in the Federal Register that these hearings were about, which was not strictly standards.

The first one was general, to include consideration of general concern, including the public and social implications of plutonium utilization and the factors involved, balancing benefits and costs.

The recommendation of this panel, the social implications of plutonium are such that it should not be an item of commerce.

I think that is a possible conclusion you could come to.

The fourth item here was applications using plutonium to include consideration of current and projected uses of plutonium and other transuranic elements.

The estimated quantities in each application and the magnitude of the possible releases to the environment: From the industry, you are going to hear a very rosy picture of the releases in the environment.

I think these non-compliance situations should cause you to regard this rosy picture with some skepticism.

Dr. Mills: Fine. Thank you.

Dr. Taylor?

Dr. Taylor: Well, his last statement has made me change the remark I was going to make. I thought it was pointed out this morning that our discussions on radiation protection standards really involved two parts, you might say: the technical part on the one hand, and the social, political and economic on the other.

We are sitting here; most of us at this table, if not all of us, are all technical people. We are certainly not politicians in the ordinary sense. I do not think any of us at this table are qualified to comment on any of the social or political implications that have been presented in this very interesting discussion.

Dr. Tamplin: You are certainly as qualified as any other human being.

Dr. Taylor: That is not the purpose of this particular conference in my judgment. I am quite willing to talk about these things, but not here.

Dr. Cochran: As we read the Federal Register this is the purpose. You may have been deceived when you were invited.

Dr. Mills: Dr. First?

Dr. First: I am not sure I understand your position here, gentlemen. On the one hand, you are talking about a lower standard than presently exists, a liability of magnitude.

On the other hand, you are saying let us do away with plutonium completely as well as all other radionuclides, if I understand your position.

Is this not incompatible?

Dr. Cochran: I do not think it is incompatible. You say our position is let us do away with plutonium. Our position at this time is you should not be recycling this material. You should not be removing it from the fuel rods.

The reason I do not think it is incompatible, I think given the present evidence as we see it, the occupational exposure standards and the levels at which people are currently being exposed are levels which we believe carry with them a high probability that these people would get lung cancer; so regardless of whether you want to do away with plutonium recycle, you should not have a standard that unnecessarily exposes the workers. A judgment on plutonium recycle involves weighing of costs and benefits. The standards issue involves consideration of the fact that when you weight cost and benefit, there is no equity arrangement, whereby the people that pay the costs are the same people that get the benefits. The workers are receiving the costs, and people who use the electricity are the receivers on the benefits side.

Dr. Tamplin: I might add one other thing. That is there is an existing plutonium industry today. There are, say, people in the military program exposed to it. So standards are something that have to be resolved whether or not plutonium is recycled.

But you have to recognize there is another industry besides the nuclear industry that would be involved in standards. One of them is the industry that makes such things as pacemakers, using plutonium 238. The other industry is fire detector equipment, where they use americium.

So the plutonium standard itself can be considered separtely from the whole question of the nuclear power industry.

Dr. First: I think that clarifies it. The point you made just now was perfectly all right, while I am sorry that you did not want to reprocess spent fuel rods.

Dose that signify that you are satisfied with the present nuclear operations if you do not reprocess spent fuel rods, or is there still another issue in your minds?

Mr. Speth: We obviously have a problem that is a major controversy in the country today, for the general safety of the nuclear power industry we have now.

Dr. First: Even I am aware of that.

Mr. Speth: I think what we are saying here, at a minimum, is let us not escalate that problem by going ahead with plutonium recycle.

Let us not escalate by going ahead with the breeder reactor. We feel that the introduction of those new technologies will represent a substantial escalation in the problem we already have, the problem that the new field is already out of control and serious.

So basically, that is what we are saying here in connection with plutonium. Let us not go ahead with the plutonium economy. It is just going to be too risky and too dangerous. It does not really address the question of whether what we already have is already too risky and too dangerous.

If you want me to address that, I can tell you what I think, but it is really not germane.

Dr. First: Well, if it is not, then I certainly would be happy to pass it over.

I think I have gotten a pretty good idea of what you are not for. In the context of the present hearing, could you tell us what you are for? What do you advocate as a positive approach, other than just doing away with things?

Mr. Speth: I am not quite sure what you are saying. It is our feeling that assuming the light-water reactors will operate, that we should explore what is the safest thing to do with this fuel.

Given that we do not favor recycling it or making the plutonium industry, or giving birth to a plutonium industry, what is the safest thing to do?

That may be what we suggested that some people should consider simply leaving it in the fuel rods.

Dr. First: Indefinitely?

Mr. Speth: Yes. At some point, a generation hence, you may want to fission that plutonium, but certainly not under current circumstances, in the world that we have today, with the problems that we have.

I am not sure that is positive enough.

Dr. First: I think that gets at what I was after.

I wanted to know what you stood for, as well as against.

One other point I would like to ask before I give up on this. That is, the information that we got this morning from a number of vistors regarding toxicity of the plutonium seems to be somewhat at

odds with the information that you presented here, in fact quite considerably.

In these presentations there was a good deal of reference to the publications and studies. I was wondering if you have documented the biological basis for your recommendation of a plutonium standard.

Did you say 100,000 times, or 1/100,000 of what the present total is, or is this something which you are planning to do tomorrow?

If it is tomorrow, I will pass the question.

Dr. Tamplin: We have a report that we have issued, and also, we have made responses to some AEC reports, a draft on the LMFBR, and draft on plutonium recycle. We have also commented on one of the more recent reports that came out of AEC on WASH 1320.

If this material is not already available to you, we would certainly make that available tomorrow.

Dr. First: Is this in the handout which I have just gotten?

Dr. Tamplin: Some of it is, but anyway, that will be available tomorrow.

Dr. First: I will pass that question, then.

Dr. Tamplin: The Environmental Protection Agency did not supply us with this material, since it was supplied along with our petition tc the Agency. I guess that is the major reason why we did not bring copies of our report.

Dr. First: I just want to be sure that it will come up at some point in these hearings, but if it is planned, I will pass it.

Dr. Cochran: I might add, we assumed that the panel members would have been familiar with most of that material already.

We submitted that material, our first report, to the EPA on February 14. They have had 10 months to call us and invite us in, if they wanted information on it. We are a little bit puzzled that they wait 10 months and want us to sit down with them in this short time and go over that material.

What we intended to do was to be prepared to answer questions on that material. If you want a presentation on that, I think we could do that tomorrow.

Dr. First: I think I have made my point clear.

Dr. Mills: Dr. Radford?

Dr. Radford: First, I have had the material that has just been referred to, so at least one member of the panel has seen it, including WASH 1320, so I am prepared to ask questions as to specific sections of that.

With regard to the presentation we have just heard, I would like a little further clarification. I am not quite clear myself.

Is it my understanding that your position is that breeder technology which is pretty dependent on plutonium isolation as I understand it, thereby, in your opinion, should not be embarked upon?

Is that one conclusion of your statement?

Dr. Cochran: I think our position with respect to the breeder program is that it cannot be justified at this time from an economic cost-benefit standpoint, that it certainly exacerbates the hazards in plutonium toxicity.

Our position would be we would advocate that you would cancel the commercial introduction of this facility. We would not propose at any time that you should just have wholesale elimination of the program.

Ultimately, if you continue to rely on fission as the energy option, eventually you would need a breeder of some sort. So we have not suggested that you cancel the R & D aspect of the program.

I think our position as we present it in our 450-some odd pages to the AEC, commenting on the impact statement of the breeder, it is a misallocation of R & D financing, that you should cut that program back and put that money where it would do more good, in other energy technologies.

Dr. Radford: Before getting to that issue, we heard testimony this morning from General Electric, and I do not believe it differs greatly from what we heard from the AEC later, that the availability of low cost uranium fuel is such that by the year 2000, maybe 2010 or 2020, depending on your estimates, we will be in a similar position to where we are with oil and the inadequate domestic resources.

The estimates for a viable breeder based fuel breeder program providing adequate electricity to supplement the light-water reactors must get underway now if we are to have it adequately tested by the time it must go on line, somewhere around 2000, or 2010 or 2020.

Now, you are in effect saying to defer a further development of the breeder program and would seem to me to say, we should also defer any further development of the light-water reactors.

Dr. Cochran: The arguments are different. You can make a case against the LMFBR, assuming you have a viable light-water reactor. I would separate those arguments from the arguments against having any sort of fission economy.

With respect to the first, the argument of why there is no economic incentive with respect to the breeder, I documented my case in a book. Subsequently NRDC, primarily the three of us here, have updated that work in NRDC's comments on the draft LMFBR Environmental Impact Statement. These comments contain analysis that takes issue with the AEC's and General Electric's position with regard to uranium availability and a number of other assumptions.

The uranium availability is only one of several keys, Dr. Wolfe was referring to earlier. It is an unpublished study that has been bounced around in OMB and NFS and elsewhere. It, too, has what I believe are some erroneous or unjustifiable assumptions about the input data. There is enough flexibility so that by shifting your assumptions with respect to the price of the reactor plants, the uranium availability, and energy demand, you can generate senarios where it appears that a breeder will be needed. We take strong exception to many of these assumptions.

Dr. Tamplin: EPA, in their comments on the fast breeder, also were quite critical of the economic analysis. When I say also, one of the questions relative to when plutonium should be used, one of the arguments for the fast breeder was it had to be a crash priority program. They wanted it by 1985.

This is one of the aspects of the economic analysis that causes it to fall apart, that the breeder would not be economical in 1985. They say the year 2000 or something, so one of the things that we are proposing is let us not move into this plutonium economy with all kinds of unresolved problems.

Let us stretch the breeder program out. Let us take the R & D funding and put it elsewhere. Then we can resolve some of these unresolved issues relative to plutonium in the interim period.

Dr. Radford: Would not you say that one of the unresolved issues about the plutonium technology or the breeder technology is whether the large breeders will work?

Is not that a fairly important issue to get settled at as early a date as we can?

Dr. Cochran: It depends on how you define "work." There are some areas of research and development that we would suggest could be continued and should be continued, because they are rather benign.

When you are talking about putting a 350 megawatt commercial facility in one of the areas of the country that has the worst meteorological conditions, when you do not know the upper bound on the explosive potential of that reactor, when the plutonium standards are in question, and when you do not have adequate safeguards programs in hand, that is not a good course of action.

So that is why I say let us cut out the commercial component of the breeder program. Then we can talk about what sort of R & D we should continue to prove out some of these unresolved issues.

Dr. Radford: I was not aware that this was really in the commercial stage, even though I recognize that some of the utilties are contributing to it. I do not think it was designed for commercial production of power.

Let us get off that subject, if I may, and get to the question which you raised on the issue of economics.

In relation to the competitive value of different fields, do you think that pure economic concerns should dominate whether we go this way, that way, or the other way?

We heard, for example, today some projections by Dr. Wolfe about how much it is going to cost to generate electric power by solar energy. Do you think that type of economic analysis, correct or not, ought to be the basis of whether we develop solar power?

Dr. Cochran: I am not an economist, but I would prefer that you be a little more specific on what you mean by economic assessment, because there are many economists who would include all the social costs and so forth in their economic assessment in the weighing of the costs and benefits.

I certainly think that economic analyses of the type you are referring to should be one input in the decision making process, but it should not necessarily be the primary one. Clearly, it should not in the case of breeder reactors or plutonium recycling.

The health and safety issues, in my view, are the primary issues because the risk in these areas is so great.

Dr. Radford: So questions of cost of the safeguards levels that

you might consider acceptable, you would not consider that necessarily binding?

Dr. Cochran: I do not understand your point.

Dr. Radford: Let us assume you could build a facility handling plutonium where you could absolutely contain it completely at sufficient cost.

Let us make the assumption, anyway, that the containment is partially a function of cost. The issue of how much that costs would not be an important issue as far as whether to go with plutonium recycle or not?

Dr. Tamplin: I think you are getting sort of at the issue there. One of the reasons why we brought up the social and political implications of the safeguards program is that safeguards programs have to exist here in the United States before being applied. The social consequences of a breakdown in the safeguards program are such that certainly, if you were going to have plutonium, whatever it costs in terms of dollars to make a safeguards system safer would certainly be justified because the social implications of a breakdown, in plutonium diversion and nuclear blackmail, are such that the dollar cost would bear no relationship to the social costs.

Dr. Radford: I am sure that some R & D could be developed, for example, to poison the plutonium fuel so that it could not be readily handled by somebody -- I just toss that out for a comment.

That is an area of R & D that could be developed.

You mentioned fines at the General Electric and Nuclear Fuel Services, West Valley plant. Were those fines for the breach of plutonium containment?

Dr. Cochran: No. They were safeguards violations.

Dr. Radford: Safeguards regarding unauthorized entrance?

Dr. Cochran: According to the report the safeguards violations involved "failure to have required intrusion monitoring, alarm systems and physical barriers to protect against industrial sabotage."

That is a quote from the AEC news release.

Dr. Radford: So that really had nothing to do with whether fission products, plutonium or other transuranics were distributed within a plant?

Dr. Cochran: That is correct.

Dr. Radford: Finally, with regard to the standards, most of the concern that you have expressed with regard to the number of these episodes deal with occupational exposure. Is that correct?

Dr. Cochran: That is correct.

Dr. Radford: Unfortunately, it is my understanding that the EPA has no jurisdiction over occupational exposure, so I ask the question, do you believe that plutonium, having the nature in itself, being what it is, is quite likely to be carried outside the plant if there are significant occupational exposures?

Are there ways to deal with this?

Dr. Cochran: I believe there is already evidence of its being carried outside the plant. Rocky Flats is the most alarming example in that regard.

I think the EPA ought to be privy to how the industry reacts to regulations. Their regulations will, in fact, affect the indstry and their effluent releases. We have presented examples of what is going on in the industry. The present situation indicates they are not following the regulations.

Some of the things that I have seen and heard from workers would suggest to me that some of these facilities are lacking in the rudiments of accepted health physics practices.

I think it would be fair for EPA to infer that if they impose stricter environmental releases standards, they should not expect any better performance by the industry than we are getting presently with respect to the worker standards.

Dr. Mills: One point of clarification on this. EPA has no regulatory authority as far as occupational is concerned.

Dr. Radford: A final question about the standards: If your standards are adopted, how would you propose that it be enforced?

Dr. Tamplin: Rigorously.

Dr. Radford: Would you have instruments available that could detect the concentrations that might occur?

Dr. Tamplin: You mean, is it possible today to go out and measure one particle per meter square of a surface? I think that is very difficult at this point, at this particular time.

The fact may be that by the time you are able to detect plutonium in the environment, you are already at too hazardous a situation.

That is a question which, in a way, this panel is addressing relative to the standard. If you can detect plutonium, are you already beyond the point in the environment where it is acceptable?

Dr. Mills: Dr. Garner?

Dr. Garner: Let us start with the trivial.

There is one statement in Dr. Cochran's presentation which I found extremely irritating. It is the sort of statement I always find irritating.

After referring to something from Rocky Flats, you talk about plutonium being found among cattle. Then you go on to say the implication of this for humans in the area is obvious.

It is not obvious to me at all. Cattle poke around in the grass and inhale a lot of material. People do not poke around in the grass and inhale this material. So to me, this is not as obvious as it is to you.

Could you expand on that?

Dr. Cochran: I do not know that it really requires a great deal of expansion. We do not know precisely how plutonium particles got into the lungs of the cows.

Certainly, it indicates that the plutonium in the area is available. How the lungs of humans in the area compares with the lungs of cows in the area is another thing, but we do know that Dr. Ed Martel has measured plutonium in the environment of Rocky Flats and he has found plutonium particles in the air in the area. So the implications are obvious, I think, but quantitatively they may not be so obvious.

Certainly, it indicates there is environmental contamination of plutonium in the area. The implications are that this may be at levels that are not adequate from the standpoint of public health.

Mr. Speth: One other comment on that.

I do not know about yours, but my kids poke around in the grass a lot. I am not sure you were serious. Were you?

Dr. Garner: It is the kind of statement that leaves things hanging in the air. I hate to see a statement where the implication is not obvious.

Mr. Speth: The report, as I understand it, is just a one page abstract of it, but it is circulating around.

Dr. Garner: As I told you, it was a trivial matter. I did not want to make a great deal of it.

Since a lot of questions have been asked, I will confine myself to just one thing, the violations.

You painted a terrible picture of violations in an embryo plutonium industry, but I think we ought to get our feet back on the ground again.

This is not unique to the plutonium industry. I think if you would like to go and look at a great many other industries, you will find equally horrifying violations.

Dr. Cochran: NRDC works in those areas also.

Dr. Garner: With plutonium, we are talking about something which may produce health effects. In other industries, such effects are certain.

Mr. Speth: We have been trying for some time to get EPA to do

something about carcinogens in the environment, with absolutely no success, so you are in a better position to try to do something about that than we are.

Dr. Garner: I am just a simple research person.

I think you have confirmed what I think you are saying, that is, that industry as a whole should look into safety precautions. Industry as a whole, not just the plutonium industry, but industry as a whole.

I would just like to end by saying one can interpret things in different ways. The files that Dr. Cochran has referred to, you could argue always, if you want to.

You could argue that if we accept G.E.'s statement, that it has operated safely, that is has not exposed people beyond a reasonable amount to plutonium, has not contributed significantly to the environment and has done this despite the fact of safety violations -- If one imposed safety regulations which are supposed to be enforced, then one could argue that things could be better still. We would be better off.

This, I know, is not a good argument, but I am simply trying to say that you can turn things anyway you like.

Dr. Tamplin: Of course, General Electric is still the safest fuel reprocessing plant in the country: it does not operate.

Dr. Mills: I would like to add for the record, there is a comment from Mr. Deuster which has to do with what Dr. Cochran was talking about, from the standpoint of NFS, Erwin.

That is, he says the alleged violation about the NFS Erwin facility does not involve plutonium. They are all uranium related.

Dr. Cochran: I thought I made the relevance of the violations to these hearings clear in my statement.

Dr. Mills: Thank you very much.

(Note: The following testimony by Dr. Tamplin was given on the afternoon of the 11th but is included here in the proceedings to aid in continuity.)

Dr. Mills: I would like to get started, please.

I would like to first bring your attention to what the main part of the schedule is like. We have run into some problems with plane schedules and what have you.

The next participants are from the Natural Resources Defense Council. Dr. Tamplin will speak.

Subsequent to that will be Ms. Judith Johnsrud from the Environmental Coalition on Nuclear Power.

After that, we would hope that the members of the biomedical group from the AEC could be around to answer additional questions the panel might have. The additional questions, we would hope to limit to, at the most, 45 minutes.

So, Dr. Tamplin.

Dr. Tamplin: I would like to start off by making just a few general remarks.

One of the things that I think should essentially be cleared up for the record, we have heard a number of people mentioning various standard setting bodies. As I read the laws of this country, there are two standard setting bodies that are standard setting bodies so far as radiation is concerned. They are the Environmental Protection Agency and the Atomic Energy Commission.

Now, there are other groups like the International Commission on Radiological Protection and the National Council on Radiological Protection and the BEIR Commission of the National Academy of Science. None of these bodies have any responsibility whatsoever for setting

standards. They make recommendations, but when it comes to the processes of setting standards, I think it is becoming quite ludicrous the way the AEC and the Environmental Protection Agency always refer to these advisory bodies as standard setting bodies and try to pass the buck there.

I might even say that if one looks at the legislative history of the National Environmental Policy Act, I think you will conclude that legislative history of that Act indicated that the NCRP and BEIR Committee were not recognized by Congress as standard setting bodies, because when that bill passed the House, it had an amendment on it which was going to emasculate the EPA's position in this situation by saying that they had to seek the advice of the National Commission on Radiological Protection and the BEIR Committee.

There was a lobby in the Congress on that and that particular item was removed in the Senate. The one passed in the Senate did not contain that and the event was dropped when the conference between the two houses took place.

I think the legislative history that established the Environmental Protection Agency indicates that the NCRP and these other committees are not standards setting bodies and are not so recognized by the Congress in that respect.

So when it comes down to setting standards, the buck stops with EPA and the Atomic Energy Commission.

Now, certainly, there is a great deal of philosophy or a great deal of principle that has to be involved in the setting of standards.

I think one of the unfortunate things that exists at this particular point, both in the AEC and in the Environmental Protection Agency, there seems to be no clear statement of what that principle is.

The various agencies such as NCRP have talked about something that is as low as practicable. That is, basically, I think we have seen in some of the discussions here, that is basically some kind of a way that an industry can survive even though the regulations which regulate it are not necessarily in the best interest of the public health and safety.

The EPA or AEC should clearly enuciate a principle that is involved in terms of setting radiation protection standards. I think we have actually sort of a legislative principle that came out of the Congress which said there should be no degradation in the air quality.

Well, this is kind of a principle. We do not see any of this in the area of radiation protection, and if you look at the ICRP recommendations, the limit for genetic exposure, they indicated that they felt the level was such that it allowed latitude for the development of the industry, and that they hoped it was a proper balance between benefits and risks that were associated.

They only hoped that; but they did know that it allowed sufficient latitude for the development of the industry. So that is kind of as low as is practicable.

But that does not seem to me to be a sound principle of public health on which to establish standards. We have also heard in these

discussions here a number of people saying, well there is not enough information at this particular point to determine what the standard should be.

Certainly we have heard that with respect to plutonium, that there is kind of a growing consensus that the standard is too high. It could be reduced, we heard here today, by a factor of ten to a hundred.

Then we hear the comments, I do not think we should do anything with the standards until we get some more information.

This, again, does not seem to be a solid principle or practice for public health. It seems to me that our Environmental Protection Agency or agencies that are set to protect the public health should clearly enunciate the principles upon which regulations will be based.

When information is lacking, they should determine the kind of approach that would be used to establish the standard. Now, when they say that in the case of plutonium, that we do not know enough to set adequate standards today, so depending upon your point of view -- Mine would be, well then, let us not fool around with plutonium until we do know what the standards should be because we do know that the plutonium standard is not adequate.

The other approach is to establish a standard on the basis of the conservative and supportable hypothesis and then let the industry develop the technology to meet the standard. But the idea of determining what industry can do before you set a standard, or wondering whether industry can survive with a particular standard, should not really be part of the practice for public health.

We have heard also here a great deal of discussion about fallout of plutonium. It is fairly easy to recognize that both the chemical and physical nature of the fallout plutonium is most likely different from that which will be expelled as part of a nuclear reactor program in the plutonium industry.

Not only is the plutonium in particles that are of much smaller particle size than one could anticipate this industry developing, the specific activity of the plutonium particles is also significantly lower. From the nuclear power industry, you can expect particles of plutonium oxide but the plutonium in the particles from fallout is mixed with the debris that constituted the remainder of the device, and also indicates that some of the surface and water is mixed in with melted and reconstituted soil.

I think there is also some question in terms of the pathways to man. Whether studies of plutonium fallout can be transposed immediately to the releases from nuclear facilities.

Of course, the other thing about the nuclear facility is their releases will for the most part be ground level releases, and they are going to cause a much more circumscribed environmental consequence than some of the very high altitude tests of nuclear weapons.

Now, I would like to then get into, briefly, a discussion of the hot particle issue and our petition to the Environmental Protection Agency and the AEC asking them to modify their radiation protection standards so far as they apply to alpha emitting radionuclides in soluble form, deposited in the lung.

Just briefly, I would like to describe the nature of the hypothesis on which this is based. I might say I have not been concerned about plutonium since the Chalk River Conference in 1944. My concern about plutonium only began in 1967.

At that particular time, when we first looked at plutonium in the laboratory, we recognized that one of the major ways in which plutonium from the nuclear industry would be dispersed into the environment would be in the form of highly radioactive particles of plutonium oxide which are insoluble in deep respiratory regions of the lung and which have long residence in the lung.

So we were presented with more or less a unique situation where you have a very small body of tissue that is irradiated to a very high dosage of radiation. When we looked at the available data that related to irradiating small bodies of tissue at very high levels, we discovered that that data indicated that cancer was an almost inevitable result from those experiments.

Now, most of those particular experiments, of course, dealt with various experimental animals and exposure of small areas of the skin. At that particular time, this represented the kind of major information you had. Plutonium particles in the lung, very high doses, and when you look at experiments that did that, you found out that cancer was a very frequent result of these terms.

So at that particular time, we suspected that these hot particles deposited in the deep respiratory tissue in the lung may represent a unique carcinogenic event. It was then last year that Tom Cochran and

I reexamined the information that was available which had been prepared and developed by Don Geesaman.

We examined that information and what new information was available and then supplied some quantitative numbers to this hot particle hypothesis which eventually led to our petition.

Now, some of the new information which is available to suggest that hot particles deposited in the deep respiratory zone of the lung may indeed represent unique carcinogenic events comes from -- I think we heard a discussion of it by Dr. Richmond, which was the lesion which was excised from the palm of a mechanic.

This lesion was caused by plutonium. I think it was .8 microgram of plutonium embedded in his skin. I would just like to read if I may the description which is found in the paper discussing that particular lesion, which he excised.

They said the autoradiograph showed precise confinement of the alpha tracks to the area of maximum damage, and their penetration into the basal areas of the epidermis, where epithelial changes typical of ionizing radiation exposure were present. The cause and effect relationship of these findings, therefore, seemed obvious.

Although the lesion was minute, the changes in it were severe. The similarity to known precancerous epidermal cytological changes, of course, raised the question of the ultimate state of such a lesion, should it be allowed to exist without surgical intervention.

Now, as I read that, I gain the impression that here was a lesion caused by a small particle of plutonium embedded in a palm of a hand

that had changes in it which made the pathologist think that if that lesion was not excised, that there was a reasonable probability that it would progress into a cancer.

Now, there have been some experiments -- These were also performed by Dr. Richmond, who injected a few small microspheres of plutonium into the femoral vein which subsequentely became lodged in the capillary beds of the lungs.

Now, commenting on these experiments which involved rats, Dr. Richmond indicated that he found lesions around these microspheres in the lungs of the rats. His description is the pertinent thing here. Such a lesion with coagulates degenerate and subsequent liquefaction due to the large local dose of radiation at high dose rate has been reported by Lushbaugh, whose description of a plutonium lesion found in the dermis is very similar to that observed for plutonium in the lung.

Now, Dr. Richmond et al subsequently went on and injected these microspheres into the lungs of hamsters. In the hamster lungs, they also observed cytological changes around the microspheres.

In the progress report for January through December 1973, concerning these lesions, they said: A consistent observation of this lesion after drastically different induction times could lead to speculation that the amount of tissue irradiated is an important element in the timing of the tumorigenic response.

There has been no increase in the tumor observed within the past year. However, the epithelial changes described above should be considered as precursors of periphoral abnormalities.

So, in other words, as we look at experiments for small bodies of tissues exposed to high doses of radiation, we find that cancer is a very frequent result. When we look at small particles of plutonium embedded in the skin, we see that they develop a lesion which suggests that it should be removed because it may develop into tumors.

When these hot particles are then put into the vast capillary bed of the lung, lesions develop around those which have similar cytological changes and which suggest some kind of an incipient carcinogenic response.

Well, now, to proceed further with standards one has to first accept the hypothesis that these hot particles of plutonium embedded in the lung tissue may be capable of producing cancer, having a unique carcinogenic risk associated with them.

If one, looking at the available data, does not accept that, then of course, the need to go ahead and talk about standards for hot particles just does not exist.

My own feeling is that the evidence suggests that we should be very cautious in considering these hot particles in the lung because experimental data and biological data, biological observations, suggest that they do pose a unique carcinogenic hazard.

So, once one has accepted that, then in order to have standards you have to, then, go ahead and develop some kind of a risk estimate for the particles. You need some approach towards a quantification of this observed, especially significant carcinogenic risk.

Well, to arrive at a quantitative approach, we use the experiments conducted on the skin of rats on which was observed a high carcinogenic response when some 24 square centimeters of rat skin was irradiated. This radiation dose got up above 2,000 rads, getting up to five tumors per rat. There were a variety of experiments with x-rays and so forth but when he put these all together, he found that the number of tumors which he observed were strongly correlated with the number of atrophied hair follicles that were produced in this irradiated mass.

It was between one tumor per 2,000 to one tumor per 4,000 atrophied hair follicles. This, then, represented a correlation between disturbed architectural unit of tissue and the subsequent development of cancer.

In developing quantitative values for hot particles we adopted this risk measurement as the risk for hot particles that when you created a disturbed tissue mass or disturbed tissue architecture that chances of that going on to developing cancer would be 1 in 2,000 as is observed for the disruption of hair follicles.

The next thing which one has to turn to is what really constitutes a hot particle. There again we use the experimental observations of Albert's skin data which indicated there was a precipitous change in respond to dosage when it went above 1000 grams. So that then we use to define that limiting activity per hot particle so that the hypothesis proposed then with the quantitative values for establishing radiation protection standards was if a particle deposited in the deep respiratory tissue is of such an activity as to expose the surrounding

lung tissue to a dose of at least 1000 rems, in one year this particle represents a unique carcinogenic risk.

The biological data suggests that such a particle may have cancer risk equal to 1 in 2000. So this then is how we arrived at the quantitative numbers related to exposure.

Now plutonium 239, a particle which delivers 1000 rems per unit, an oxide particle which delivers 1000 rems per year would be a particle 6/10th of a micron in diameter and containing .07 microcuries. Than then was the basis for establishing the hot particle standard which we proposed to the EPA and the Atomic Energy Commission.

I might say that personally I feel that the observed biological changes associated with hot particles in the palm tissue and in the rat and hamster lungs surrounding these hot particles, these histological changes are sufficient for me to strongly believe that these particles represent a unique carcinogenic risk, and that the uncertainties related to our hypothesis or related to our standards the quantitative values which we selected in order to determine the standards. So the uncertainty is the risk of cancer for disruptive tissue mass comparable to that for disruptive hair follicles.

We selected the 1 to 2000 as the chance of one of these lesions going on and becoming cancer. The other uncertainty is a particle capable of irradiating the surrounding tissue mass at a rate of 1000 rem per year sufficient to produce such a lesion.

We picked the 1000 rem per year because that correlated with the beginning incidents of tumors and atrophied hair follicles in the

Albert experiments.

The second part is the activity that we have selected as the minimum activity to represent a hot particle. The observations of Richmond et al that the microspheres in the lungs of hamsters, these cytological changes which they have observed in the hamsters occurred with particles that were about 60 times or had 60 times more activity in them than the critical particle activity which we selected.

In order to get 60 times more activity in the particle, you have to increase its diameter by a factor of 4, so that then gets us from a 6/10th micron particle of plutonium 239 to 2.4 micron particle which is still in the range where the particle can be inhaled and deposited in the deep respiratory zone.

With high burn-up fuel which would be used in the nuclear power industry, that critical particle size would be smaller, because of the plutonium 238 which contaminates plutonium 239.

So the evidence then would suggest that we really do have a hot particle problem and the question where there would be uncertainties involved, just how critical is that hot particle problem? We see the histological changes in the lung particle sizes which can enter the deep respiratory zone and which can be expected to be produced within the nuclear power industry.

Is the risk of such a particle comparable to the risk of the disruptive hair follicle, something like one in 2,000. We tried to arrive, by using some biological data, at another value for the risk associated with the particle. We were unable to come up with it.

Maybe someone else can. So far they have not. I might say that in terms of the rest of the testimony that has been presented here in these two days, the only testimony, factual information that was presented which was proposed to relate to hot particles dealt with the exposures in the Manhattan workers.

A particle size distribution for the Manhattan workers was presented. No one really knows what the particle size distribution was in those Manhattan workers.

The other thing is, even if they knew the particle size at this point, they do not know what the specific activity per particle was. The particle size distribution which was presented here was one that was comparable to the particle size or was the particle size distribution determined for the fire at Rocky Flats.

So it represented the plutonium oxide particles that were generated as a result of burning plutonium. The studies of Hempelmann describing contaminating events at Los Alamos indicates that the way in which the plutonium was dispersed in the environment was a result -- one of the major sources was adding peroxide to plutonium nitrate solution and aspiration of droplets from there.

When one looks at the concentrations of plutonium in those solutions, you have to have particle sizes for the most concentrated solutions which they used; the concentration varies from one to 40 grams per liter.

The most concentrated one, the 40 grams per liter, the particle size had to be some 5 microns in order to have this limiting particle activity which we have suggested here.

The data which you saw here were for particle sizes above .6 micron, something like a factor of ten below.

Certainly, the Manhattan workers, since they represent some 30 years down the line, we did have some better information about what the nature of the particles that might have been involved in their exposures were. We might be able to shed a little bit more light on this.

But at this particular point, there is really no way of using the Manhattan workers. The information and the nature of the examination would suggest that hot particles as we have defined them were involved, and if a critical particle activity for a hot particle is something like 60 times what we have suggested, well, then, the chances are extremely remote that they were involved in that.

I might say, though, with respect to what the critical activity to make something qualify as a hot particle, that the experiments on the hamsters were involved with animals that had relatively short life spans, and there is no reason to rule out that if particles of lower activity existed in animals with a longer life span, that the kinds of histological changes that were seen in the hamsters would appear at lower and lower particle activity.

Also, there is a suggestion that since none of these hamsters developed a cancer that that tends to rule out the hot particle hypothesis. But there is no a priori reason for believing that the induction time by this mechanism is compatible with the life span of a hamster.

So, that then, is sort of a condensation of the nature of the hot particle hypothesis, following the approach which we used to insert quantitative values into the hypothesis in order to derive exposure standards associated with a unique carcinogenic risk.

With that, I guess I will meet with your questions.

Dr. Mills: Thank you, Dr. Tamplin.

For the record, I would like to point out what you probably already recognize. Under the legislative authority of EPA, with the transfer of the Federal Radiation Council, there is a legislative history associated with that which calls for the administrator of EPA to consult with NCRP, the president of the National Academy of Sciences, as well as other groups. So it is consultation, then.

I am somewhat intrigued by this critical architectural unit petition. A great deal of the hypothesis has been proposed, related, and I assume, you are making a relationship between a hair follicle such as units in the lung.

Would you care to broaden this particular unit in terms of a particle that might localize in other tissues, as what this unit might be?

Dr. Tamplin: I think the observation of Lushbaugh on the single particle embedded in the palm of the mechanic suggests that the critical architectural unit is more diffused in that particular tissue.

I think the same thing applies relative to the observations of Richmond around the microspheres, that the critical architectural unit

in terms of the skin experiments happen to be a hair follicle that was more sensitive to this kind of disruption than was the rest of the skin tissue.

But there is no reason to suspect that other portions of the skin would not also, a particle would not have accrued a disruptive tissue mass of a sufficient size to represent a unique carcinogenic event.

Dr. Morgan mentioned earlier the experience of Finkel in which he injected a microgram quantity under the skin of rats and produced a high incidence of cancer.

There is also the experiments at Argonne which put things such as small pieces of mylar film under the skin of rats and produced cancer.

What you are talking about here is a disrupted tissue architecture. The experiments of Bruse would suggest that you could do this, that with a hot particle you are creating an altered tissue mass which in itself creates or may be creating a new surface which represents a unique carcinogenic move towards the surrounding tissue.

So I would say that on both the lesion and size by Lushbaugh and observations on the rat and hamster lungs suggests we probably should never have used the critical architectural unit kind of thing.

We suggest that this is rather diffuse in some cases.

Dr. Mills: You would expect this to be diffused in the lymph nodes? The particle might be located in the lymph nodes?

Dr. Tamplin: I would not rule out the possibility that there would be such areas within the lymph nodes. At this particular point,

I am only talking about the lung and the observations that epithelial metaplasia and so forth is occurring around the particles deposited in the lungs.

I think the evidence concerning these cytological changes exists.

Dr. Mills: As I understand it, you propose a thousand rems per year constitutes essentially a threshold dose for the induction of lung cancer? I am asking this from the standpoint of a broader issue than the hot particle. Obviously the threshold concept from the standpoint of setting standards has not been adopted.

Would you care to comment on that from the standpoint of the use of a threshold in setting standards?

I am not sure I really understand a thousand rems per year. Is that the lowest dose that will induce the lung cancer?

Dr. Tamplin: We stated in our report that we selected this because this was where there was a precipitous change that occurred in the Albert data, and in my presentation here, I indicated that when you use that, you arrive at a certain particle activity.

The observations of Richmond at this particular time, he has observed that these cytological changes around particles are about 60 times the minimum activity which we selected.

That is one of the uncertainties in there. We also say in this nothing about particles of lower activity. That does not mean something that delivers 990 rems is innocuous. As a matter of fact, I think someone like Ed Martel would pick up on that end of the spectrum and propose a new hypothesis associated with particles of lower

activity than the ones we are suggesting.

We in this particular case were trying to define the biological consequences of the effects of particles of a particular size. Any inference about lower particles or so forth, I do not think can be made from the information.

Dr. Mills: I think it would be interesting, have you received any comments, either you or Dr. Cochran, from Dr. Albert or Dr. Lushbaugh as to the interpretation that has been applied to these?

Dr. Tamplin: Ever since we submitted this report to the EPA and AEC, we have been treated like lepers. There have been many opportunities.

When we submitted it, we had hoped that what this would do would be to begin a constructive dialogue that might lead to resolution, and that is why we welcomed the chance to come here.

We can begin with the sequence of events. This is in the material you have. In our critique of the Bair, Richmond, Wachholz report, WASH-1320, we go through the background of this.

I might read it since you asked the question. On February 14, 1974, the Natural Resources Defense Council petitioned the Atomic Energy Commission and the Environmental Protection Agency to amend their radiation protection standards applicable to hot particles, plutonium and other actinides where hot particles were defined more fully in the accompanying reports.

I will skip over that. That is what happened on February 14.

On March 15, 1974, the AEC released its draft of the Liquid Metal

Fast Breeder Reactor Environmental Impact Statement. This statement contained a 15 page discussion of the hot particle problem. This discussion, based on an earlier report by John Healy of the Los Alamos Scientific Laboratory, was used as justification for ignoring the approach taken in the Tamplin-Cochran report for estimating lung cancer incidents associated with the inhalation of plutonium particulates and using instead the assumption of uniform lung exposure, even where hot particles are concerned.

On March 28, 1974, the AEC gave notice in the Federal Register of NRDC's filing its petition and requested public comment.

On April 16, when NRDC submitted to the AEC a critique of the hot particle in the draft LMFBR environmental impact statement, since the hot particle discussion in the draft statement drew heavily from the Healy report -- As a matter of fact, much of it was produced verbatim -- the NRDC comments were a critique of the Healy report itself.

On August 5, the AEC said it was releasing a draft impact statement on mixed oxide fuel, which they called effectively draft GESMO, and NRDC in a letter of February 21, 1974, requested the AEC to give this generic environmental statement full and candid discussion of the recommendations supporting evidence presented in the NRDC division and accompanying report.

In the draft GESMO, just as in the draft LMFBR, the uniform exposure assumption was used to calculate the lung cancer risk for hot particles.

The first paragraph from the final quote from the draft GESMO gives justification for this assumption, and the remaining two paragraphs describe the AEC's treatment of the NRDC petition and the Tamplin-Cochran report.

I will not read this whole thing, but I just wanted to say that what occurred there was, in the draft GESMO -- This is now put out some six months after we responded to the draft, the LMFBR statement, they put the Healy report in the draft GESMO and totally ignored our comments on the Healy report.

Finally this comes out, WASH 1320, this is coming out now, about eight months after we have submitted out comments on the Healy report. It covers much the same material that was covered in the Healy report and which we commented on.

In this they did not acknowledge any of our comments. They have absolutely refused, and I say this applies to EPA, they have absolutely refused to engage in a dialogue with us.

So here we are here today for the fifth time, repeating the same argument, and hearing the same ones.

Dr. Mills: I am afraid you interpreted my question much too broadly.

What I specifically asked you was, had you in fact had any comments from Dr. Albert or Dr. Lushbaugh?

Dr. Tamplin: As I say, we have been treated like lepers. We have received no comments from anybody, EPA or anyone.

As a matter of fact, they had a meeting on plutonium at Los Alamos, and it was by invitation only. Of course, we were not invited.

We have been around. People could have written to us, and we could have responded.

Dr. Mills: OK. I have no further comments.

Dr. First?

Dr. First: I have none.

Dr. Mills: Dr. Radford?

Dr. Radford: Arthur, some years ago, you and John Gofman submitted a number of critiques of the then existing radiation standards for population distribution in general.

One of the critical issues that you raised at that time was the concept of the doubling dose for radiogenic cancer. Is that correct?

Dr. Tamplin: Yes, we indicated that our impression was that the available data would support the idea that all forms of cancer, the natural incidence of all forms of cancer, would be doubled by the same level of radiation.

Dr. Radford: Without taking anything away from the value of the analysis you did, do you still believe that that statement you just made is correct?

Dr. Tamplin: I have not seen any solid information at this point which would cause me to change that. I might say that I do not feel, in terms of the issues that we were raising and in terms of setting radiation protection standards, that that was an hypothesis upon which

the effects of radiation had to live or die.

I would say that certainly the hypothesis has not been proven, but at this point, I have not seen any sufficiently cogent arguments causing me to reject it, based upon the available data.

Dr. Radford: As you know the BEIR committee went through an exercise very similar to what you and John Gofman had gone through and they reached a conclusion that the doubling dose was not constant for different types of cancers.

Different organs or different tissues within organs would respond differently to the same radiation exposure.

Have you read that section?

Dr. Tamplin: I read that section and, quite frankly, I think they have milked the data for a little bit more than it was worth.

I was somewhat concerned about the dosimetry approach that they used with respect to spondylops. At the same time, the answer that they came to in terms of the practical problem of radiation protection was not all that different.

So, so far as the biological effects of radiation are concerned, I feel that their committee report is a perfectly adequate document for reasonable people to make reasonable judgments on.

I think the disagreements I have with it are more academic than practical.

Dr. Radford: One rather important academic or practical conclusion germane to today's discussion is the reading of sensitivities of differ-

ent tissues. That is the point I am trying to get at.

Do you believe that different tissues in the body, in man now, the available human data, differ in their likelihood of developing cancer when the radiation exposure is, as far as we can evaluate it, approximately equivalent?

Of course, one of the biggest groups where we can do this clearly is the Japanese survivors, where they all got the same kind of exposure, even if it might differ in quantity. There, the evidence is clearly that certain types of cancers are not increased whereas other cancers are very significantly increased.

Dr. Tamplin: The evidence which I have looked at and which was most compelling to me at that time, you might say I have not checked back in on the atomic bomb casualty commission data, I figure I would wait another few years because, among other things, I would like to see the people who were very young at the time of the exposure.

I would like to see their subsequent experience in terms of cancer, but anyway, I recall back when I was first learning radiobiology that they were talking about radioresistent tissues and radiosensitive tissues.

At that particular time, the leukemia in bone marrow was considered the most radiosensitive because you found a lot of leukemias. A radioresistent organ was called a thyroid gland.

It was not very long after that that they began to find these thyroid cancers in children who were irradiated in the sinus during infancy. Anyway, when they finally put the radioresistent organ and

this radiosensitive organ together, they calculated the number of cancers per rad, it turned out to be the same for both of them.

So, I became a little bit skeptical of that at that time.

Dr. Radford: We can all have our opinions about what statements have been uttered by people in the past. That is not really what I am trying to get at here.

Dr. Tamplin: I do not understand exactly what it is you are trying to get at. I have not, at this point, and I am willing to be convinced by the evidence, but I have not set aside the idea that there is a doubling dose related to carcinogenesis.

I understand this is modified by things like synergism and so forth, and I do not think that the data in the BEIR report and the analysis in the BEIR report sets that aside at all.

But I agree that the consensus of the BEIR committee was that the doubling dose concept was not applicable.

I might also say that once I saw that, I was working on other things, I have not gone back through the data in any great detail.

Dr. Radford: But the implication of your written material and, to some extent, your oral material today, was that there were critical, self-divided groups in the skin which would be more at risk, and that specifically was the hair follicle.

Now, would you say that the hair follicle is more at risk than other tissues in the skin or not?

Dr. Tamplin: I see what you are getting at there.

Yes. I would say the hair follicle was such that the mechanism involved there, in those terms, the hair follicle was the one that developed the tumors, as they increased the radiation dose and killed over the tissue there irradiated, forms of cancer began to appear from the underlying tissue.

So I would say certainly the observations in terms of the experiments conducted by Albert indicated that the hair follicle developed cancer sooner than the other tissues did. Yes.

Dr. Radford: Sooner, in general, would mean that it is more sensitive?

Dr. Tamplin: OK. If you want to define it, it is the same way leukemia occurred much earlier and thyroid cancers and so forth.

Dr. Radford: With regard to the problem of setting air or other standards for plutonium in soluble particles, what specific tissues -- where do you expect the problems lie?

Is it because you are concerned with particles getting embedded in the skin? Or how are you going to regulate that?

I would like to know where you think the problem is. I have read it in your material. I would like to get it from you personally.

Dr. Tamplin: Our petition was specifically related to inhalation and particles in the lung. Certainly I think the particle that was excised by Lusbaugh suggests you would not want to have 200 or 300 of those particles embedded in the palm tissue, but our petition was directed towards the lung.

Dr. Radford: Now, in the lung of man, do all tissues show the propensity to produce cancer?

Dr. Tamplin: You are bringing it down from organ tissue. As you indicated yesterday, the major ones are pulmogenic carcinomas and the uranium miners; there would be different kinds.

Dr. Radford: And the gas workers, and the metal workers, and various other workers. But let us leave the histology out for a moment. We have enough problems as it is.

The point is they arise from the bronchial cells, correct?

Dr. Tamplin: Yes.

Dr. Radford: So that the question at issue is what is the specific dose from a particle going to do to bronchial epithelia tissues. Is not that correct?

Dr. Tamplin: I am not sure that we are talking about what a specific dose does. The whole effect, in this particular case, may be mediated by radiation injury or killing of cells in the development of a lesion, rather than, say, a carcinogenic mechanism caused by the radiation effect.

Dr. Radford: But the cell damage might occur by a subpleural particle, and might not be likely to have any effect on the bronchial epithelial, say.

Dr. Tamplin: I do not know what the dimensions are involved.

Dr. Radford: I am trying to get at the point, where does the damage occur?

Dr. Tamplin: The particle is deposited in the alveolar tissues below the ciliated bronchi where it is deposited in there.

Dr. Radford: But cancers in man do not arise from alveolar tissue, except extremely rarely?

Dr. Tamplin: Yes. And the particle is lodged in there and it creates a disturbed tissue mass.

Dr. Radford: We have a great many disease processes that lead to disturbed tissue as architecture in the lung, yet they are not associated with cancer in that site.

For example, in an asbestos worker, they do not develop cancers in the alveolar cells even though they have asbestosis. They develop it in the bronchi, right?

Now, I am trying to get at the question, if you inhale insoluble plutonium particles, how do you postulate that they are going to produce the disturbed architecture and the radiogenic changes in a tissue which would be sensitive to carcinogenic change?

You have indicated that they are deposited in the alveoli, as I have tried to point out --

Dr. Tamplin: You are proceeding mechanistically.

Dr. Radford: You cannot say just because you handle a particle, you are going to get cancer at some remote point. That would have to be a scope or effect, the likes of which I do not know.

Dr. Tamplin: We would expect that this particular particle radiates a tissue mass and causes much the same as we saw on the palmer tissue or as the particles in the Richmond experiment which were

deposited in the capillary bed produced this epithelia metaplasia.

Dr. Radford: But the changes in the Richmond studies were in tissues that do not have epithelial hyperplasia or growth. There may be modifications in the cells, but it is not a point at which cancers normally arise in man.

There are differences between animals and man. I do not want to get into that in detail here. I would prefer to get with Dr. Bair on this, but the point I am trying to get at here is, to my knowledge, in general, environmental effects on lung tissue have not produced cancer except in the bronchial tissues or in the mesothelium cells, not in the lung itself. Would you say that is a fair statement?

Dr. Tamplin: I would have to confess that my knowledge of that, I cannot answer that question at this time.

Dr. Radford: Let us assume that it is the bronchial epithelial tissue at risk here. Then the question is, how would you postulate that an inhaled plutonium particle would affect the likelihood of bronchial epithelial undergoing a malignent change?

Dr. Tamplin: It depends upon if you want me to affect that directly, one would have to look at where the particles were ultimately deposited.

As I recall some of the observations that were made, for example, one of the things they suggested was the particles were kind of moved around and eventually, they are engulfed in macrophages or in the epithelial cells. One would then have to --

My problem at this particular point is I do not have the dimensions of this thing perfectly well in mind. I can see a particle deposited in the alveolar space near the terminal bronchi, which is killing cells in a broad area.

Dr. Radford: Forty microns?

Dr. Tamplin: No. It would be bigger than that because of the spongy nature. I do not think that at this particular point I will be able to answer your question.

I am going to have to think about it some more.

Dr. Radford: In other words, the model which you presented on deep lung deposition really referred to alveolar deposition and retention?

Dr. Tamplin: Yes. Because the indications are it's only in the deep respiratory zone below the ciliated bronchi that this resting time exists.

My knowledge at this particular point of the dimensions of what we are talking about --

Dr. Radford: In other words, if I may summarize briefly what you have just said, your model postulates a certain deposition in the alveolar tissue, with a radiation of that type of tissue predominantly, leading to cancer?

Dr. Tamplin: I do not say it predominantly. I simply, at this point, would not want to agree that that is what we are saying at this point.

Dr. Radford: Can you make any other statement as to what might

occur in terms of the risk to individuals inhaling insoluble particles?

Dr. Tamplin: No. As I say, you can see what that is based upon. I would like to go back and look into this aspect of this question which you raise here.

Dr. Radford: We may, if we have time, get some comments from other panelists, the AEC representatives, which may help you out a little on this.

You are familiar with the fact that Dr. Albert did some earlier epidemiologic evaluation of children irradiated for ringworm in the scalp and found some skin cancers?

Do you recall what the dose was which those children received?

Dr. Tamplin: No. I did not review that particular work. I also understand that subsequently they developed some pyschological problems.

Dr. Radford: Psychological problems, too, yes. That is direct evidence in man of the carcinogenicity of radiation on the skin.

The reason I bring that up, is there any reason to believe that the skin has a somewhat different dose response curve than other tissues? More of the threshold type, or likely to have?

Dr. Tamplin: I cannot postulate any reason for suggesting that the skin --

Dr. Radford: Basing it upon experimental evidence, such as it is, in man?

Dr. Tamplin: Not to my knowledge.

Dr. Radford: As you know, skin cancer was one of the first radiogenic cancers that have been described?

Dr. Tamplin: Yes.

Dr. Radford: So far as we can see, it does appear that the skin is somewhat more resistent to an overdose, at least, this is a tenable hypothesis compared with other tissues in the body where significant effects have been observed at low doses.

And, indeed, the animal experiments of Dr. Burr showed earlier seem to show that with relatively low doses, carcinogenic cancers can occur.

I would like to come back to this question of the significance of your thousand rem per year. Is there any reason why you put a per year on that? In other words, why is there a critical dose rate?

Dr. Tamplin: The basis for that was it may seem to suggest that that was a reasonable terminal turnover rate for the epithelial.

Dr. Radford: Except in a number of tissues that are not greatly turning over more rapidly than that or the same as in the case of the bone cells. We have heard about the radium-224 data that protracting the dose does not seem to have very much effect.

It may have in some cases an enhancing effect, and in other cases a slightly less enhancing effect. But traditionally, and in keeping with the ICRP view of these things, protracting the dose for high L.E.T. radiation does not really change the cancer. It is the total accumulated dose.

Would you agree with that?

Dr. Tamplin: Yes. The reason for selecting, putting the one year on there, again, as I say, we were postulating as a mechanism here. It was more of an injury media mechanism, rather than a biological transformation of cells into carcinogenic cells as a result of the radiation.

Therefore, the idea was in that respect that this would tend, then, to kill essentially a large fraction of the cells within the irradiated body, so that is why we were concerned with what was representing turnover time.

I say that is one of the uncertainties that are involved here: What constitutes a hot particle?

Dr. Radford: In other words, if I can put it in another parlance -- I will let you agree or nor agree -- At high enough doses, ionizing radiation acts as its own co-carcinogen. Would you go along with that as a statement?

Dr. Tamplin: I have heard that, yes, that you both damage tissue --

Dr. Radford: You transform some cells and you destroy the architecture. Is that, in essence, what you are saying?

Dr. Tamplin: I think it is plausible. I do not think it is necessary in all cases that both things happen. It is possible in the case of these particles that that does occur, but I do not think it is necessary that both events occur.

Dr. Radford: But you implied that there had to be a disturbance in the normal architecture as a necessary condition, which is almost

the same thing.

Dr. Tamplin: OK. In other words, it was simply that changed architecture as a potential carcinogenic mechanism, such as the mylar film --

Dr. Radford: What I am really trying to get to is the question, what about the smaller doses or dose rates, or what about the other isotopes like plutonium 238 which would have a higher dose per unit volume?

Would you expect that plutonium 238 would have a higher rate or a lower rate than plutonium 239?

Dr. Tamplin: On a per particle basis?

Dr. Radford: Let us put it on a per curie basis, although that is a little difficult because, obviously, the particles are --

Dr. Tamplin: A particle of plutonium 238 which was not sufficient activity would be no more or no less than plutonium 239.

Dr. Radford: Yet a particle of plutonium 238 would be substantially smaller, I think. I have calculated quickly.

Dr. Tamplin: Yes. It would be.

Dr. Radford: About one 300's of a volume, so it would be around -- I cannot do it quickly. So, in other words, a particle of plutonium 238 would have a much smaller volume, would deliver your thousand rems a year from a much smaller particle?

Dr. Tamplin: But if you took a particle of plutonium 238 that was one micron in diameter, a particle of 239 which was one micron in diameter, we would suggest that the effects would be the same.

Dr. Radford: But the activity is much greater?

Dr. Tamplin: The activity would be much greater, but it is the particle that is involved rather than the activity.

Dr. Radford: Then, in other words, the dose distribution around the particle is really not critical here?

Dr. Cochran: Let me say I believe you are trying to read more into the model than we thought the biological data suggested.

You could say the biological data is poor. Everybody admits that. We tried to build a model and assign some risk numbers on the basis of available data.

I think you are carrying this beyond what we thought at the time we could build into the model from the available data. We assigned a risk per particle and made that the same risk per particle regardless of the activity level of the particle, as long as it was above some minimum activity level sufficient to disrupt the architectural structure which in turn carries some probability of developing into a cancer.

Your questions are useful questions, but is sounds like you believed we had more depth into the model than we really did.

Dr. Radford: I am beginning to get that impression. Yes. But I still think in contrast there is a good body of information. The sophistication of dosimetry that has been applied experimentally, even in man, to radiogenic cancer is a very high level indeed.

In effect, what you are saying is that dose is not germane to this issue, which I find difficult to believe.

Dr. Tamplin: In this particular case, I do not know that we are

proposing a novel mechanism for carcinogenesis. Other people have suggested injury media mechanism before. We feel that the particles are involved in a different mechanism of carcinogenesis than uniform radiation or more uniform radiation tissue, with the same number of curies.

I am proposing that the mechanism involved here is identical with this other mechanism for carcinogenesis.

Dr. Radford: What you are saying seems to imply to me that if you have particles below a certain critical diameter, then everything is all right.

Dr. Cochran: No. We just meant we offer no opinion. We offered an opinion where we believe the available biological data supports the hypothesis and a petition to EPA and AEC to amend the standards. We offer no opinion on some of these other areas.

Dr. Radford: All right. If I may summarize now, then I will pass on the microphone here.

If I may summarize, you are saying on the basis of a skin radiation effect, predominantly by Albert, you come out with the impression that a hair follicle constitutes a significant target for radiation, and that from his data, you infer that about one in every two thousand, when radiated above a thousand rems, and he really did not work very much below that, incidentally -- so you cannot say on lower doses what might have been expected.

On that basis, then, you translate that to a risk factor for particles deposited in the alveoli of man. Am I correct in that bridge

there?

Dr. Tamplin: As I indicated, if you want to develop radiation protection standards, in order to do that, you have to assign some risk value.

Now, the risk value which we used was related to this disrupted tissue architecture that derived from the alveoli. That said that if you have a disrupted tissue mass that the chance of it developing into cancer was like one in two-thousand.

It is one of the uncertainties in this thing, as to whether or not that happens to be a number which is available which relates to disturbed tissue architecture, to cancer.

The other uncertainty in it involves the size of the activity of a particle that is required to produce this disturbed tissue architecture.

There are other mechanisms of the biological effects of radiation that one can postulate, but this is the nature of our hypothesis and the nature of the data that we used to quantitate it in order to arrive at numbers that would be available for setting radiation protection standards.

It is uncertain, and this question about particles below the critical particle size, we come to no conclusion on, in that respect.

Dr. Radford: What was the nature of this disturbed architecture in Albert's experiments?

Dr. Tamplin: He said the tumors that developed were similar to those, and he plotted it, atrophied hair follicles versus tumors.

Dr. Radford: But the disturbed architecture, then, was atrophy?

Dr. Tamplin: That is how he described it, yes.

Dr. Radford: But atrophy simply means the cell division has stopped, which in those doses it almost certainly would have. Is that disturbed architecture?

Dr. Tamplin: Well, certainly. In other words -- I am afraid I do not --

Dr. Radford: The implication from your hypothesis, as I understand it, is you get liquefaction of tissue, you get actual radiolysis of tissue. That is very different from atrophy of a hair follicle, from simply stopping cell division, is not it?

Am I wrong in assuming that one of the disturbed architectural features that you are describing is the very intense radiation exposure right around a particle where it is killing cells?

Dr. Tamplin: And creating a lesion.

Dr. Radford: That is very different from atrophy of a hair follicle. Would you agree?

Dr. Tamplin: Not necessarily. No. I would not necessarily agree with that. I would be willing to look at some other approach towards determining what the risk, say, associated with these cytological changes that are observed around these particles are.

That happened to be a number which was available that represented disrupted tissue and subsequent cancer. It may be there may be better choices.

Dr. Mills: Dr. Garner?

Dr. Garner: Dr. Tamplin, let me tell you that when I first read your petition, there were several things that troubled me. I guess it started off with this tremendous leap from effects, let us say, of about 1,000 rems of electron radiation delivered in a few hours to skin, to the effects of a 1,000 rem delivery over a year to a lung.

But the thing that bothered me most, I think, was that you simply had not reviewed all the literature. You made the statement that you and Dr. Cochran had noted all the information available, but you had not read all the information available, to my mind.

You mentioned -- Many of them, I agree, but there are several which suggest strongly to me that non-uniform radiation is less effective than uniform radiation.

Above all, the thing that seemed most significant to me was that you built the entire hypothesis practically on Albert's experiment with electronic radiation of skin. Yet you have omitted to refer to one paper which was specifically addressed to this tissue, one which appeared in Radiation Research, Volume 30, 1967.

This was work on tumor formation from electronic radiation in a rat. It addressed itself specifically to this problem.

Its introduction starts off: "The cancer hazard arising from occupational exposure to ionizing radiation is almost never associated with a uniform distribution of dose in exposed tissues. Non-uniform radiation patterns may take extreme forms. In the case of radioactive

particles in the lung, the dose to very small volumes of tissue close to the particles may be thousands of times as high as the average for the organ as a whole."

It goes on to say, "The extent of the cancer risk from such highly non-uniform dose distributions is called the "hot particle" problem in the field of radiological health protection."

It came up with the results, and I quote from them. It states the observations suggest that "at very high non-uniform pattern radiation doses the skin responds as if it were uniformly irradiated, but at lower doses the observed tumor yield following non-uniform radiation can be considerably below the predicted level."

Dr. Tamplin: If I am not mistaken, we did discuss the sieve pattern which Roy Alberts performed. They indicated when they used the sieve pattern, carcinogenic response was suppressed.

Subsequently, there were some additional experiments which were done. One of the problems with the carcinogenic response seemed to be dosimetry because of the high scattering of electrons.

In the proton experiments, the carcinogenic response was not suppressed in the sieve pattern. The presumption there was that the dosimetry was better understood.

What was the volume on that?

Dr. Garner: Volume 30, page 525.

Dr. Cochran: That is our reference 35 in "Radiation Standards for Hot Particles."

Dr. Garner: What I was really getting at, it seemed to me to be

rather a one-sided review of the information available.

You have not made use of all of the information available. That is how your petition struck me.

Dr. Tamplin: We did not reference all the information. Some of it, we thought, was not relevant. It does not mean that we have not looked at it.

Dr. Garner: But you did not give the other side of the picture.

Dr. Tamplin: In proposing this, we did not say we had proven anything. We said this is a hypothesis that seems to be supported by observations, and presented information which we felt was supportable.

Dr. Cochran: I might add, there seems to be some confusion between a hot particle hypothesis, as we have proposed it, and this concept of uniform versus non-uniform dose on a per microcurie basis. We tried to discuss and clarify this issue in our critique of WASH 1320. There are numerous experiments on uniform versus non-uniform dose, which suggest that when you analyze it on a per microcurie basis, the more spread out the dose, for example, spreading the activity on more particles, the higher the tumor incidence. But these data can be exactly consistent with the hot particle hypothesis. The point is you are examining tumors per microcurie, whereas the hot particle hypothesis is based on tumors per particle. So it is not particularly relevant to say such and such an experiment sees a higher tumor risk with more uniform exposure. That could be consistent with a hot particle hypothesis. If you take the same activity and put in on more particles assuming there are hot particles you get a higher tumor

risk according to the hot particle hypothesis. You really have demonstrated nothing, that is to say, you have not tested the hypothesis.

Dr. Garner: So that is one point of view.

Dr. Mills: Dr. Morgan?

Dr. Morgan: Most of the questions I might have asked have been addressed.

In interest of the lateness of time, I will refer to your statement, Dr. Tamplin, that we should have a quantitative approach to the risk in hot particles.

I think we all agree to this very much. It is a question -- certainly Herb Parker and I and a few others have lived with it for over 30 years, and worried and wondered about.

There have been many other questions of similar importance that we have had to face in setting our radiation protection standards.

You indicated that you and Dr. Cochran and perhaps others, because of the position that you are taking, that you were looked upon as lepers. Certainly not in my eyes -- not through my eyes do I look on you that way.

You tell me when the time comes that all people that are willing to stand up and take a position are ruled out -- When this is no longer possible, then I will tell you the time when there is no longer democracy, because I think it is very essential that we have people like you around to believe in something and take a position, and enable us to thrash these things out.

Some years ago, six or seven years ago, you and Gofman suggested

that the environmental exposure level of 500 millirems per year should be reduced by a factor of ten.

Well, independently, the Atomic Energy Commission reduced the exposure factor by 100. They went one better than you.

I rather doubt now, from any information that I have seen, that they will reduce the figure that you have suggested, reduction factor of a ten to the fifth, and suggest a factor of ten to the seventh.

We have similar questions, of course, to the hot particle question that we have had to address and to live with for many years. Even in external exposure, there is a question at times of whether to take a surface dose, the average dose, the mid-line dose, the gram-rem dose, or the gram-rem dose average.

We really do not know which best repesents the risk, to man or to animals. So basic questions like this still remain to be resolved, but this is not unique to ionizing radiation.

You have even more when it comes to the environmental pollutants that we have to deal with. When it comes to internal dose, the internal dose committees of ICRP and NCRP have made a number of simplified assumptions, hopefully that they were justified on the basis of limited biological data.

For example, the average dose over an entire organ, we knew this basically is not what we would like to do. The kidney is not really one organ, but we average the dose to the kidney over the entire kidney.

If we had more biological data, if more hundreds of millions of

dollars could be spent on research, and perhaps some time it will, then we would treat these as separate organs and average over the different components.

When it comes to bone, we are doing a little better through the years. Thanks to the biolgoical data that has been accumulated at Hanford and at Salt Lake and at a number of other laboratories, we now believe that we might be justified in averaging the dose to the tissue, and the Commission suggested averaging it out to a distance of ten microns in this tissue.

This seems a rather arbitrary approach, but maybe we are getting a little closer to the target that we are shooting at.

Then, when it came to the question of lung dose, as has been pointed out by several of the very fine papers here today, when insoluble material like plutonium dioxide goes into the respiratory system, a large fraction of it ends up in the pulmonary lymph node.

Even in some human cases, considerable amount of plutonium in soluble form is localized there. But the International Commission, again, has wrestled with this problem through the years, for over a decade, and suggested many different solutions. But we never found a satisfactory one other than it appears at the present time, from the data that we have at hand, that the lymphatic tissue is not a likely target for these malignancies.

They do not seem to show up in animals. They do not seem to originate in these particular cells, even though they received very large doses. To me, this was the most satisfactory argument for not

using the pulmonary lymph node as critical tissue although the doses would be in the order of thousands of rads compared to some 15 rads per year to the average lung.

So, from step to step, in setting standards, we had to make what appeared to be rather arbitrary decisions, but we tried to base them on what the observations are in animals and in man.

So, for example, with an alpha particle, we would not dare suggest that you take a dose along the track of alpha particle, even a dose of a cell through which the alpha particle passes, because it receives roughly 100 rads.

So we have to make a decision then. What body of tissue are we going to take? Some decisions are poor; we hope that most of them are decisions that we and our grandchildren are about to live with.

I do not believe at this present time that we have enough information to accept a radiation protection standard based on the localized dose, as we defined it, hot particle implanted in tissue.

I do believe, though, that there is good evidence that plutonium in bone in very small quantities leads to very high incidence of tumors. Why you do not get similar results when plutonium is contained in hot particles in the lungs, to me, remains an unanswered question.

I think that there are really other unanswered questions besides the hot particle problem, but I certainly do not believe that there is sufficient evidence to reduce the permissible exposure levels for plu-

tonium in the lung or the body burden on the basis of the evidence that we have today.

At this time, maybe you would like to comment?

Dr. Tamplin: I understand what you are saying.

I have a philosophical problem with that, though, and that is by not setting the standard, you in effect set one. In other words, by saying that there is not enough information available at this time to set a standard for hot particles, you are in effect setting a standard.

I guess what you are really saying is that you do not feel that any changes you have made because of hot particles would be significant. Therefore, you do not feel compelled at this time to set a standard for them because in your gut you feel that such a standard would not be very different from the one that exists today because, in effect, by not setting one, you are setting it, it seems to me.

Dr. Morgan: Of course, I do not speak for the International Committee, but I think their response might have been for some unknown reason, the risk when plutonium in past specific activities localized in the skin of animals, and at least one case in man, the risk seems to be rather large in skin. But this does not seem to be the case in the lung because, as Dr. Radford pointed out, the tissues behave differently. There seems to be some difference there which at least I do not understand.

On this account, then, they feel it is satisfactory to continue the present practice of averaging the dose, not only of the hot

particle, but also that delivered from the plutonium contained in the lymph nodes over the entire lung.

Dr. Tamplin: It does not seem like there is any comment I can make on that.

We made our proposal and submitted our petition. As I say, there are certain philosophical aspects of this which, personally, my gut feeling says that these hot particles may represent an undue hazard.

Hopefully, what will happen now is more information will be brought to bear on the subject, so that another 30 years from now we would not be talking about the Chalk River conference which was 30 years ago.

It seems to me that as we look at what is potentially going to happen, the rapidly expanding plutonium industry, that we have to come to grips with the problem today because if you do have the industry, it has to be designed around certain exposure standards so that the idea that you can wait another ten years, I do not think that is true.

Some decisions relative to this have to be made right now. The decision may be that Dr. Cochran and I are greatly overestimating the risk and the existing standards are apt.

Dr. Morgan: Or it might be that 30 years from now, when we reconvene here, that we will have discovered that the real problem with plutonium in the lungs is that it localizes in large measure in the lymph nodes which serve as reservoirs.

Then you have leakage to the skeleton and the liver and here is

the problem of chronic environmental exposure.

Dr. Mills: Let me thank you very much, Dr. Tamplin and Dr. Cochran, for this time.

Next on the agenda, we have speakers from the Atomic Energy Commission.

Heading this group will be Dr. Jim Liverman. If any of you have written statements, it will help the reporter.

276

Introductory Testimony
by James L. Liverman
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part of the AEC presentation at the
EPA Plutonium Standards Hearings
Washington, D. C., December 10-11, 1974

My name is James L. Liverman. I am Assistant General Manager of the Atomic Energy Commission with responsibilities for biomedical and environmental research, waste management, and safety programs. I will provide introductory testimony and will be followed by members of AEC and contractor staff who will provide more specific and detailed testimony. Mr. Lester Rogers, who will represent the regulatory and licensing activities of the Atomic Energy Commission, is scheduled to testify tomorrow.

It is our understanding that these hearings are being held to gather information relevant to EPA's intention to evaluate whether new guidelines and standards are needed to assure adequate protection of the environment and public health from potential contamination of the environment by radionuclides of the transuranium elements. Judgments by EPA regarding new guidelines and standards for transuranic elements will influence development of nuclear energy to help meet nationwide energy needs, national security programs, and other matters of substantial importance to our society.

Public concern regarding the manufacture and use of transuranium elements is, I think, based on several facts.

1. Increasing quantities of the transuranics are being produced, and the rate of production will increase substantially in the foreseeable future

as nuclear fuels provide a growing fraction of our national energy requirements.

2. Several radioisotopes of plutonium and other transuranic elements have exceedingly long half-lives and, once released, will persist and accumulate in the environment for time periods extending over many human generations. This is, of course, also true for some naturally occurring alpha-emitting radioisotopes such as those of radium and uranium.
3. These naturally occurring alpha-emitting radioisotopes are known to produce cancer of the lung, bone, and liver in humans exposed to large concentrations.
4. Comparable concentrations of alpha-emitting transuranic elements are known to produce cancer of the lung, bone and other organs in experimental animals.

These facts make it clear that, in operations involving the production and use of transuranic elements, bioenvironmental health and safety considerations are necessarily of primary concern. This point was recognized at the very outset of the nuclear age -- when some of the first plutonium made was turned over to biomedical investigators. Since that time (in 1944) bioenvironmental and control technology programs have proceeded in parallel with and have guided engineering development of the nuclear technology. More than thirty years of research and development have produced a substantial fund of knowledge and understanding regarding the health and safety aspects of operations involving the production and use of transuranics. Through application of this knowledge, experience, and understanding, it has been possible to establish health and safety (radiation protection) procedures which have permitted many thousands of kilograms of

plutonium to be produced and processed, and we have yet to identify successfully a major health consequence attributable to its radiotoxicity. This record contrasts sharply with that for the commercial use of radium earlier in the century where manufacture and use of a few grams resulted in extensive occupational exposures and many cases of cancer.

I would like to make five points regarding the setting of standards, criteria, and guidelines for the transuranium elements and comment briefly on each.

1. Meaningful judgments on the adequacy of current standards and guidelines must be based in part on the knowledge and understanding acquired in the course of nuclear development including the research in the life sciences. This knowledge is extensive; it cannot be presented, evaluated, or even adequately summarized in a few days. It is, however, available to all, and specific measures have been taken to assure accessibility and to expedite wide dissemination of this information.

   For example, Nuclear Science Abstracts (NSA) contains well over 10,000 references on all aspects of the physical, chemical, environmental, and biological properties of plutonium and other transuranic elements. RECON - a computerized bibliographic searching system -- permits rapid access to NSA and other bibliographic data bases from terminals dispersed widely through AEC, its contractors, other Federal agencies, and some universities.

   There are in addition to this broad bibliographic base a number of specialized information centers relevant to the collection, dissemination, and evaluation of information on the transuranic elements. These include the data base on comparative metabolism of plutonium maintained

at the Comparative Animal Research Laboratory of the University of Tennessee and the environmental plutonium data base, the Information Center for Internal Exposure, and the Nuclear Safety Information Center, all located at Oak Ridge National Laboratory (ORNL). ORNL also maintains direct access to the "Tox-line" and "Med-line" systems and computer information systems of the National Library of Medicine.

To have another example, scientific meetings provide an important opportunity for information exchange. In 1974 alone, five meetings devoted to (i) the biological effects of internally deposited alpha-emitters, including the transuranium elements, (ii) plutonium in the environment, and (iii) radionuclide carcinogenesis have been held this year (at Los Alamos, Richland, Seattle, Alta, Utah, and Las Vegas). Proceedings of these meetings are published in the AEC Symposium series or by the sponsoring laboratory. Meetings of professional societies also provide opportunities for exchange of scientific information. Numerous international meetings on the environmental and biomedical effects of the transuranics have been sponsored by the International Atomic Energy Agency.

Finally, there are monographs on this subject, an instance of which is the recently published volume of the Handbook of Experimental Pharmacology entitled, "Uranium, Plutonium, Transplutonic Elements."

2. The next point I wish to make regarding the setting of standards relates to those organizations independent of government which have played an essential role in the analysis of much of the relevant

biomedical and environmental information and in the development of the standards, guidelines, and general procedures which are currently used for the nuclear industry. It is essential that the objectivity which these organizations represent continues to be involved in this process.

These organizations include the United Nations Scientific Committee on the Effects of Atomic Radiations, the IAEA, the International Commission on Radiological Protection (ICRP), the National Council on Radiation Protection and Measurements (NCRP), and the National Academy of Sciences (NAS) through its various committees. All of these address themselves to the analysis and evaluation of pertinent data. More so than the others, the ICRP and NCRP are involved in the development of radiation protection criteria and standards. From time to time these organizations consider special issues such as the "hot particle" issue now under consideration by a committee of the NAS.

3. Judgments regarding the adequacy of current guidelines and standards need to be based on evaluation of the results of their application to specific development and operational activities and in regulation. Particularly in the case of plutonium already in the environment the establishment of additional "generally applicable" standards may not be as effective an approach to cost-effective control of radiation hazards as can a case-by-case analysis based on current standards and guidance. Our experience suggests that in such situations specific circumstances such as physical and chemical form of the material, climate, and current and projected land use are highly variable and site specific. Each of these circumstances may exert an important influence on the

practicability, including cost-effectiveness, of alternative remedial actions. Since the number of contaminated sites is likely to remain small, it might be more effective to deal with these situations on a case-by-case basis using current standards than to attempt to develop additional standards and guidance generally applicable to all of them.

If additional guidance is developed for this purpose, it would be essential that it include the flexibility required to assure effective application in widely varying circumstances.

4. Despite the citation in Point 1 of thousands of references, information on the biomedical and environmental behavior of plutonium and other transuranics is not complete. It is not likely to ever be complete. We need to know that it is adequate to assure safety in current and future activities and we need to identify specific areas where increased understanding is likely to have the greatest impact on specific developmental, operational, and regulatory decisions so as to focus our research there.

   We do wish to point out, however, that there are much greater deficiencies and uncertainties in data that would permit assessment of the environmental and health impacts of alternative energy sources leading one to the conclusion that major efforts are still required in all energy forms.

5. The AEC has a major research program on the biomedical and environmental aspects of the transuranics. This program focuses on those areas where additional information is most likely to critically influence development programs, operations, and regulations.

We continue to support research on various species of experimental animals exposed to transuranic elements in various forms. A major portion of efforts in this area focus on determining the consequences of inhaling small quantities of aerosolized transuranics and quantitating the effects of aggregation of alpha activities into "hot particles."

We continue observations on humans exposed to plutonium more than twenty-five years ago and we are expanding the Transuranium Registry of potentially exposed occupational workers.

In the environmental area we continue observations on the behavior of transuranic elements dispersed globally by weapons testing and studies of the behavior of plutonium in the quite diversified environments near weapons test areas in the U.S. and the Pacific and around operating facilities in the U.S.

The aim of this research is to reduce the need for conservative and possibly very costly assumptions by providing the information needed to make more realistic estimates of potential health and environmental hazards of transuranium elements. The results of this research are published regularly and are accessible through the various routes I mentioned earlier.

Increasingly, in anticipation of ERDA, we are integrating research activities in this area with research on the environmental behavior and potential health consequences of pollutants from alternative energy sources so that we will be better equipped to assess bioenvironmental aspects of alternative energy technologies so as to help orchestrate

their development and to provide a sound basis for operating and regulating these technologies as they are installed.

Mr. Chairman: I realize these comments have been all too brief but they will be expanded in major ways to cover in detail much of what I have alluded to during the course of the afternoon and tomorrow morning. If I could simply introduce those who will participate with me at this point and in the order in which they will appear, I could remain quiet as we proceed:

Dr. Yoder, AEC's Div. of Operational Safety will discuss Source Terms and Control

Dr. Ed Wrenn, followed by Dr. B. Bennett, will discuss Environmental Levels of the Transuranics

Dr. W. J. Bair, Battelle Northwest Lab, will discuss Transuranics in Experimental Animals

Dr. W. W. Burr, Deputy Director, DBER AEC, will talk concerning Human Exposures

Dr. Chet Richmond formerly of Los Alamos Lab but now with Oak Ridge National Lab will discuss Biomedical Effects in Humans

Dr. Roy Thompson, Battelle Northwest Lab, will finally discuss Implications with Regard to Protection Criteria

AVAILABLE INFORMATION

- NUCLEAR SCIENCE ABSTRACTS
- RECON
- SCIENTIFIC MEETINGS: A FORUM
- INTERNATIONAL SCIENTIFIC MEETINGS
- MONOGRAPHS

NON-GOVERNMENTAL ORGANIZATIONS

- PARTICIPATION IN:
  - ANALYSIS AND EVALUATION OF DATA
  - DEVELOPMENT OF RADIATION PROTECTION STANDARDS
  - ADDRESS SPECIAL ISSUES

- GROUPS INVOLVED IN ONE OR MORE OF ABOVE:
  - UNSCEAR
  - IAEA
  - ICRP
  - NCRP
  - NAS
    - BEAR COMMITTEE
    - BEIR COMMITTEE
    - "HOT PARTICLE" COMMITTEE

Dr. Mills: Thank you. Did you want to respond to questions now?

Dr. Liverman: I will be happy to take any questions the panel may have, or you might like to wait until after the other speakers; I will leave it to you.

Dr. Mills: I think Dr. Taylor has a question.

Dr. Taylor: This morning, Dr. Sagan mentioned, and you mentioned again in your testimony, the desirability of including flexibility in the standards.

The very thought of flexibility appeals to me, but any time we have in the past tried to make anything flexible, we get our ears beaten back by the regulatory people, or the cities, or the states.

I wonder if you have some bright ideas as to how we can make some flexible standards?

Dr. Liverman: I am not sure that I do. I was rather intrigued with something Dr. Sagan was proposing regarding the issue, but I have no special way that one can approach this matter.

It just seems from a sort of layman's standpoint that if you are in a wide open country and there is nobody around, the issue is not quite as critical as it is if you were in the middle of the city.

How one achieves that becomes almost a specific, localized activity subject to change as time goes on. As we heard from the General Electric man, and I happen to agree with him, it is very difficult to engineer a changing regulation into a system.

I really have none.

Dr. Taylor: This low as practicable concept was centered about

flexibility, but it is being made as rigid as a dead man.

Dr. Liverman: I have no particular solution.

Dr. Radford: I have a comment, Mr. Chairman.

I would like to know, is it the intent of the AEC panel to complete their testimony within an hour?

Dr. Liverman: No, sir. We had never intended or felt that could be done. We had, in fact, I believe, requested of the EPA at the time we submitted our testimony that it would take perhaps as much as four hours.

We are not acting as a panel. They are independent and separate papers. There are five different groups of paper. They could have been listed as individuals.

Dr. Radford: I specifically raised this question this morning because I was a little concerned looking at that list and knowing some of the technical expertise that is represented.

Do you want to make a ruling on that? The question is are we going to have any time for questions this afternoon?

Dr. Mills: The schedule that we established was based upon the fact that the response that we got to the Federal Register in the case of the Atomic Industrial Forum, they specifically stated that they would have a panel discussion and that would be 60 minutes.

In the case of the Atomic Energy Commission, they did not propose this whole listing as a single panel. I would suggest that we would allow the Atomic Energy Commission their requested time,

which was four hours for this particular aspect.

We also recognize that we will not get through this afternoon. Therefore, we will at some point in time, when it seems to be that we have covered a particular topic, we will adjourn until tomorrow morning.

Dr. Radford: It is the intent, then, to question each one of the speakers after his presentation?

Dr. Liverman: Dr. Radford, in discussing it with Dr. Mills, it is perfectly permissible to question Dr. Yoder after his presentation.

The next two speakers, you should hear them both through before the questions.

Dr. Bair is operating essentially alone; then, Dr. Burr and Dr. Richmond are a pair; and Dr. Thompson is a single.

I would suggest that you question them in that order, but the Chairman is the man who decides this issue.

The topics in the order I have given them to you are closely interrelated.

Dr. Radford: If I may make a suggestion: In the interest of not turning us off before we are through here, would it be possible that the speakers would depart from their written testimony and emphasize the highlights and shorten their presentations?

I am not trying to throttle them, but I think that many of the issues will come out in the discussion. I think, perhaps, one of the things that may be apparent to the audience is that it is in the questioning that we begin to get at the nub of some of these

issues.

The formal presentations can be shortened down to give the highlights. The only other alternative I see, frankly, is to go on into an evening session.

Dr. Liverman: Of course, since I am through, I can say yes. But I think the thing for us to try to do is to summarize our comments.

Dr. Mills: The agenda for tomorrow afternoon is lighter. We may be able to make up for some of the time we lose today, so I would not propose that we go into the evening hours in trying to address this.

However, I would say that some attempts could be made to summarize the comments, as Dr. Liverman has suggested. Then we would ask questions in terms of specific topics as shown under the AEC portion of the agenda.

Dr. Radford: I am concerned, frankly, that we not be running so late that Dr. Tamplin's presentation will be thereby curtailed, if not by pressure of the time, by pressure of the fact that people start to leave.

So I think it is very important that we have plenty of time available for questioning Dr. Tamplin at length just as we hope we will have time to question the AEC representatives.

Dr. First: Would it be possible to start tomorrow earlier and cut tomorrow's lunch to an hour?

Dr. Mills: Dr. Tamplin is scheduled for tomorrow afternoon,

so I think we have sufficient time to get him on tomorrow afternoon without shortening his presentation.

In spite of the time frame, for the benefit of the reporter who has to keep all of this going into her machine, let me call for a ten minute recess until she has time to catch her breath.

(Brief recess.)

Dr. Mills: We will resume the hearing.

Our next speaker is Dr. Yoder.

Potential Source Terms and Control Measures

by Robert E. Yoder, Jr., Ph.D.
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Introduction

The information presented in this discussion will include the current sources of transuranium materials within the Atomic Energy Commission (AEC) operations, an indication of projected inventories, and an overview of control measures taken to reduce effluents. This is not intended to be an exhaustive review of the subject matter, but to highlight the AEC actions in managing its transuranic materials operations. Specific information regarding the location and quantity of material which has been released to the environment will be presented later.

There have been releases of plutonium and these have been well publicized. The quantities of materials involved in these instances have ranged from much less than one to a few kilograms of material, and steps have been taken to reduce the accident potential in AEC operations. A comparison of the quantities released to the quantities in use shows that a very small amount has been released in accidents. Routine emissions are now very low and still decreasing. Because the AEC is concerned about environmental discharges and any attendant buildup in the environment, it is fully implementing the "as low as practicable" concept. For example, if our routine emissions continue at the present levels by the

year 2000 less than 3 additional curies of plutonium will be discharged to the environment, compared to the kilocurie quantities already present from atmospheric weapons testing. The intensive environmental sampling program which quantifies the amount of plutonium in the environment and its specific location in identified pathways provide confirmation that our control programs are effective. Information developed in this program will be available and analyzed well before a potential problem exists and will allow ample time to take effective action.

In those instances in which environmental cleanup actions have been required, specific measures tailored to the specific site have been used. Because the number of the cases is very small, they are best handled on a case-by-case basis so that a comprehensive evaluation can be made to effectively limit the availability of these materials.

Cost-Benefit

The AEC uses plutonium or handles plutonium in three broad program categories: national defense, energy research and development, and service to other agencies and private industry. The benefit-risk analyses with regard to each of these areas is developed along separate lines of reasoning: (1) The executive and legislative branches of the government have established the benefit-risk associated with a viable national defense program which requires plutonium for its development and maintenance. The AEC produces and manufactures plutonium components for use by the Department of Defense. Also, as required by the Test Ban Treaty, the AEC maintains a viable nuclear development and test program. (2) The current energy situation has brought into focus a number of elements pertinent to the risk-benefit of plutonium reactors as sources of electric

power. The AEC conducts the research and development necessary to support the industry options to use these reactors for electric power production. (3) Service functions are associated with the devolopment of nuclear radioisotopic thermoelectric generators which are manufactured by the AEC for agencies who themselves have developed the risk-benefit analyses supporting their use. In this case, the AEC merely supplies the material in a form suitable for the specific program use. As an additional service function, the AEC provides the burial facilities or interim storage facilities for transuranic materials.

In June 1973 the AEC began the preparation of an environmental impact statement for the overall Liquid Metal Fast Breeder Reactor (LMFBR) program (WASH-1535) as required by the National Environmental Policy Act (NEPA). The environmental impact statement, now in the final stages of review prior to release, differs from the conventional statement because it addresses the important environmental and societal impacts from the assumed eventual commercialization of LMFBRs which are expected if the research and development goals are attained rather than the impact of the research and development activities. It was necessary, therefore, to look ahead some 40 to 50 years to foresee an LMFBR industry that would provide about 40 percent of the total installed electric generating capacity in the United States by the year 2020.

The direct costs include LMFBR development program costs and those costs normally imbedded in the price of electrical energy. Over 70 separate postulated cases were considered in estimating United States electrical power production costs over the period 1974-2020. One of the major quantifiable conclusions of the direct economic analysis was that

the introduction of a fast breeder into the United States electric power utility system will produce significant financial benefits. These benefits result largely from a reduction in uranium ore and enrichment requirements. Additionally, the fast breeder results in a nuclear power industry that will have total power costs, in constant dollars, that decrease with time. Capital requirements accumulated to the year 2020 are estimated to be about 10 percent less with a fast breeder industry due to the reduced requirement for mining, milling, and enrichment facilities.

Indirect benefits, though no less significant, come partly from the improved resource utilization. The use of plutonium as a reactor fuel for electric power production would free the finite resources of fossil fuels for their optimum use, thus assuring the domestic availability of fuel for electric power production for the long term. A mature LMFBR industry together with the nonbreeders can generate sufficient fissile material for the nuclear industry to be able to use stockpiled depleted uranium for hundreds of years as the sole source of fertile fuel material.

Other indirect benefits of note are in the cumulative health and safety effects for both occupational and public groups.

Inventories

The AEC has produced several tens of tons of plutonium-239 in its reactors, including several tons of nonweapon grade plutonium, since the mid-1940's. In addition, 200 kg of Pu-238, 4 kg of Cm-244, and 2 grams of Cf-252 have been produced in the Savannah River reactors. Additional quantities of transplutonium elements have been produced in Savannah River reactors, separated, and refabricated into targets for further

irradiation as part of the Cf-252 program.

Plutonium-238 is used principally as power sources for space research, satellites, and heart pacemakers. These applications have required about 40 kg of plutonium-238 since 1961. The requirements for specific applications through FY 1986 project a need of about 540 kg of plutonium-238. Since 1961 the United States has launched radioisotope thermoelectric generators containing 34.7 kg of plutonium-238. Of this quantity, 13 kg are on the lunar surface, 6.8 kg are in long-lived earth orbit, and 9.4 kg have been ejected out of the solar system. One kg was released to the earth's atmosphere in a reentry burnup (as designed), 2 kg of encapsulated material were recovered from the Santa Barbara Channel following a missile abort, and 2.5 kg impacted intact (as designed) in the South Pacific Ocean following an aborted lunar mission. No plutonium-238 was released from the latter two incidents.

Small quantities of plutonium-238 will be required for heart pacemakers. A potential equilibrium number of 170,000 of these devices will be needed in the United States by the year 2000. The total quantity of plutonium-238 required ranges from 25-75 kg. Several companies at present are licensed to implant these devices and an equilibrium implant rate of 10,000 per year is expected to be reached in the early 1980's.

The major increase in plutonium inventory is anticipated to be that associated with commercial nuclear power reactor activities which are projected to have "on-hand" a potential commercial plutonium inventory of 117,000 kg in the year 2000. Reactor research and development program annual plutonium requirements are projected to vary in the range of 500-2,500 kg over the next 10-year period.

The types of operations in the AEC involving plutonium include its production in reactors at Savannah River and Richland, chemical processing to separate plutonium from uranium and fission products, reduction to the metal, casting, machining, and other metallographic operations. In addition, scrap material is processed for recovery of plutonium by incineration, digestion, precipitation, and solvent extraction. Plutonium also is removed from liquid effluent streams by filtration and precipitation to reduce the volume of material which must be sent to waste handling and storage facilities, and to reduce the quantity present in waste streams. The AEC also manufactures experimental fuel elements containing plutonium and operates reactors containing plutonium fuel elements, such as the EBR II. Waste material from all AEC operations is placed in retrievable storage if the plutonium or transuranic material concentration in the waste is in excess of 10 nCi/g. A proposed rule-making would cause all commercially generated transuranic waste in excess of this limit to be sent to AEC storage sites pending the development of a final repository (Federal Register, Volume 39, September 12, 1974). In the execution of these programs the AEC engages in the transportation of radioactive materials in interstate commerce. However, this material is safeguarded as appropriate to the type and quantity of material, and the associated potential hazards.

The quantity of transuranic materials now stored or buried at AEC sites totals about 950 kg contained in approximately 1 million cubic meters of material. This material is located in burial grounds at the Idaho National Engineering Laboratory, Idaho; Richland, Washington;

Savannah River, South Carolina; and Oak Ridge, Tennessee. The characteristics of transuranium-contaminated waste will change as the breeder reactor program develops and will require the storage not only of transuranic materials, which are primarily alpha emitting materials, but also transuranic materials contaminated with gamma activity in fuel hulls which contain induced radionuclides and fission products. The assessment of projected quantities of transuranic wastes expected by the year 2000 is presented in Table 1.

Emissions

A concerted effort to accelerate the reduction of all emissions of all radioactive materials from AEC operations was initiated in 1970, including a program to quantify all past releases from AEC facilities. Figure 1 summarizes the total plutonium release data from all AEC sites having significant releases for the years 1967-1973. Figures 2 and 3 provide a breakdown of these data to show the quantities released via air and water. The important point to note is that the releases from all sites have been approximately 1.5 Ci over the 6-year period. From our operational experience and the improved control measures at all facilities, we anticipate that AEC releases will not exceed, through normal discharge systems, 0.1 Ci/yr from all operations from all sources.

In 1973, 0.053 Ci of plutonium and approximately 0.002 Ci of other transuranics were released offsite. In the same year approximately 100 Ci of plutonium and approximately 0.1 Ci of other transuranics were released onsite to treatment and disposal systems such as seepage basins. The

composition of the 1973 onsite releases is shown in Table 2. The largest component of this discharge occurred at Richland, however, this operation has been sufficiently modified so that no plutonium has been discharged to date during CY 1974. We anticipate that in CY 1974 less than 1 Ci will be discharged onsite from all sources of plutonium at all AEC sites. These reductions should be viewed with the fact in mind that much larger quantities have been discharged onsite in the past. The impact of the releases and a full assessment of their significance in the environments surrounding AEC facilities is available in WASH-1259.

Control Measures

An intensive reevaluation of the AEC handling of plutonium was initiated following the 1969 Rocky Flats Plant fire. All plutonium operations and storage facilities were surveyed and new safety criteria developed for these operations. Because the new criteria addressed in detail areas not previously highlighted, there are certain modifications which cannot be undertaken in present facilities, particularly regarding natural phenomena (tornado, earthquake) protection. However, in these cases additional safeguards and alternate protection has been provided. Plutonium operations are being conducted in glovebox and/or canyon facilities, which provide at least three barriers (e.g., glovebox, operating compartment, and outer facility walls) between the operation and the outside environment. Where possible, inert atmospheres are used to reduce the potential of fire. Fire protection is provided through the use of sprinkler systems and, in some cases, inert gas protection. Firebreaks and operation compartmentalization are used to limit the extent of any incident. At least

three high efficiency air cleaning devices are required between plutonium operations and the outside environment. This criteria is being met through the use of three or more stages of high efficiency filters or two stages of high efficiency filters in addition to a sand filter. To provide assurance for the control of plutonium in the event of a postulated accident, emergency power and protected, isolated emergency control rooms are available. A formal safety analysis report requiring AEC approval must be written for all new plutonium operations. These safety analysis reports critically review every operation, every control measure, and every interaction between operations and controls to avoid a possible loss of control. To date over $210 million for construction has been committed to upgrade or replace existing facilities. A significant sum has been spent also in accomplishing a myriad of small projects.

The AEC has always operated under the "as low as practicable" philosophy with regard to the release of any radioactive material to the environment. However, values associated with "as low as" have continually decreased with increased operating experience and improved control technology. Every transuranium operation has been reviewed recently and additional safeguards installed to reduce effluents to the lowest level that is economically possible. At the Rocky Flats Plant, for example, a water treatment plant to clean and permit the reuse of process water is scheduled for FY 1977 in order to minimize the quantity of potentially contaminated waste water which is discharged from that site.

The plutonium-238 encapsulation operation at the Mound Laboratory is being transferred to an upgraded plutonium facility at the Savannah River Plant. By 1980 primarily only encapsulated plutonium-238 material will be handled at Mound Laboratory. This program will restrict the availability of unencapsulated material and reduce significantly the release potential of plutonium-238 oxide as well as minimize the quantity of waste material, and the number of shipments required.

Accidents

The release of plutonium and other transuranic materials in decreasing order of quantity are associated with:

1. atmospheric weapons testing;
2. weapons tests at the Nevada Test Site;
3. accidents--both from military operations and AEC plant operations; and
4. effluents from normal discharge waste streams.

The major plutonium releases associated with AEC plant operations have occurred at Oak Ridge, Rocky Flats, Richland, and Mound. The total quantity involved amounted to a few tens of curies, which represents a small fraction of that in process. In each of these areas intensive environmental survey programs are underway.

An analysis of three accidents associated with military operations is provided in the supporting documentation. The important element in the cleanup actions for these accidents is the careful analysis of the significance of any material not removed. The experience we have gained from these accidents has led to an enhancement of our capability to survey and

cleanup accident sites. Portable monitoring instrumentation useful for onsite surveys provides a sensitivity of .1 $\mu Ci/m^2$ of plutonium on the soil surface. An aerial monitoring program using sensitive radiation monitoring instruments and helicopters, allows the survey of large areas with a sensitivity of 0.3 $\mu Ci/m^2$. This survey technique allows operation at 100 feet altitude above the ground surface and at an air speed of 60 knots. Analytical analyses for plutonium in environmental samples provide assessments such that we can determine plutonium at levels below 10^{-5} $\mu Ci/m^2$. Now a number of AEC laboratories have a proven capability to process, specifically for plutonium, soil or vegetation samples with this sensitivity. The limit of sensitivity in these cases is limited by the quantity of material which one can manipulate in the chemical processes and the capability to analyze a large number of samples, such as may be required in an accident situation. The accidents which have occurred were in quite different environments and required very different techniques for cleanup. As a matter of course one removes all radioactive material which is practical to remove and which poses a potential significant source of exposure. The techniques which can be used include excavation, plowing, and fixation. New techniques to fix plutonium to reduce its movement prior to cleanup are under development. The guidelines which can be used for the cleanup levels must be specifically set at each site because the pathways for human exposure and ability to cleanup will vary from site to site. The situations which occurred at Palomares, Spain; Thule, Greenland; Rocky Flats, Colorado; the Nevada Test Site; and Enewetak Atoll are all unique. No two have the same problems nor do they appear at this time to be amenable to the same cleanup techniques. The quantity of plutonium involved

in any accident represents a very small fraction of the quantity of that material in the inventory, and the quantity left after cleanup is even smaller.

Summary

There have been releases of plutonium and these have been well publicized. The quantities of materials involved in these instances have ranged from much less than one to a few kilograms of material, and steps have been taken to reduce the accident potential in AEC operations. A comparison of the quantities released to the quantities in use shows that a very small amount has been released in accidents. All routine emissions are now very low and still decreasing. Because the AEC is concerned about environmental discharges and any attendant buildup in the environment, it is fully implementing the "as low as practicable" concept. For example, if our routine emissions continue at the present levels by the year 2000 less than 3 additional curies of plutonium will be discharged to the environment compared to the kilocurie quantities already present from atmospheric weapons testing. The intensive environmental sampling program which quantifies the amount of plutonium in the environment and its specific location in identified pathways provide confirmation that our control programs are effective. Information developed in this program will be available and analyzed well before a potential problem exists and will allow ample time to take effective action.

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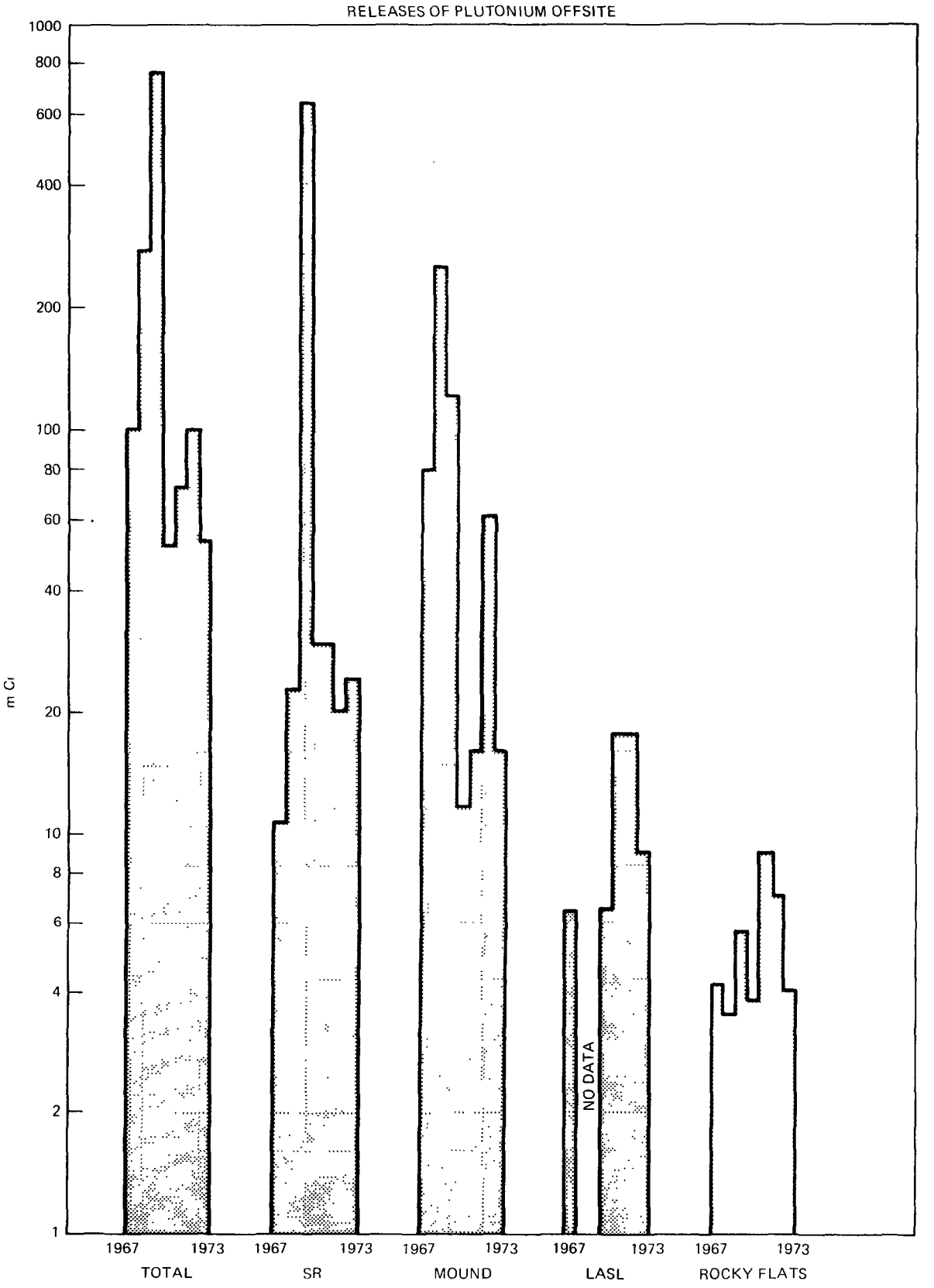
RELEASES OF PLUTONIUM OFFSITE
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ROCKY FLATS

Figure 1

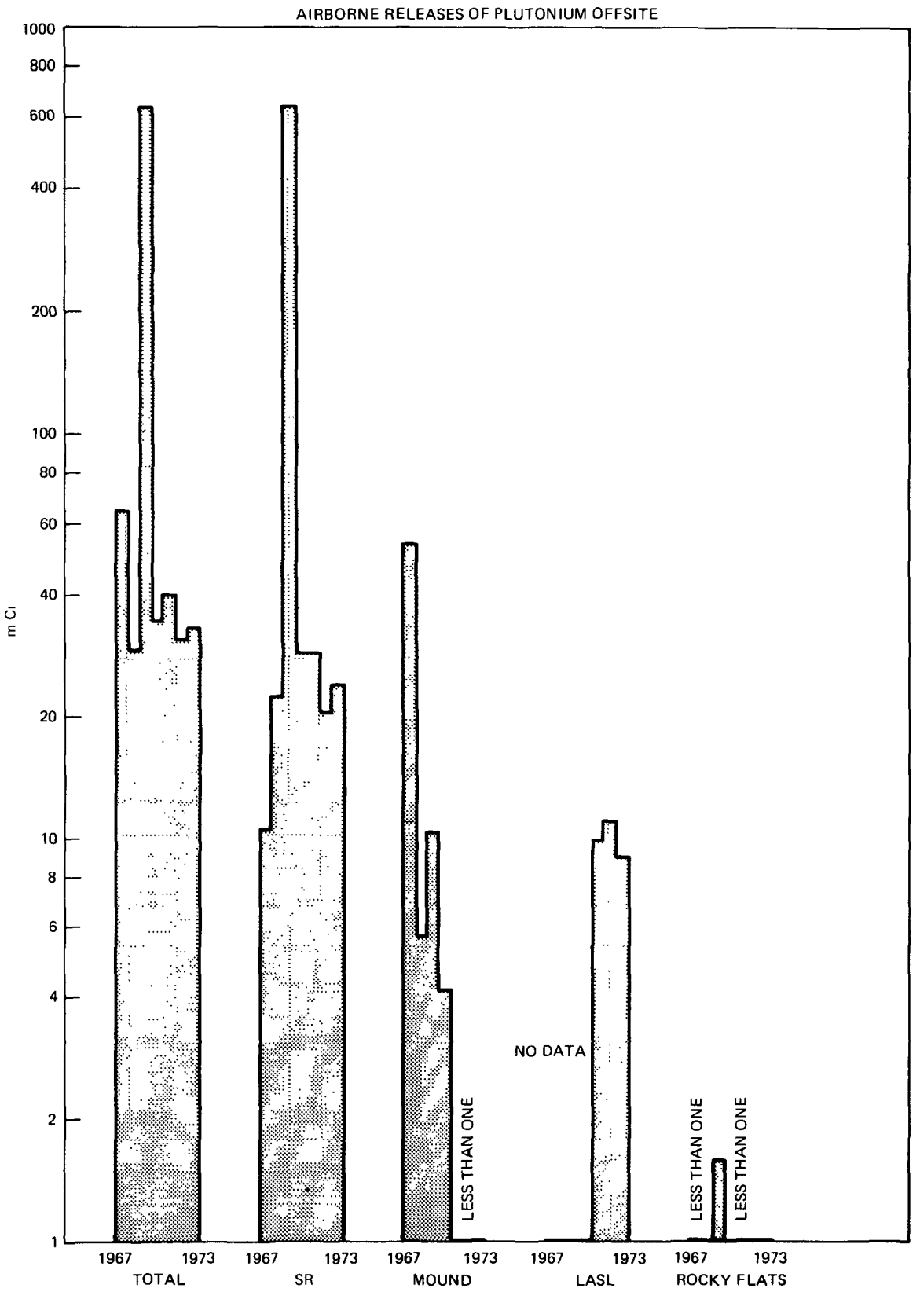
AIRBORNE RELEASES OF PLUTONIUM OFFSITE
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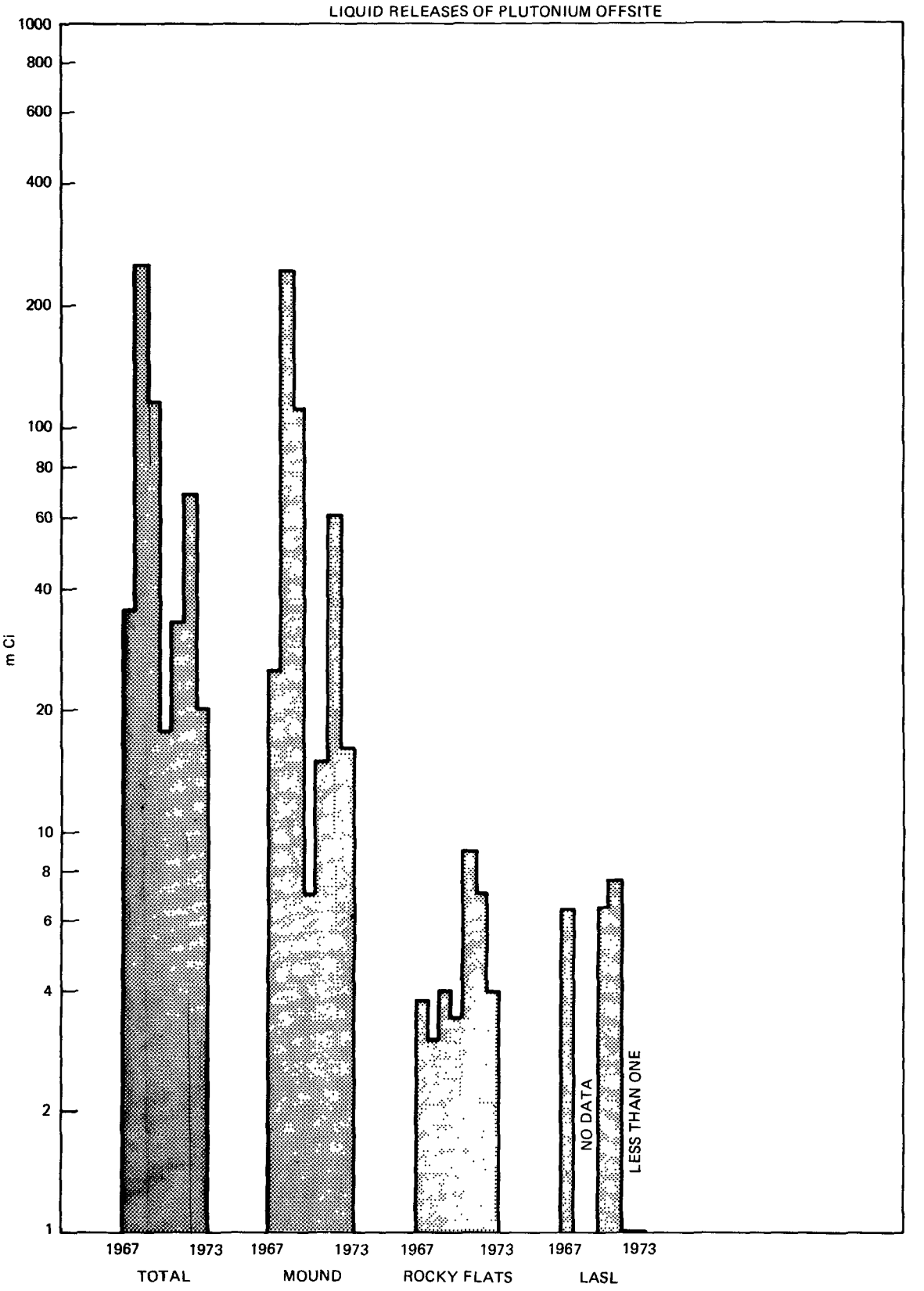
Figure 2


LIQUID RELEASES OF PLUTONIUM OFFSITE
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LESS THAN ONE
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TOTAL
MOUND
ROCKY FLATS
LASL

Figure 3

TABLE 1

TRANSURANIUM-CONTAMINATED WASTES REQUIRING REPOSITORY STORAGE
(Accumulation Thru Year-End)

Year	Alpha Activity		Alpha-Beta-Gamma Activity	
	Cubic Meters	Pu & U-Kilograms	Cubic Meters	Pu & U-Kilograms
1980	9,300	220	6,770	13
1985	36,200	1,160	16,700	46
1990	70,100	3,510	28,900	131
1995	125,000	8,400	48,100	302
2000	244,000	18,900	85,600	632

Reference: "Projected Shipments of Special Nuclear Material and Wastes by the Nuclear Industry," ORNL-TM-4631, August 1974.

TABLE 2

AEC TRANSURANIC RELEASES

CY 1973

Onsite Discharges (rounded)

Plutonium	100	Ci
Curium	0.10	Ci
Other transuranics	.001	Ci

Effluent Discharges

Plutonium	0.053	Ci
Americium	0.001	Ci
Curium	.0004	Ci
Neptunium	.0005	Ci

TABLE 3

CONVERSION FACTORS

Plutonium-238	$\frac{17 \text{ kCi}}{\text{kgm}}$
Plutonium-239	$.063 \frac{\text{kCi}}{\text{kgm}}$
Curium-244	$81.8 \frac{\text{kCi}}{\text{kgm}}$
Californium-252	$539 \frac{\text{Ci}}{\text{gm}}$

SUPPLEMENTAL INFORMATION

DIVISION OF BIOMEDICAL AND ENVIRONMENTAL RESEARCH

Potential Plutonium Source Term for Medical Uses

Radioisotope-Powered Cardiac Pacemaker

1. The purpose of the AEC program is the demonstration that technology exists which will permit the production of nuclear-powered cardiac pacemakers which will, with great confidence, substantially improve upon the reliability and lifetime capabilities of presently available chemical battery-powered pacemakers.

   The 1974 pacemaker population is approximately 126,000 world-wide. The potential U.S. nuclear pacemaker market is estimated to be 10,000 per year with an equilibrium number of 170,000 in the U.S. population in the year 2000.

   The primary environmental implications are from radiation during normal use and from potential exposure to fuel following a breach of the capsule and a release of the fuel to the environment.

   The benefits of a long-lived nuclear pacemaker are direct functions of minimizing the number of reimplantations during the patients remaining lifetime.

2. Approximately 350 nuclear pacemakers are currently in use in the U.S. Three companies are presently licensed to implant 20 units per month each. An equilibrium implantation rate of 10,000 per year is expected to be reached in the early 1980's.

   The inventory of plutonium-238 in the nuclear pacemakers ranges from 140 to 420 milligrams per unit. Thus, the total plutonium-238 inventory for a population of 170,000 in the year 2000 ranges from 24 to 71 kilograms.

3. The fuel capsule has demonstrated its capability to survive all the safety tests defined by the AEC's "Interim Safety Guide for the Design and Testing of Nuclear Power Cardiac Pacemakers" with additional substantial safety margins.

4. Fuel processing losses which are unuseable wastes amount to about 1 percent of the starting inventory. For 10,000 units per year the plutonium wastes would be in the range of 15 to 40 grams per year.

THE WASTE MANAGEMENT OF TRANSURANIC SOLID WASTE

Solid wastes of widely diverse nature and contaminated to varying degrees with heterogeneous amounts and forms of plutonium are generated in several AEC facilities. The radioactivity in such wastes has been confined within controlled areas of AEC sites by burial in shallow trenches or pits and since 1970 in easily retrievable containers. The principal burial sites include the Richland site, the Idaho Falls site, Los Alamos Scientific Laboratory, Oak Ridge National Laboratory, and the Savannah River Plant.

The waste matrices in which the transuranic isotopes are contained vary greatly in their composition. Normally, they can be segregated into those which are noncombustible and those which are combustible. Depending on the facility, the noncombustible fraction may comprise up to one-half of the total volume of waste generated, while the combustible portion includes such things as paper, rags, plastics, rubber, and discarded clothing. Table 1 shows the results of a waste composition survey taken by the Los Alamos Scientific Laboratory. This table gives an idea of the tremendous variation in composition of wastes generated by different laboratories.

Table 2 shows the projected increase in production of transuranic waste. If current process techniques continue, by the year 2000 approximately 244,000 cubic meters of alpha waste will be generated; and an additional 86,000 cubic meters of waste will be generated which has a high gamma background. Although these wastes will require much improved treatment and handling systems, our past experience indicates that release of TRU nuclides to the environment will be well within AEC guidelines based on recommendations of the International Commission on Radiological Protection. Current management programs offer little chance for environmental contamination by transuranics. Effluent treatment processes which produce some solid waste materials may lead to limited offsite radioactivity releases but these are extremely low and must always be within AEC guidelines.

Several years ago the AEC reexamined its policy regarding the management of its own transuranium-contaminated radioactive waste. Until that time, it was felt that the remoteness of the burial sites combined with favorable geological and hydrological conditions would assure the safety of the environment from TRU wastes. However, there exists the possibility that the status of sites may change as a result of new national priorities. Also, the quantities of transuranic waste generated are expected to increase substantially as a result of the generation of nuclear power. It was decided to limit the outright burial of transuranium-contaminated waste, and in March 1970, the AEC issued a directive[1] requiring its contractors to segregate transuranium-contaminated waste from nontransuranium-contaminated waste and to store the transuranics in a manner which would

[1]"Policy Statement Regarding Solid Waste Burial," USAEC, IAD No. 0511-21, March 20, 1970.

TABLE 1

ESTIMATED COMPOSITION OF LABORATORY TRASH
CONTAMINATED WITH TRANSURANIUM NUCLIDES*
(WEIGHT PERCENT)

Waste Material	Hanford	LASL**	Mound	Rocky Flats	Savannah River
Paper & Rags	18	46	50	30	53
Rubber	15	7	25	20	25
Plastics	20	9	20	50	4
Glass	1	17	--	--	--
Metal	30	21	--	--	--
Misc.	16	--	5	--	13

* Reference: "Transuranic Waste Research and Development Program," LA-5281-MS, May 1973.

** Survey included all radioactive waste generated at LASL.

TABLE 2

TRANSURANIUM-CONTAMINATED WASTES REQUIRING REPOSITORY STORAGE (ACCUMULATION THRU YEAR-END)

Year	Alpha Activity		Alpha-Beta-Gamma Activity	
	Cubic Meters	Pu & U-Kilograms	Cubic Meters	Pu & U-Kilograms
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Reference: "Projected Shipments of Special Nuclear Material and Wastes by the Nuclear Industry," ORNL-TM-4631, August 1974.

permit them to be readily retrieved in a contamination-free condition for a period of at least 20 years. This would permit time to develop a national policy which would be acceptable to the public for disposal of transuranium-contaminated waste.

The transuranic waste storage site at the Idaho National Engineering Laboratory (INEL) at Idaho Falls is a good example of current practices resulting from this directive. Here the waste is stored on an asphalt pad which has a four inch gravel base. The surface is sloped to permit moisture drainage. The waste is packaged in 55-gallon steel drums or in plywood boxes which are coated with fiberglass. The 55-gallon drums are currently lined with a 90-mil polyethylene liner to prevent contact of the waste with the wall of the drum. These packages are stacked on the pad in sections of approximately 150 feet by 80 feet. Once a section is full, the stacked waste is covered with plywood and a plastic sheet and then mounded over with earth. Normally a 3-foot space is left between each section of the pad. This 3-foot section is filled with earth and provides a fire-retarding wall.

The volume of transuranium-contaminated waste in the U.S. and the contained transuranium nuclides is expected to increase greatly in the coming years as a result of the use of plutonium in the production of nuclear power. Due to this projected increase, the Directorate of Regulation* of the AEC has proposed a change in the Federal Regulations regarding licensee management of transuranic waste. In September 1974, a notice[2] was published in the Federal Register regarding a proposed rulemaking which would result in Federal management of these wastes.

According to current plans, the operating arm of the AEC** would manage commercially generated transuranic waste in the same manner as they manage AEC-generated transuranic waste. The waste would be placed into 20-year retrievable storage just as it is at INEL. The generator would pay a one-time fee which would cover the cost of all future management. An environmental impact statement[3] is being prepared by the AEC which discusses alternatives for waste management in detail and is available in draft (WASH-1539).

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* To become NRC about January 1, 1975.

**To become part of ERDA about January 1, 1975.

[2] "Transuranic Waste Disposal," Federal Register, Vol. 39, No. 178, Thursday, September 12, 1974, pp. 32921-32923.

[3] "Management of Commercial High Level and Transuranium-Contaminated Radioactive Waste," WASH-1539, USAEC, September 1974 (draft).

In Table 3 the total volume of radioactive waste at the major AEC sites is shown in the first column in cubic meters. The total quantity of transuranium nuclides contained in all of this solid waste is about 950 kilograms. Of this quantity, roughly 175 kilograms is stored in a readily retrievable fashion and the remaining 775 kg has been buried. The volume of waste retrievably stored is roughly 29,000 cubic meters, and it contains roughly one-fifth of the total quantity of transuranic nuclides generated to date.

The buried transuranium nuclides at AEC sites and the 80 kg of plutonium at licensed facilities will require continued long-term surveillance. The waste package is not considered to have any integrity after it is buried. Monitoring and surveillance programs at AEC sites have shown that migration of the buried transuranics has been negligible.[4] However, the wastes will remain hazardous for an extremely long period of time and one cannot predict with certainty what, if any, environmental changes will take place during this time.

In consideration of the long periods of time for which these wastes must be confined, the AEC is developing hazards analysis procedures to determine the risk to man and his environment which may result from these wastes in the future. Based on these analyses, the AEC will be able to decide whether it will be necessary to remove these wastes from the burial areas.

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[4] "Environmental Monitoring at Major USAEC Contractor Sites," WASH-1259, USAEC, August 1973.

TABLE 3

QUANTITIES OF SOLID WASTE AND TRANSURANIUM NUCLIDES STORED/BURIED AT MAJOR AEC SITES THROUGH JUNE 1974[a]

Site	Total Estimated Radioactive Waste		Readily Retrievable Waste	
	Cubic Meters	TRU-Kilograms[b]	Cubic Meters	TRU-Kilograms
LASL	222,000	14	1,317	7
NRTS	159,000	492	22,172	116
ORNL	176,000	14	879	5
RL	200,000	387	3,144	26
SRP	273,000	45	1,070	21
TOTAL	1,030,000	952	28,582	175

a - Based on information contained in July 1974 Waste Management Site Plans except Richland which is based on the July 1973 site plan data.

b - Excluding quantity of TRU nuclides disposed of to on-site cribs, ponds, and pits. (About 193 kg are contained in these areas at major AEC sites.)

SNS PLUTONIUM OPERATIONS

I. General Program Aspects

For the past 15 years, the AEC has been developing Radioisotope Thermoelectric Generators (RTG) to provide electrical power for both space and terrestrial applications. These devices convert thermal energy derived from the decay of radioactive isotopes to electrical energy utilizing the thermoelectric properties of bimetallic couples. Several isotopes have been considered as thermal sources; however, the most desirable one from an overall system point of view has proved to be Plutonium-238. The following discusses Space Nuclear Systems (SNS) operations utilizing Plutonium-238 as a fuel form.

A. Purpose

The purpose of the Plutonium RTG program is to develop long lived, unattended, reliable and light weight power system for space applications.

It is the intent of SNS to develop these systems so as not to present undue hazards to operating personnel, to the general public or to the worldwide population.

B. Advantages of Nuclear Systems

The following are advantages of using nuclear systems for space missions:

1. With the proper isotope, the system can be designed for long life, it can be compact, and it can provide a high power to weight ratio.

2. In space, it need not be dependent on sunlight or sun orientation. All outer planet exploration missions must use nuclear power because of the lack of solar energy.

3. A nuclear system is naturally radiation hardened for military applications and will withstand radiation emitted by planets.

4. It can provide both electrical and thermal power anywhere in space.

C. Specific Advantages of Plutonium

Plutonium-238 provides a specific power which enables the RTG design to meet the advantages indicated above. Because it provides its thermal power from alpha decay, little shielding is required. Also, because of its reasonably long half-life, no power flattening is required for missions as long as 10 years. The oxide of plutonium provides a reasonably high melting point which permits the design of space systems to preclude Plutonium-238 releases in thermal environments to which the system may be exposed if flight aborts should occur.

D. Safety Criteria

The general safety design objectives of a radioisotope heat source and/or its associated power system components are to contain the radioactive materials (the isotope fuel form and its radioactive products) and to limit the interactions of the radioactive materials with humans and the environment. For normal operations, containment and interaction requirements are absolute; for potential accident situations, containment requirements are based on probabilistics and are determined by a given source term (amount of radioactive material released) and/or the direct external dose to one or more random human receptors.

Containment and the limiting of interactions between the radioactive source, humans, and the environment are absolutely maintained in normal factory-to-flight and post missions operations. The exposure limits for radiation workers, individuals and the general public applicable to normal mission operations are those set forth in the Code of Federal Regulations (CFR), Atomic Energy Commission Manual Chapters (AEC-MC) and the International Commission on Radiological Protection (ICRP).

In the event of random earth impact situations, the safety objectives are to locate and recover the nuclear heat source(s).

For accident situations, the following recent probabilistic criterion is required of the system: the total probability of releasing one millicurie of fuel and/or its daughter products or exposing one or more people to a direct external radiation dose exceeding the limits set forth in the above documents should be less than 10^{-5} per flight, given the occurrence of any accident. For source terms other than one

millicurie, scaling the fuel release probability inversely-proportional to the source term should be considered. The above probabilistic criteria should be demonstrated at a reasonable confidence level ($\geq$ 50%) by analysis and/or test.

E. Safety Assessment

Before any nuclear system is used, it must be reviewed and evaluated on the bases of risk to the general public and the environment by an Interagency Nuclear Safety Review Panel (INSRP) who must submit a Safety Evaluation Report (SER) to National Security Council (NSC) for presidential approval action. This INSRP is comprised of experts in the field of nuclear system design, launch vehicle design, accident evaluations, aerodynamics, thermodynamic, meteorology, terradynamics, oceanography, astrophysics, health and safety, biology, medicine and others from EPA, NASA, DOD, AEC, NOAA, and their government agencies and their contractors.

The review covers all aspects of possible accidents from factory-to-flight including ground transportation, launch, suborbital, orbital reentry, impact and post impact situations. The panel reviews the results of safety verification tests which are generally conducted by the systems contractor to evaluate the response of the heat source in overpressure, launch-pad fires, reentry, impact and post-impact environments.

A Safety Evaluation Report prepared by the panel provides an analysis of the risk to man and the environment based on the results of the INSRP review.

Since the AEC is not the user agency of the nuclear systems, it is not responsible for benefit analyses and environmental impact statements. These requirements and the request for launch approval are the responsibility of the user agency.

II. Plutonium Applications

A. Current Applications

The following programs are currently using plutonium or contemplate using plutonium in the very near future:

1. Pioneer 10 and 11 - NASA mission of two spacecraft to Jupiter which use four RTG's per spacecraft (1200 grams each RTG). Launches in March, 1972 and April, 1973.

2. Viking - NASA mission of two Mars landing spacecraft which will carry two RTG's per spacecraft (1200 grams each RTG). Launches are in August and September, 1975.

3. LES 8/9 - DOD mission of two satellites to synchronous altitude will use two RTG's per satellite (4.2 kg per RTG). Simultaneous launch of both satellites on the same spacecraft in November, 1975.

4. Mariner/Jupiter Saturn (MJS) - NASA mission of two spacecraft to Jupiter and Saturn with three RTG's per spacecraft (4.2 kg each RTG). Launches in August and September, 1977.

B. SNS Operational Sites

The following sites are presently being utilized by SNS for their RTG activities:

1. Monsanto Research Corp. (MRC), Mound Laboratory, Miamisburg, Ohio, provide encapsulated, sealed plutonium heat sources for use in all of the programs.

2. Launches are from either Kennedy Space Center or Cape Canaveral Air Force Station, Florida.

3. The AEC's Savannah River Plant at Aiken, South Carolina, will begin providing Plutonium-238 fuel forms for the space program in the 1977 time period.

C. Current Plutonium Inventories in Space

Since 1961, the AEC has launched 34.7 kilograms of Pu-238. Of this amount, one kilogram was released to the earth's atmosphere by burn-up during reentry, two kilograms were recovered from the Santa Barbara channel after a missile abort, two and a half kilograms deposited and contained in the South Pacific Ocean near the Tonga Trench, after an aborted Apollo mission, 13 kilograms are on the lunar surface, 6.8 kilograms are in long lived earth orbit, and 9.4 kilograms have been ejected out of our solar system into deep space.

D. Forecast Inventories at Fabrication Sites

Plutonium inventories planned at fabrication sites for future SNS activities include the following:

1. Mound Laboratory - Unencapsulated fuel at Mound will be decreasing from about 40 kg at present to zero by FY 1980, in accordance with SNS plans to transfer fuel form fabrication to Savannah River. Mound Laboratory will continue assembly of heat sources in the future, using encapsulated fuel forms supplied by Savannah River. Time-average inventories of this encapsulated fuel at Mound Laboratory are expected to approximate 30 kg/yr by FY 1978.

2. Savannah River - Beginning in FY 1977, inventories will increase from zero to a time-averaged level approximating 40 kg/yr, including associated process salvage.

3. Inventories in R&D at Savannah River and Mound Laboratory will approximate 3 and 7 kg/yr, respectively. Time-average inventories in recovery operations at Savannah River may approximate 10 kg/yr.

E. Future Applications

Additional Viking missions to Mars are planned by NASA in the 1981 time period. Post 1980 missions planned by NASA include a Mariner Jupiter Uranus flyby, a Mariner Jupiter Orbiter, a Pioneer Jupiter Orbiter, a Pioneer Jupiter Probe and a Mars Sample return mission. The DOD has several planned missions in the post 1977 time period. All of these missions will utilize plutonium fuels for electrical power. The following plutonium inventories are contemplated to meet the above requirements:

1. FY 75 - 30.9 kg
2. FY 76 - 19.4 kg
3. FY 77 - 14.4 kg
4. FY 78 - 35.3 kg
5. FY 79 - 59.0 kg
6. FY 80 - 69.7 kg
7. FY 81 - FY 86 - 331.8 kg

III. Control Technology

A. Past Effluent Releases

Early isotopic space systems were designed to burn up on reentry yet provide absolute containment for all ground handling and accident situations. In 1964, SNAP 9A burned up on reentry as designed after an abort on ascent to orbit. One kg of Plutonium-238 was burned up in the stratosphere (particle size - 0.4 μ).

Systems after the SNAP 9A were designed for intact reentry. Two aborts after 1964 released no radioactive material. The first, a Nimbus spacecraft was aborted in 1968 after launch at the AF Western Test Range. It was intentionally destructed at 100,000 feet after the launch vehicle went off-course. The radioisotope capsules were retrieved intact from the Pacific Ocean (contained 2 kgs). The second, an Apollo 13 aborted in 1970 and the LEM returned to earth with the radioisotope capsule. The capsule sustained reentry and impacted in the deep ocean south of the Fiji Islands in at least 20,000 feet of water with the Plutonium-238 contained in multi-containment capsules.

B. Projected Effluent Control Plans

No releases are projected in the future. Systems are designed to remain intact under all normal and all credible accident conditions. Also in the design of future systems, consideration is given to possible search and recovery of aborted systems. Plans and techniques for worldwide search and recovery exist now and are continually being updated. Salt water actuated pingers are standard items on all flights to assist in locating and recovering the Pu-238 in the event of an advertent water impact, should early launch vehicle accidents occur.

Effluent control at the Savannah River is under the Production Programs and at Mound Laboratory is under Weapons Programs, except that the SNS operations at Savannah will be a "dry process" producing no effluents.

C. Containment Test Programs

1. To verify containment design, extensive safety test programs are conducted under all simulated accident conditions: fire, over-pressure, reentry, impact, and post-impact environments.

IV. Projected Waste Quantities

No waste quantities are projected as the result of space operational activities.

Manufacturing site wastes are projected as follows:

1. Savannah River - less than 120 grams/yr, accumulating annually beginning in FY 1978.

2. Mound Laboratory - less than 600 grams in FY 1975 decreasing to less than 50 grams in FY 1980 and thereafter.

3. Transuranium wastes are sent to appropriate AEC burial sites.

DIVISION OF PRODUCTION AND MATERIALS MANAGEMENT

Overview on Plutonium and Transuranic Elements -
Source Terms and Operations

1. Production and Materials Management Program Summary

The nuclear reactors at AEC's Richland and Savannah River plants were built to produce nuclear materials for the Nation's defense program. Continued operations under AEC policies will enable the plants to continue providing protection of the population and the environment from adverse effects of radioactivity while fulfilling the function of producing plutonium and tritium for National defense. The principal product at Richland is plutonium and at Savannah River both plutonium and tritium are produced. Small quantities of other transuranic isotopes such as Np-237, Pu-238, Am-241, Am-243, Cm-244 and Cf-252 are produced at the AEC production sites. The Idaho Chemical Processing Plant, which recovers enriched uranium from test reactor and Navy irradiated fuels, is also a part of the production program.

The Richland plant was initially built during the second world war and has been in operation about 30 years. The original plant consisted of a uranium fuel fabrication facility, three graphite moderated water-cooled reactors, two chemical separations plants for plutonium recovery and decontamination and a facility for the final isolation and purification of plutonium nitrate solution. Production capacity at Richland was expanded on numerous occasions between 1948 and 1962. Six additional reactors were built including N reactor which is a dual purpose reactor producing steam for electric power production in addition to plutonium. Only N reactor is presently operated. The original batch-type plants for the separation of plutonium were shutdown by 1956 and replaced by two continuous solvent extraction plants. Neither of these plants are being operated today but one plant is being held in standby for future operation. Facilities were also provided for conversion of plutonium nitrate to oxide and metal and for the fabrication of weapons components. The fabrication plant has been shutdown for several years and is currently being dismantled. The Richland plant includes facilities for the treatment and storage of liquid radioactive wastes.

The Savannah River Plant was built in the early 1950's and included facilities for fuel and target element fabrication, five heavy water moderated and cooled production reactors, two chemical reprocessing plants for both plutonium and enriched uranium recovery, tritium separations facilities, and a heavy water production plant. Currently, only three reactors are operating. Facilities have been added for the fabrication of targets to be irradiated to produce other transuranics such as Np-237, Pu-238, Am-243, Cm-244, and Cf-252 and for the separation of these products. New facilities are currently being provided to fabricate Pu-238 oxide fuel forms for thermoelectric power sources. Facilities are also provided for the treatment and storage of liquid radioactive wastes.

The Idaho Chemical Processing Plant includes facilities for the separation and purification of irradiated enriched uranium from test reactor and Naval reactor fuels. Facilities are also provided for the temporary storage of liquid radioactive waste which contain transuranic elements. The liquid waste is converted to a calcined granular solid in a fluid bed and subsequently stored in stainless steel bins.

2. Applications of Transuranics

The principal mission of the AEC production reactors is the production of plutonium and tritium for weapon application. However, significant quantities of non-weapon plutonium has been produced in support of the civilian nuclear reactor development program and smaller quantities for foreign sales. Pu-238 is produced for use as a heat source in thermoelectric power for space application and for R&D for possible medical application (pacemakers, artificial heart, etc.). Cm-244 has been used in R&D programs and may be used as a replacement or supplement for Pu-238 in space applications. Cf-252 is used as a neutron source for neutron radiography, cancer therapy, etc.

The AEC has produced several tens of tons of plutonium in its reactors including several tons of non-weapon grade plutonium since the beginning of the production program in the mid 1940's. In addition, 200 kg of Pu-238,

4 kg Cm-244, and 2 grams of Cf-252 have been produced in Savannah River reactors. Additional quantities of transplutonium elements have been produced in Savannah River reactors, separated and refabricated into targets for further irradiation as part of the Cf-252 program.

3. Control Technology

The AEC plutonium production plants control releases of transuranic elements by the following procedures:

1. All process air passes through at least two high efficiency particulate filters (HEPA) before release. All effluents are monitored for releases.
2. Any liquid waste streams containing significant quantities of transuranic elements are stored in waste tanks. Liquids containing extremely low levels of transuranics such as evaporator overheads are released to seepage basins or other controlled facilities.

The total current releases of transuranics to controlled facilities at Richland and Savannah River are about one curie per year while stack releases from Richland and Savannah River average about 0.0013 and 0.02 curies, respectively. Releases to date from our plants are shown in the table below.

Releases of Transuranics in Curies to July 1, 1974

	Richland[1/]	Savannah River[2/]	Idaho Chemical Processing Plant[3/]
Stack Releases - Ci	1.36	3.64	*
Seepage Basins, Ponds, Cribs, Ditches, etc. - Ci	18,750**	20.13	0

* In the separation of enriched uranium at Idaho, fission products and plutonium are separated from enriched uranium. The high level liquid waste which contains the fission products and plutonium is subsequently calcined to a granular solid. In this operation a small

amount of radioactivity is released from the plant stack. The plutonium releases from this operation which are essentially below the level of detection are reported as less than 1 curie per year.

** The true level may be only about 66% of the reported level due to the overstatement of quantities in the Z-9 crib.

In an effort to further reduce releases, the liquid process waste from the plutonium finishing and scrap recovery operation, which was being discharged at Richland to cribs or covered ditches, is being sent to waste storage tanks. At Savannah River, a new sand filter is being built in each of the two separations areas and all air from the plutonium and transplutonium processing operations will be routed through a final sand filter in addition to at least two HEPA filters. At Idaho, a filter is being installed which will substantially reduce stack releases of radioactivity which is principally fission products but contains traces of transuranics.

The AEC has established new criteria for facilities which process or store plutonium including resistance to fires, earthquakes and tornados. Facilities meeting the new criteria are available at Richland for the storage of plutonium as metal, oxide, nitrate solution or scrap. Vaults meeting the new criteria are available at Savannah River for plutonium storage. At Savannah River a new facility is being built within an existing building for converting Pu-238 oxide powder to specific fuel forms. This building is being upgraded to meet the new plutonium criteria. The process air from this building, which will be filtered by from two to four HEPA filters, will be routed through the new F Area sand filter as further backup against potential releases.

4. Future Projections

In the future, if production levels continue at about the same level, the releases of transuranic elements can be expected to be held at about the present level or slightly reduced due to the use of new facilities which are under construction. Increases in the production of transuranic elements with short half-lives such as Pu-238, Cm-244, Cf-252 could

require additional control facilities to control releases at the current level. Such facilities would be provided in accordance with accepted AEC policies; however, at the present time there are no plans for increased production of these elements.

1/ Data taken from [ARH-2806 4Q REV], "Radioactive Liquid Wastes Discharged To Ground In The 200 Areas During 1973", and [ARH-2807 4Q], "Radioactivity In Gaseous Waste Discharged From The Separations Facilities During 1973", and updated with reports for first six months of 1974.

2/ Data taken from draft WASH-1537 Environmental Statement - Waste Management Operations, Savannah River Plant and updated from SR monthly reports.

3/ Data taken from draft Environmental Statement, Waste Management Operations, National Reactor Testing Station.

Overview Reactor Research and Development Program Area
Source Terms and Operations

Prepared for

EPA Public Hearings - 12/10/74

1. Reactor Research and Development Program

For over 20 years the AEC has been engaged in the development of nuclear power reactors to help meet the Nation's need for energy. To date, several reactor systems have been successfully developed and some have come into commercial use. These commercial reactors are now producing about 5 % of the Nation's electricity from the energy released from the fission of uranium, with plutonium as a by-product.

Because of limitations inherent in today's nuclear power plants, only 1 to 2% of the energy potentially available in uranium can be used. The fast breeder reactor, which is in an advanced stage of development can extract 60% or more of the energy in uranium, including depleted uranium, and also utilize the by-product plutonium for the initial fissile fuel. This use of plutonium, through the development of the fast breeder reactor to the point of large scale commercial application would mean the availability of low cost uranium sufficient to provide a large fraction of the Nation's electric energy requirement for hundreds of years, if needed.

Several promising breeder concepts have been investigated and the focus of the AEC reactor development program is now on the sodium cooled Liquid Metal Fast Breeder Reactor (LMFBR). At the same time, other breeder options are being held open by carrying forward technology efforts for breeder reactor concepts such as the Light Water Breeder Reactor (LWBR), the Molten Salt Breeder Reactor (MSBR), and the Gas-Cooled Fast Breeder Reactor (GCFR).

The LMFBR program has as its objective the timely development of technology for a breeder reactor that will offer a commercially competitive and environmentally acceptable option for helping to assure the Nation's long-term electric energy supply. The program recognizes that domestic economic uranium (and thorium) resources are finite and that of the 220 or more nuclear power plants, now in operation, under construction, or on order in the U.S., the preponderance are light water reactors which operate on the uranium-plutonium fuel cycle. The overall LMFBR program for the development of the required broad technological and engineering base, is being carried out by AEC laboratories and by industrial firms at a number of locations throughout the country. This includes many facilities which are variously used to permit testing of physics, fuel, components and instrumentation. Some of these facilities have plutonium inventories.

The total of the plutonium inventories at RRD facilities is in the range of 4000 kgs Pu. Table 1 lists the inventories of plutonium reported by each of the major field offices for RRD programs as of June 30, 1974. Table 2 shows the estimated annual Pu requirements for major RRD programs thru 1986.

Table 1

RRD Pu INVENTORY
MAJOR FIELD OFFICES BY COEI*
TOTAL KGS AS OF 6-30-74
NMIS REPORT P-114

Field Office	Categories 110	120	130	140	150	160	170	180	Total
LASL (Los Alamos Scientific Laboratory)					6.7				6.7
Chicago		786.1		2.8	2661.5		22.6	3.9	3476.9
Oak Ridge		1.8		0.4	3.1		1.2	0.1	6.6
Richland	0.1	266.5	8.4	12.1	524.5		86.5	7.5	905.6
Idaho					0.2				0.2
San Francisco		0.1	0.7	1.4	1.8		0.3	2.4	6.7
Subtotals	0.1	1054.5	9.1	16.7	3197.8		110.6	13.9	4402.1
% of Total	-0-	24.0	-0-	0.5	72.5		2.5	0.5	100.0

*Composition of Ending Inventory

110 Stored, No definite use
120 Stored, Definite use
130 In fabrication or conversion
140 In reactor or critical
150 Misc. R&D (Not included above)
160 Irradiated and unirradiated scrap in recovery
170 Unirradiated scrap stored
180 Irradiated scrap stored

Table 2

MAJOR RRD PROGRAMS REQUIRING PLUTONIUM
(Annual Requirements in Kilograms Total Plutonium) (Rounded)

rogram or roject 1/	1975	1976	1977	1978	1979	1980	1981	1982	1983	1984	1985	1986
FTF Core equirements	870	480	400	160	0	0	800	800	800	800	800	800
RBR Plant	-	-	-	-	460	900	900	430	900	900	*	*
MFBR - ND Program	170	160	140	200	260	240	280	350	350	350	350	350
PR	50	20	0	250	-	500	500	500	500	-	-	-
OTAL	1090	660	540	610	720	1640	2480	2080	2500	2050	1150	1150

dditional Pu for Clinch River Breeder Reactor to be supplied by plant owner.

1/ FFTF - Fast Flux Test Facility

CRBR - Clinch River Breeder Reactor (Demonstration Plant)

LMFBR - Liquid Metal Fast Breeder Reactor

ZPR - Zero Power Reactor

In June 1973 the AEC began preparation of an environmental impact statement on the overall LMFBR Program (WASH-1535) as required by NEPA. The environmental impact statement which was developed, and is now in the final stages of review prior to release, differs from the conventional statement in that the important environmental and societal impacts [which are assessed] would not arise from the proposed research and development activities, but rather from the eventual commercialization of LMFBRs which would be expected if the research and development goals were attained. It was necessary therefore to look ahead some 40 to 50 years to foresee an LMFBR industry that would constitute about 40% of the total installed electric generating capacity in the U.S. by the year 2020.

Many estimates and forecasts were made for this study which could prove useful in assessing the quantities and impacts of the plutonium that would be in use. Pertinent tables from the report will be used in the following discussion. In addition, an intensive cost-benefit assessment was undertaken, considering both the direct and the indirect costs and benefits of the development of the LMFBR.

The direct costs were confined to LMFBR development program costs and to those costs normally imbedded in the price of electrical energy. Calculations for over 70 separate postulated cases were performed to estimate U.S. electrical power production costs over the period 1974 - 2020. One of the major quantifiable conclusions of the direct economic analysis was that the introduction of a fast

breeder into the U.S. electric power utility system will produce significant financial benefits. These benefits result largely from a reduction in uranium ore and enrichment requirements. Additionally, the fast breeder results in a nuclear power industry that will have total power costs, in constant dollars, that decrease with time. Capital requirements accumulated to the year 2020 are estimated to be about 10% less with a fast breeder industry due to the reduced requirement for mining, milling and enrichment facilities.

With the breeder, the nuclear industry can eventually free itself of the need to mine uranium. The advanced oxide fueled breeder, with an estimated 10 year compound doubling time, can meet the fissile fuel demand of a growing nuclear power industry with self-generated plutonium shortly after the turn of the century. Specifically, without the LMFBR, the cumulative U_3O_8 requirement to the year 2020 is 6.3 million tons, while the cumulative U_3O_8 requirement with the LMFBR is 2.6 million tons. Without the LMFBR, U_3O_8 will be mined at an ever increasing rate, while with the LMFBR, the annual ore requirement becomes insignificant after about the year 2015, with similar trends for separative work capacity requirements.

Indirect benefits, though no less significant, come partly from the improved resource utilization. The use of plutonium as a reactor fuel for electric power production would free the finite resources of fossil fuels for their optimum use, thus assuring the domestic

availability of fuel for electric power production for the long term. A mature LMFBR industry together with the non-breeders can generate sufficient fissile material for the nuclear industry to be able to use stockpiled depleted uranium for hundreds of years as the sole source of fertile fuel material. A premium market would be established for the plutonium produced by LWRs. There would also be the potential for substituting electricity for fossil fuels in energy-intensive applications.

Other indirect benefits of note are in the cumulative health and safety effects for both occupational and public groups. Major improvements in occupational health and safety arise from the fact that the LMFBR system does not have associated with it the mining of uranium and replaces fossil plants burning coal. Timely introduction of the breeder could reduce occupational accident fatalities by 3000 persons through year 2020 (and an additional 2000 persons after 2020 due to plants then in operation). In contrast the use of coal instead of nuclear fuel would lead to an additional 51,000 occupational fatalities and 27,000 more public fatalities due to associated fuel transportation accidents.

These are but a few of the conclusions from the extensive study soon to be published, which will be available to the EPA.

2. Applications Using Plutonium

As has already been stated, plutonium is a by-product of the reactors built, under construction and planned by the electric utility industry, both LWRs and High Temperature Gas-Cooled Reactors (HTGRs). Plutonium now is being considered as a potential fuel for recycling in the LWR reactors and as a fuel for the breeder. The AEC Directorate of Licensing has prepared a draft generic environmental statement for the use of recycle plutonium in light water-cooled reactors (GESMO - WASH-1327, August 1974). Starting on page VIII-65 of "GESMO" there is a discussion of the dollar value of plutonium as a reactor fuel for recycling. Using the assumptions stated, plutonium has a near-term value of about $11.00 per gram fissile. Since this value is tied in to the cost of enriched uranium, the value continues to rise to about $16.50/gram fissile plutonium in 1995. As a breeder reactor fuel the value is expected to be considerably higher. These are the prospective values shown in GESMO:

Projected Plutonium Value*
($/gm fissile plutonium)

Year	Pu Value
1975	9.90
1980	11.75
1985	14.89
1990	15.81
1995	16.50

*if recycled promptly in LWR's.

To make the assumed value more meaningful one may look at the quantity of plutonium that will be produced by the commercial reactors and that can be

reused as reactor fuel. AEC's publication, "Nuclear Power Growth 1974-2000" (WASH-1139 (74), February 1974) projects 4 cases. Case D, one of the more conservative cases, assumes a general reduction in the growth of electricity use and some improvement over recent experiences in nuclear plant construction and regulation. Under these assumptions, Case D forecasts the following nuclear generating capacity in thousands of MW:

Year	MW x 10^3	Year	MW x 10^3
1975	47.3	1990	475
1980	102.1	1995	760
1985	250.0	2000	1090

Table 3 taken from WASH-1139 (74), shows the fissile plutonium recovery and utilization in the U.S. using Case D assumptions.

As shown in Table 3, the total plutonium recovered by the year 1995 would aggregate to about .86 million Kg. Assuming a value of $16.50/g in 1995 (according to GESMO) this inventory would be worth about $14.2 billion if it were to be used in recycling, and potentially more as a breeder fuel. Considering the plutonium inventories and their prospective values, it would appear that we are already in a plutonium economy

3. Control Technology - Identification of Source Terms

In the LWR and HTGR fuel cycle, plutonium is present in the irradiated or spent fuel. It is stored for a cooling period and then shipped in shielded containers to a reprocessor for the recovery of plutonium and uranium.[1/]

1/ Environmental Statements have been prepared by Directorates of Licensing and Regulatory Standards, USAEC.

Table 3

FISSILE PLUTONIUM RECOVERY AND UTILIZATION, KILOGRAMS
United States, Case D (Plutonium Recycle, 75% capacity factor)

	RECOVERY					UTILIZATION					
-CY-	LWR	BREEDER	NATURAL AND OTHER	TOTAL ANNUAL	CUMULATED	LWR RECYCLE	BREEDER FUEL	OTHER USES	TOTAL ANNUAL	CUMULATED	YEAR END INVENTORY
1973	0	0	0	0	0	0	0	0	0	0	0
1974	0	0	0	0	0	0	0	0	0	0	0
1975	230	0	0	230	230	0	0	16	16	16	220
1976	2400	0	0	2400	2600	380	0	680	1060	1080	1570
1977	5200	0	0	5200	7800	2400	0	1500	3900	5000	2800
1978	8600	0	0	8600	16400	6300	0	1690	8000	13000	3400
1979	10200	0	0	10200	26600	7400	0	2100	9500	22500	4200
1980	10300	0	0	10300	36900	7900	0	2400	10300	32800	4100
1981	12200	0	0	12200	49100	9700	0	2400	12000	44800	4300
1982	17000	0	0	17000	66200	14900	0	0	14900	59700	6500
1983	21300	0	0	21300	87500	18800	0	0	18800	78500	8000
1984	25300	0	0	25300	112800	23100	0	0	23100	101500	11200
1985	30400	0	0	30400	143200	20500	0	0	20500	130000	13200
1986	35600	0	0	35600	178800	31200	0	0	31200	161200	17600
1987	42800	0	0	42800	221600	35800	3400	0	39200	200400	21100
1988	48300	0	0	48300	269900	41900	820	0	42700	243100	26700
1989	54900	0	0	54900	324800	41200	7200	0	48400	291500	33300
1990	62300	860	0	63200	388000	45000	11400	0	56400	348000	40000
1991	69800	1480	0	71200	459200	46300	18000	0	64300	412300	47000
1992	77900	3000	0	80900	540100	48700	25500	0	74200	486400	53700
1993	86300	6600	0	92900	633100	49400	36200	0	85600	572000	61100
1994	94100	11800	0	105900	739000	48700	48800	0	97500	669500	69500
1995	101100	19400	0	120500	859500	47800	65400	0	113200	782700	76800
1996	108200	29400	0	137600	997100	46100	82400	0	128500	911200	85900
1997	115500	42000	0	157400	1154500	44600	103400	0	147900	1059100	95400
1998	121900	57600	0	179500	1334000	49000	123800	0	172800	1231900	102000
1999	127400	76100	0	203500	1537500	57000	137400	0	194400	1426300	111200
2000	132400	97400	0	229800	1767300	59000	164300	0	223300	1649600	117700

In the LMFBR fuel cycle, plutonium and uranium bearing materials would be combined at the fuel fabrication plant for use in the reactor. After cooling, the irradiated fuel would be shipped in specially built containers to the reprocessing plant. The separated fission products would be solidified and eventually shipped to a waste storage facility[2/] and the plutonium would be recycled as LMFBR fuel. A summary of materials and quantities shipped for a 1000 MW LMFBR is shown in Table 4.

2/ WASH-1539, Draft Environmental Statement" Management of Commercial High Level and Transuranium Contaminated Radioactive Waste" September, 1974.

Table 4

A SUMMARY OF MATERIALS AND QUANTITIES SHIPPED FOR A 1000-MWe LMFBR REACTOR

Type of shipment	Probable mode of transport	Quantity shipped per year[a] (kg)	Quantity shipped per package[a] (kg)	Est. gross package weight (kg)	No. of packages per vehicle	Heat generated per package (W)	Est. activity per package (Ci)	Average No. of shipments per year	Est. average shipping distance[h,i] (miles)	Shipment destination[j]
Unirradiated material										
UF_6	Truck	17,335	8,604	15,090	1		3.21	2.01	750	FP
UO_2	Truck	16,048	97	245	64	2.6×10^{-3}	1.60	2.58	750	FP
PuO_2	Truck	1,679	9	105	64	81	1.04×10^{5}	2.91	750	FP
Fresh fuel – core and axial blanket	Truck	16,123	235	1,820	4	218	2.81×10^{3}	17.15	750	PS
Fresh fuel – radial blanket	Truck	2,702	229	1,820	4	6.3×10^{-3}	3.78	2.95	750	PS
Irradiated material										
Spent fuel – core and axial blanket	Rail	15,462	667	114,000	1	1.33×10^{4}	3.26×10^{6}	22.83	750	RP
Spent fuel – radial blanket	Rail	2,669	681	114,000	1	1.83×10^{3}	4.54×10^{5}	3.92	750	RP

Type of shipment	Probable mode of transport	Quantity shipped per year (ft^3)	Quantity shipped per package (ft^3)	No. of packages per year	No. of packages per vehicle	Heat generated per shipment (W)	Est. activity per shipment (Ci)	Average No. of shipments per year	Est. average shipping distance[h,i] (miles)	Shipment destination[j]
Waste from fuel preparation and fabrication plants										
Alpha waste	Rail	5,000[b]	c	c	c	22.5	2.79×10^{4}	5	1,000	FR/BG
Low-level beta-gamma waste	Truck	21,000[b]	7.4	2,800	64	2×10^{-3}	0.475	45	500	BG
Solid waste from power stations										
Low-level beta-gamma waste	Truck	2,000	7.4	270	64	2.85	475	4.2	500	BG
Tritium	Truck	6.12[d]	0.16	38	64	1.13	3.2×10^{4}	0.60	1,000	FR/BG
Solid wastes from reprocessing plants										
Alpha waste	Rail	770[b]	c	c	c	22.5	2.79×10^{4}	0.77	1,000	FR/BG
Alpha beta gamma waste	Rail	2,000[b]	25	80	3	1.12	500	27	1,000	FR/BG
Low level beta gamma waste	Truck	3,000[b]	7.4	405	64	2×10^{-3}	0.475	6.3	500	BG
Cladding hulls	Rail	165[e]	3.5	47	36	10.3×10^{3}	1.46×10^{6}	1.3	1,000	FR/BG
High level waste	Rail	55	6.28	9	12	2.5×10^{4}	7.8×10^{6}	0.75	1,500	RSSF
Noble gases	Truck	1.7[f]	1.7[g]	1.0	6	1.47×10^{3}	9.0×10^{5}	0.164	1,500	NGSF
Iodine	Truck	0.078	0.16	0.5	64	1.0×10^{-3}	1.46	0.0076	1,000	FR/BG

[a] All quantities of materials shipped are given in kilograms of heavy metal.

[b] Compacted a factor of 10 from original volume generated.

[c] Alpha waste is packaged in 55-gal (7.4-ft^3) drums and large boxes; each rail car contains 1000 ft^3 of waste.

[d] Shipped as $Ca(O^3H)_2$.

[e] Hulls compacted to 8.8 ft^3 per ton of fuel.

[f] Compressed gas at 2,200 psi.

[g] Standard gas cylinder.

[h] Estimated distance to one-of-a-kind repository, 1500 mi; between facilities, 750 mi; to multiple burial ground sites, 500 mi.

[i] Distance of 1000 mi is a compromise between 1500 mi to one-of-a-kind repository and 500 mi to multiple burial ground sites.

[j] FP: fabrication plant; PS: power station; RP: reprocessing plant; FR: Federal repository; BG: burial ground, RSSF: retrievable surface storage facility; NGSF: noble gas storage facility.

The estimated releases of alpha-emitting transuranic elements from normal operations of the LMFBR fuel cycle are summarized in Table 5. The principal airborne release is from the fuel reprocessing plant, totaling 0.36 mCi per 1000 MWe-year. Other airborne releases are small by comparison. Liquid transuranic effluents are assumed to occur only for the fuel fabrication plant and are estimated at 0.05 mCi per 1000 MW-year.

The estimated population dose from alpha-emitters expected from operation of the LMFBR fuel cycle is shown in Table 6. The estimated man-rem exposure from LMFBR transuranic releases is shown in Table 7.

In addition to normal operational experience various accident situations were postulated in developing the environmental impact statement for the LMFBR program. Estimated releases of transuranic elements for major accident categories are summarized in Table 8 which shows only those quantities of material estimated to pass all containment barriers which have been designed into the system. The total plutonium released annually due to postulated transportation accidents would average less than 10^{-6} Ci per year associated with the operation of a 1000 Mw LMFBR.

Table 5

ESTIMATED RELEASES OF TRANSURANIC ELEMENTS DURING NORMAL OPERATION OF THE LMFBR FUEL CYCLE

Facility or Process	Release Mechanisms	Protective Systems	Nature of Release	Radio-nuclide	Quantity (Ci/1000 MWe Yr)
Fuel Repro-. cessing	Particles entrained by gas from all parts of process	Process equipment, cells, and HEPA[b] filters (CF[c] = 2×10^9)	Airborne particles of PuO_2 or $Pu(NO_3)_4$ AMAD[c] ~ 0.3 μm	Pu-238	$.18 \times 10^{-3}$
				Pu-239	$.04 \times 10^{-3}$
				Pu-240	$.05 \times 10^{-3}$
				(Pu-241)[d]	(5.4×10^{-3})
				Am-241	$.01 \times 10^{-3}$
				Cm-242	$.07 \times 10^{-3}$
				Cm-244	$.01 \times 10^{-3}$
				Total α	$.36 \times 10^{-3}$
			liquid		zero
Fuel Fabrication	Particles entrained by gas, principally from PuO_2 powder grinding	Glove boxes, roughing and HEPA filters (CF = 10^{12})	Airborne particles of PuO_2 AMAD ~ 0.3 μm	Pu-238	$.36 \times 10^{-6}$
				Pu-239	$.07 \times 10^{-6}$
				Pu-240	$.10 \times 10^{-6}$
				(Pu-241)[d]	(10×10^{-6})
				Am-241	$.02 \times 10^{-6}$
				Total α	$.55 \times 10^{-6}$
			liquid	Pu-238	$.030 \times 10^{-3}$
				Pu-239	$.006 \times 10^{-3}$
				Pu-240	$.008 \times 10^{-3}$
				(Pu-241)[d]	$(.91 \times 10^{-3})$
				Am-241	$.002 \times 10^{-3}$
				Total α	$.046 \times 10^{-3}$
Reactor	Failed fuel to sodium to cover gas	Cover gas purification system			negligible

Table 5 Continued

Facility or Process	Release Mechanisms	Protective Systems	Nature of Release	Radio-nuclide	Quantity (Ci/1000 MWe Yr)
Waste storage	Exhaust air from receiving and handling areas	HEPA filters			$< 1.5 \times 10^{-6}$ [f]
Transportation					zero

[b] HEPA = high efficiency particulate.
[c] AMAD = activity median aerodynamic diameter.
[d] Beta emitter not included in totals. The 5.4×10^{-3} Ci of Pu-241 decays to produce an additional 0.16×10^{-3} Ci of Am-241, which is included as a part of the source term, where appropriate.
[e] CF = Confinement factor = Ci processed/Ci released.
[f] The estimated normal release of radioactivity from waste storage is 1 mCi/yr (4.6.3.1); this includes all radioisotopes, the isotopic distribution of which will depend upon a number of variables. The RSSF is forecast to hold all of the commercial high-level waste produced through the Year 2000, including all types of reactors. In order to be conservative it is assumed that the entire 1 mCi consists of α-emitting transuranics solely from the LMFBR power capacity during a given year only (1999). (This ignores cumulative power production up to 1999 and radioisotopes other than the α-emitting transuranics.) In 1999 LMFBR generating capacity is estimated at 178 1000 MWe-year [derived from the metric tons of uranium fabricated in that year (3090 - Sect. 4.1) and the metric tons of uranium required per 1000 MWe-year reactor (17.335 - Fig. 4.5-1)]. In addition, there will be 20,170 metric tons of uranium fabricated for other types of reactors (Table 4.1-1). Assuming that the quantity of high level waste is approximately the same from all types of reactors (see 9.1.2), then

$$1 \text{ mCi} \times \frac{3090/23260}{178} = 1.3 \times 10^{-3} \text{ mCi, or } < 1.5 \times 10^{-6} \text{ Ci.}$$

Table 6

ALPHA-EMITTING RADIOISOTOPES IN THE POPULATION OF THE UNITED STATES

Source	Amount of Alpha Emitters in U.S. Population (curies)	Population Dose from Alpha Emitters in U.S. Population (man-rems/ 70 year lifespan)	
		Bone	Lung
Natural Radioactivity	$> 10^{-1}$ [a]	$> 7 \times 10^{8}$ [a]	$> 7 \times 10^{8}$ [a]
1000-MWe-year LMFBR	$< 10^{-8}$ [b]	< 30 b	< 4 b

[a] Source: Ionizing Radiation: Level and Effects, Vol. I, "Levels," United Nations, New York, 1972.
[b] See Table 4.7-2

Table 7

ESTIMATED MAN-REM EXPOSURE FROM FALLOUT PLUTONIUM AND FROM LMFBR TRANSURANIC RELEASES

Organ	Dose Equivalent To Current Generation from Fallout Pu[a] (man-rem)	Dose Equivalent to all Subsequent Generations from LMFBR Transuranic Releases (man-rem)	
		For Generating Capacity of 1000 MWe-Year[b]	For Year 2020 Generating Capacity of 2,200,000 MWe-year
Lung	3.0×10^6	4	0.9×10^4
Bone	1.4×10^6	17	$4. \times 10^4$
Liver	0.8×10^6	7	$2. \times 10^4$
Lymph nodes	100×10^6	200	40×10^4
Gonads	----	0.23	0.05×10^4

[a]Estimate of Bennett, based on New York City air concentrations.[60]

[b]Derived in Tables II.G-10 to II.G-14.

Table 8

ESTIMATED RELEASES OF TRANSURANIC ELEMENTS DUE TO MAJOR ACCIDENTS ASSOCIATED WITH THE LMFBR FUEL CYCLE

Facility or Process	Type of Accident	Nature of Release	Quantity of Alpha-activity Released (10^{-3} Ci) per Accident	Quantity of Alpha-activity Released (10^{-3} Ci) per 1000 MWe-Yr[a]
Fuel Reprocessing[b]	Leakage of Highly Radioactive Material	to air	1.8	.002
	Solvent Fire	to air	0.11	.0001
Fuel Fabrication[b]	General Facility Fire	to air	3.7	.005
	Criticality	to air	0.18	.0002
Reactor[c]	Class 9 Core Meltdown with Breach of Primary Containment	to air	37	.00004
Waste Storage[d]	Rupture of Dropped Canister	to air	0.4	.002
Transportation[e]	Railcar Fire	to air	1.4	.0003

FOOTNOTES FOR TABLE 8

[b] Beta emitter not included in totals.

[c] Assumes one accident of the designated type, per fuel cycle facility, per 10-year interval (discussed in text).

[c] The calculated release of plutonium to the environment from a hypothetical core disruption accident in a 1000 MWe-yr LMFBR is 0.1 gram (Sec. 4.2.7.8.3). Assuming that the alpha-emitting transuranic radioisotopes released in a HCDA consist of the same isotopic distribution, by weight, as that normally released by a fuel reprocessing plant (Table II.G-1), the activity released is as follows:

^{238}Pu	18.7 mCi
^{239}Pu	4.3 mCi
^{240}Pu	5.3 mCi
^{241}Pu	577.4 mCi
^{241}Am	1.1 mCi
^{242}Cm	7.3 mCi
^{244}Cm	0.1 mCi
Total	614.2 mCi
Total α-emitting transuranics	36.8 mCi

The probability of a core meltdown with a release from the primary containment vessel with subsequent leakage of 0.1 gram plutonium through secondary containment for a 1000 MWe yr is less than 10^{-6}.[4] Assuming a risk of 1 in 10^6 per year, or 1 in 10^6 reactor-years, then 36.8 mCi ÷ 10^6 reactor-years equals 36.8 mCi x 10^{-6}, or 36.8 mCi per reactor-year. A maximum credible accident is estimated to release approximately 10 mCi of activity to the environment (Sec. 4.6.3.1.5). Of the waste inventory anticipated in the Year 2000, 4.5% is expected to consist of α-emitting transuranic elements ("Retrievable Surface Storage Facility Alternative Concepts: Engineering Studies," Atlantic Richfield Hanford Company, July, 1974, ARH-2888 REV, Table 10-II). Therefore, assuming a similar isotope distribution, of the 10 mCi released, 0.45 mCi would be α-emitting transuranic isotopes. If LMFBR power capacity (1999) is 178 1000 MWe-yr (see Table II.G.1-1), then the release per 1000 MWe-yr is 2.5 μCi. (This ignores power produced in previous years and so is conservative on a per unit basis.)

[e] Of the 58 mCi Pu release given in 4.5.5.4, 2.4% consists of α-emitting radioisotopes (Appendix II.N.4). The number assumes a total of six 1000 mile alpha waste shipments required per 1000 MWe-year (4.5, Table 4.5-12) and 2.23 accidents per 10^6 railcar miles (Appendix II.C). There would be only 6 x (2.23 x 10^3) / 10^6 = 13 x 10^{-3} accidents per year involving alpha waste shipments by rail. About 1.5% of all rail accidents involve fire (Appendix II.A). Thus, there would be about 2 x 10^{-4} alpha waste rail car fires per 1000 MWe-year. Alternatively, there would be one such fire for every 5 x 10^3 1000 MWe-years. Thus, the addition of this accidental release would add 1.4 mCi/5000 = 0.0003 mCi to the routine release of 0.36 mCi per 1000 MWe-year. Americium-241 buildup from the decay of plutonium-241 would increase this to 0.0006 mCi per 1000 MWe yr.

The development of reactor technology that would be reliable and safe and reduce radioactive effluents including the transuranics, to levels that are as low as practicable has been one of the concerns of the Division of Reactor Research and Development from the beginning. One example is a current research and development program to further reduce the effluents expected in the reprocessing of LMFBR fuels to meet as low as practicable guides. This concern for public safety from man-made sources of radiation has been a feature of the fuels program, the engineering and components development program and is a major concern of the reactor safety activity of the division, as well as the statutory requirement of the AEC.

SOURCE TERM FOR TRANSURANIC MATERIAL OF WEAPONS ORIGINS

The principal environmental contaminant will be weapons plutonium. Initially, the major alpha source following a weapons plutonium release incident would be 239-Plutonium. After a decay-growth period, then would be added 241-Americium at a substantial level relative to the 239-Pu level.

The amounts of plutonium involved in the U. S. weapons program are necessarily classified. As an unclassified approximation it can be stated that yearly plutonium processing is on the order of 100,000 Curies.

The only reason for U. S. weapon plutonium to enter the environment would be from accidental circumstances. Historically, the AEC's accidental releases have taken place during production. Most plutonium fires are fully contained within the production facility; however, plutonium contamination has escaped in fractional curie amounts during one or possibly two fires. Contamination in amounts from 10 to 100 Curies escaped in a waste spill from rusted waste storage drums. Improved methods and facilities make the possibility of these types of release highly improbable. Based on accident history, releases of transuranic contamination from the AEC's weapon program total less than 100 Curies. Future accident release potentials from the weapons program are conservatively estimated at 1 Curie per year for five years lowered to a small fraction of a Curie per year after 1980 due to better facilities and improved performance. Future releases from routine operations of the weapons program are estimated at 0.01 Curies per year.

While the U. S. no longer conducts atmospheric testing of nuclear weapons, foreign atmospheric testing and other foreign nuclear weapons operations might continue to contribute 500 to 5,000 Curies per year until there is a complete stop to atmospheric testing.

COSTS OF PLUTONIUM FACILITY IMPROVEMENTS

Expenditures for fire safety and operating conditions improvement in plutonium facilities following the fire at Rocky Flats have been greater than $240 million. Major items are tabulated below:

1. Rocky Flats Plant - $155 million

   a. New Plutonium Recovery and Waste Treatment Facility

   b. Filter Plenum Improvements, Various Manufacturing Buildings (four buildings - two tunnels)

   c. Liquid Plutonium Waste Treatment Facility Improvements (Building 774)

   d. Inerting Hazardous Gloveboxes, Various Manufacturing Buildings

2. Los Alamos Scientific Laboratory - $75 million

   New plutonium processing facilities and improved fire protection.

3. Pantex Plant - $1.7 million

   Mainly fire protection for production facilities.

4. Mound Laboratory - $1.6 million

   Fire protection and fire detection in gloveboxes.

RADIOACTIVE MATERIAL SPREAD BY WEAPONS FIRE

An accident occurred at McGuire Air Force Base in 1960 in which a missile containing a nuclear weapon burned. Certain aspects of the physical situation at McGuire would probably be pertinent to many weapon fire circumstances: (1) a weapon containing plutonium and explosives was involved, (2) the weapon was housed in an enclosed structure, (3) water was used to fight the fire, and the fire occurred in the presence of quantities of jet fuel. No HE detonation took place.

The explosive burned along with the jet fuel with an intense heat for nearly an hour. The plutonium became melted and much of it puddled under the burned out missile. No criticality problems occurred. The detectable plutonium spread was mostly limited to the area covered by smoke and water from fire fighting efforts. Environmental monitoring conducted on the day after the accident showed almost no contamination scatter. Zero ground contamination was found beyond 100 feet from the accident location. Some close-in contamination was found; evidently this was associated with fire-fighting water. No air contamination was detected.

While the cost due to decontamination and loss of the weapon was high, the overall magnitude of the accident was less than that which might have resulted from a one-point detonation and caused no serious off-site effects. Under these or similar circumstances, the off-site effects of this type of accident at a weapons maintenance facility would probably be much less severe than those for a one-point detonation.

WEAPON RADIOACTIVITY SPREAD BY DETONATION IMPACT

On January 17, 1966, a B-52 aircraft carrying four nuclear bombs collided with a KC-135 tanker over Palomares, Spain, during refueling operations. Four bombs broke free in the crash as the disabled aircraft plummeted near the village. One fell in a steep bank of soft earth and did not detonate. One fell into the sea and was later recovered. However, the HE components of two weapons did detonate upon impact; one in low mountains and the other on land used for agriculture. The wind velocity at the impact site was approximately 30 knots at the time of the impact and the area contaminated by plutonium from the detonated weapons was long and narrow. The area contaminated from 3.2 to 32 $\mu Ci/m^2$ was slightly over one-half mile long and one-sixteenth of a mile wide, with plutonium detectable to a distance of approximately two miles.

As mentioned above, the high explosives in two of the weapons detonated on impact. The quantity of plutonium involved in these weapons remains classified. Evidentially, much of the plutonium involved in these detonations was converted into a fine, oxide and was dispersed by the 30 knots wind which prevailed at the time of the accident. The Air Force survey showed that the 32 $\mu Ci/m^2$ level covered something over five acres with an additional 41 acres contaminated to more than about 3.2 microcuries per square meter. An additional 500 acres were found to be contaminated to greater than 0.32 $\mu Ci/m^2$.

The Air Force did careful appraisals to learn the whereabouts of all radioactive material and radioactive contamination following the accident. Most of the aircraft wreckage was found to be uncontaminated or to have negligible contamination. All of the wreckage with slight contamination was gathered and disposed of by dumping in deep, remote Atlantic waters. More contaminated wreckage was picked up, packaged, and transported to the United States for disposal.

No plutonium or tritium contamination was found in the sea water at any time following the accident nor was any tritium found at the impact sites or anywhere in the Palomares area higher than background.

Shortly after the accident, United States experts met with officials from the Spanish Government to advise and assist Spain in handling this contaminating accident, and to decide upon criteria for disposal of contaminated soil. It was agreed that soils contaminated with more than 32 $\mu Ci/m^2$ would have the top 10 centimeters (four inches) removed for disposal in the United States. Areas with less contamination (3.2 to 32 $\mu Ci/m^2$) would be plowed to a depth of about 30 centimeters.

Based on the agreement reached with Spain on the decontamination process the top four inches of soil for the area which had been contaminated at greater than 32 $\mu Ci/m^2$ were removed from approximately 5.4 acres and placed in drums for shipment to a United States storage site; approximately 550 additional acres which had been contaminated to less than 32 $\mu Ci/m^2$ were plowed to a depth of about 30 centimeters.

While it had been agreed to plow areas having contamination levels greater than 32 $\mu Ci/m^2$, in the actual field operation areas plowed included all down to about 3.2 $\mu Ci/m^2$ where feasible. Crops grown on soil on the area which had been contaminated to more than 32 $\mu Ci/m^2$ were also shipped to the United States for burial, while those grown on the deep-plowed soil in the area which had been contaminated to less than that figure were burned at the sea shore on days when the wind was blowing toward the sea.

After the decontamination was finished, lung counts for radioactivity were taken on the 100 villagers most likely affected and no positive counts were found in the group. Urine samples for plutonium were negative for 70 persons and showed only insigificant amounts for the others (0.1 to 0.2 dpm in a 24 hour sample).

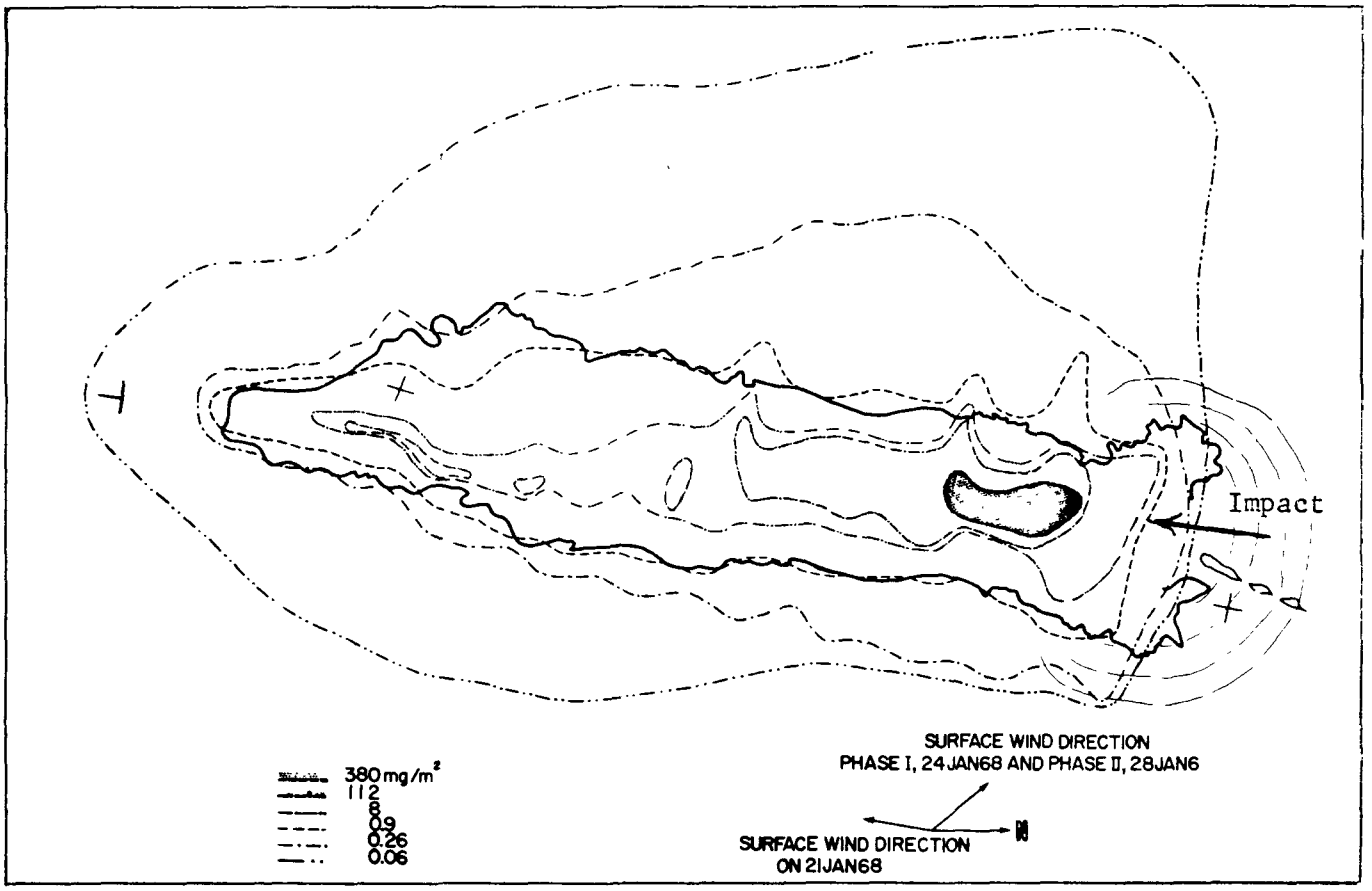
In 1971, six years after the accident, there appeared to be little change in the community from the time before the accident. Farming habits have changed, but mostly due to other factors such as drought, flash flooding, and economics. Followup studies show little change in exposed persons and none is expected.

RADIOACTIVE MATERIAL SPREAD BY AIRCRAFT CRASH

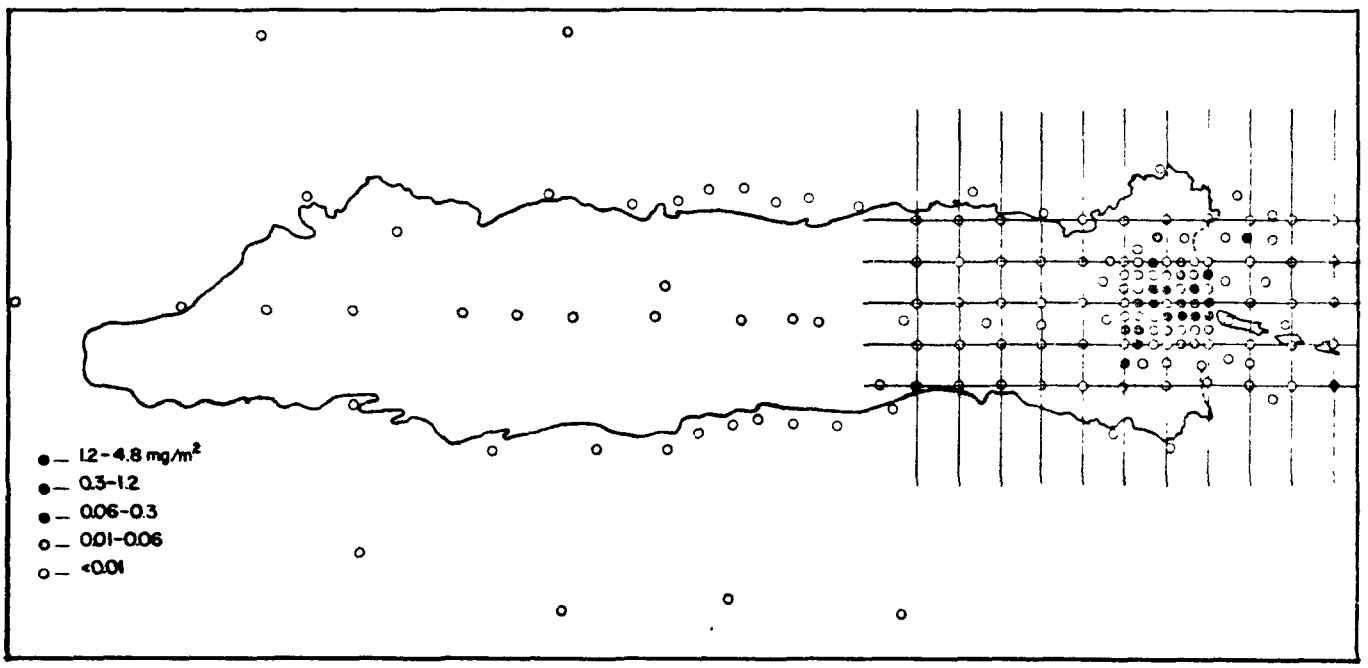
An aircraft carrying four unarmed nuclear weapons crashed on ice in the Arctic while attempting an emergency landing necessitated by an on-board fire. The angle of impact of the main body of the plane was about 15°. The left wing was about 60° low, and the velocity of impact was estimated at 500 knots or greater. At impact, it appears that the high-explosive components of all four weapons detonated, dispersing the plutonium in the devices into the conflagration resulting from ignition of the jet fuel, all of which was released with high forward velocity at the instant of impact and detonation of the weapons' high-explosive components.

The gross weight of the plane was about 1.9×10^5 kg, of which 1.0×10^5 kg (35,000 gallons) was JP-4 fuel. The perpendicular momentum vector would be attenuated very fast by the inertia of the ice and water and the binding and crush strength of the ice (30 to 40 inches thick), while the parallel vector would undergo relatively slow attenuation, resulting in a great forward splash of fuel and debris. This deduction was clearly indicated by an aerial photograph of the crash site, showing a long patch of black discolored ice extending away from the aircraft's impact point (See figure).

At impact, there was a large explosion and intense fire. The fire continued to burn for at least 20 minutes. Actual measurements of the cloud showed a height of approximately 2400 feet and a length of about



Plutonium contamination levels observed.



Ice core sample locations.

2200 feet. At the earliest possible time, the crash site was monitored for occurrence of nuclear criticality. Absolutely no evidence was obtained of any nuclear yield, limiting the problem to one of contamination of the broken ice in the impact area and the surface of the packed snow by plutonium, tritium, uranium, plane debris, and jet fuel.

The plutonium in the accident was converted largely to oxides by the explosion and fire. The plutonium oxide was dispersed as fine insoluble particles (from fractions of a micron to several microns in diameter). Plutonium oxide is notoriously insoluble; its solubility in sea water at 20°C is only 20 micrograms (μg) per liter. Particles of plutonium oxide were impinged into all bomb and plane surfaces struck by the high-explosive shock wave, entrained and carried forward in the splashing fuel, blown into the crushed ice at the impact point, and carried aloft in the smoke plume along with the combustion products of the burning fuel.

At the time of the crash, there was a 6-knot wind blowing from slightly east of north to slightly west of south. There was a stable inversion at approximately 2400 feet altitude and no turbulence. This stable condition persisted for several hours after the crash. Three days after the crash, a surface wind of about 25 knots (with gusts up to 45 knots) persisted for approximately 12 hours. Four days later, a similar storm occurred which persisted for about 24 hours. These winds blew from southeast to northwest, spreading some surface contamination in the downwind direction.

TECHNICAL INFORMATION

Following the accident, certain technical information was obtained, including: amount, distribution, particle size, and mode of fixation of plutonium in the crushed and refrozen ice in the impact area; the amount and distribution of plutonium contamination remaining on the surface; particle size, depth, and degree or mode of fixation of plutonium in the surface crust; tenacity of fixation of plutonium to the metal debris of the aircraft in the event large, highly-contaminated pieces went through the ice; monitoring of the bottom end of ice core samples taken around the impact area in the event large pools of contaminated jet fuel had been trapped beneath the unbroken ice; and sampling and analyzing snow surfaces along nearby shorelines.

Surface Distribution of Plutonium

It appears certain that a large fraction of the fine debris from the disintegrating aircraft and the plutonium oxide from the weapons were entrained in the large amount of JP-4 fuel released and projected forward by the impact and detonation of the weapons' high-explosive components. When the ignited fuel dropped back to the surface of the snow, it continued to burn until oxygen and temperature dropped below combustion levels. Extinction of the fire left a large quantity of unburned fuel, particularly in the blackened crust, some of which percolated down into the white snow pack beneath. The fuel that went below the blackened zone, however, carried little or no plutonium with it. From 1 to 40 percent of jet fuel on-board may remain unburned at the crash site, depending on the porosity and other characteristics of the surface

over which the fuel is spread. Packed snow would appear to constitute a porous surface. In this incident, estimation of the jet fuel in random samples of the blackened crust suggests that about 18 percent (1.9×10^4 kg, 6500 gals.) of the fuel remained unburned.

Microscopic and autoradiographic examination of solids filtered from melted samples of blackened crust showed plutonium oxide particles frequently associated with small fragments of debris of all kinds (metal, glass, and nylon fibers, plastic, rubber, flecks of paint, etc.).

The significance of these observations, of course, has to do with the ultimate distribution of the plutonium in the event large amounts of the blackened crust were allowed to break up with the ice and melt. The fact that large amounts of jet fuel are involved, in which the plutonium associated with low specific gravity debris may float, could result in contamination of the shore line during the summer season.

Plutonium Surface Deposition from Monitoring Results

Large-area monitoring was accomplished by running two radial grids, and the immediate vicinity of the crash site was monitored according to a rectangular grid (50-foot intervals). On another occasion the crash site was monitored at 50-foot intervals along the long axis of the blackened pattern and along three diagonals (readings at 25-foot intervals), one on each end and one near the middle. The counts per minute readings along each grid line and radial were plotted and fitted with smooth lines, from which interpolations were taken for contour plotting using the combined data. The contour readings were converted to milligrams (mg) of Pu^{239} per m^2 by an instrument calibration factor (determined both in the

laboratory and the field) adjusted by x-ray absorption factors determined through correlations between field readings and laboratory analysis of crust samples representative of the principal contour areas. Integral areas within the contours were determined by planimetry. Total amounts of plutonium were then estimated by integrating the surface concentration of plutonium as a function of area. The plutonium values obtained are probably good to $\pm$ 20 percent out to the edge of the blackened crust area, which corresponds roughly with the 0.9-mg/m^2 contamination contour. This information indicates 3150 $\pm$ 630 g of plutonium on the surface, of which about 99 percent was in the blackened area and would be removed by removing the full thickness of the blackened crust. Assuming removal of crust and packed snow to an average depth of 4 inches, the volume of material removed would be 6,000 m^3 (1.6 x 10^6 gallons). Assuming further that the volume ratio of packed snow to water is approximately 5.0, this would constitute 3.1 x 10^5 gallons of water, which would contain between 2,500 and 3,700 g of plutonium.

Plutonium Particle Size in Crusted Area

The diameters of plutonium oxide particles and the inert particles to which the plutonium oxide particles were frequently attached were measured in two blackened crust samples using a photomicrographic-autoradiographic technique.

The average plutonium oxide particle count median diameter (CMD) was about 2 microns with a standard deviation (σ_g) of approximately 1.7. The average calculated mass median diameter (MMD) was about 4 microns. The MMD of the inert particles with which the plutonium was frequently associated appeared to be 4 to 5 times larger than the plutonium particles themselves.

Lavation of Plutonium from Metal Debris

In order to learn how contaminated metal debris might behave after it reached sea water, pieces of metal varying in weight from 10 to 120 g, which had been recovered from the crash site, were subjected to the washing action of sea water, and the removed activity was determined. Total removal after 41 hours of washing varied from 23 to 89 percent. The rates of removal were different for each sample. All lavation curves, however, tended to level off with time. One might expect the rates of lavation and total amounts of plutonium removed to vary from sample to sample, depending on the velocity at which the plutonium oxide was impinged and on the hardness and nature of the surface against which it was blown.

Amount, Distribution, and Nature of Plutonium Contamination in and Under the Ice in Impact Area

To investigate the distribution of plutonium in and below the ice, a total of 182 core samples (7.5 cm in diameter) were taken. The plutonium activity in the cores was usually segregated into one or two bands associated with blackened material. Some cores showed a single band of activity, ranging from about 5 to 30 cm in thickness. This band was usually near the top, but in a few cases (about 18 percent of the samples in the crushed ice area) it was near the bottom, indicating that an occasional ice cake had been contaminated and inverted. Some cores showed both top and bottom bands of blackened activity. The bands were usually horizontal but were occasionally tipped at a significant angle with respect to the core axis.

Nature or Form of Fixation of the Plutonium

Differential analysis of the plutonium within the cores indicated that about 85 percent (range 75 to 95 percent) was associated with large fragments of material which settled out almost immediately when the cores were melted. Microscopic examination showed the plutonium associated with fragments of fiberglass, rubber, plastic, metal, paint, etc. There was no JP-4 fuel floating on the surface but only a thin film of fine carbonized material. The remainder of the plutonium was retained on the surface associated with this carbonized film. Only about 1 percent was suspended through the water phase as very fine particles. This rapid settling of most of the plutonium decreases greatly the possibility of shoreline contamination from floating debris when the ice melts.

Amount and Spatial Distribution of the Plutonium

As would be expected from the mode of dispersal, no plutonium was found in or on the bottom of the ice except in the immediate vicinity of the primary impact point where the ice was drastically broken, displaced, and refrozen.

The only significant plutonium contamination in the impact area was confined to the vicinity of the point of primary impact where the ice had been severely crushed and broken.

The observed plutonium distribution pattern in this area was highly erratic and suggested a highly segregated pattern probably related to reorientation of blocks of ice displaced at the moment of impact and detonation of the weapons' high-explosive components.

Plutonium Contamination of Land Areas

The amount of plutonium accounted for on the surface within the contours and in the broken ice at the primary point of impact is less that the total inventory of the four nuclear weapons. The remainder of the plutonium was removed with the salvaged aircraft debris and carried up in smoke plume, which had a visible height of about 2400 feet and a length of about 2200 feet. The plutonium carried up in the cloud with fine particles of debris and combustion products of the fuel. The meteorological conditions persisting at crash time and for several hours thereafter caused wide dispersion in a southerly direction. Undoubtedly, the substance of the cloud and the accompanying plutonium traveled hundreds of miles and settled out over a vast area, producing extremely low surface plutonium levels. The amount of plutonium involved in this long-range distribution pattern and associated with salvaged aircraft debris will never be known and can never be estimated perhaps to better than an order of magnitude. However, the low-level surface contamination was measured on land masses in the near vicinity of the crash site. Plutonium analyses of these samples showed contamination levels that were insignificant with respect to producing any risk either to the inhabitants or to their ecology.

Summary

Complete plutonium accountability estimates are only approximate and some of that information must necessarily remain classified. However, it can be estimated that only a small percent of the total plutonium involved in the accident escaped as an airborne aerosol for distribution away from the local area of the accident. The plutonium was distributed

over a relatively small patch of ice about 100 meters wide by 700 meters long where it attached to the surface ice and snow. The balance of the plutonium was attached to aircraft and bomb fragments scattered about the crash location.

After the accident, independent scientists concluded that the amount and distribution of plutonium in the area after the accident was such that it could not be of significance to the health of inhabitants*(as close as about 10 kilometers).

*Even so, all the contamination that was reasonably accessible on the ice was removed so that the amount of remaining contamination was substantially reduced.

Dr. Mills: Thank you, Dr. Yoder.

I have a few comments initially.

When you speak of routine emissions continuing at the present rate, are you talking about a constant amount of material or are you taking into account the growth of the industry?

Dr. Yoder: We are looking at the growth and what we are projecting with the data I presented and the trend that we anticipate with regard to improvements in our facilities and techniques, I think we can conservatively project that those quantities may be what would be added to the environment.

Dr. Mills: Does that include some indication of what new technology you expect to be in existence by the year 2000?

Does it include some anticipation of new technology that might come into existence?

Dr. Yoder: No. Just current technology.

Dr. Mills: But it does include the projected growth?

Dr. Yoder: Yes. Of AEC operations. My comments are directed to AEC, government owned contractor operated facilities and operations.

Dr. Mills: I see. You are not talking about commercial nuclear power plants?

Dr. Yoder: No.

Dr. Mills: Could you indicate from the standpoint of the loss in the inventory of plutonium; that is, the amount that is produced and the amount of handling, would you even like to guess as to what

a ballpark figure might be as to that released fraction?

Dr. Yoder: The difference between what is produced and what is released?

Dr. Mills: One would expect to find in the environment.

Dr. Yoder: I do not believe I would like to take a guess on that one. I do not know anyone who has the answer to that, at least as I understand the question.

Dr. Mills: How do you utilize, then, the information from the accidental releases? That is, one makes a determination of what the developments are. How do you consider these releases in the future assessment of plutonium in the environment?

Dr. Yoder: We are trying to prevent all accidental releases and making substantial progress in containing in facility (building) releases within the facility itself.

I have limited my discussions to routine releases.

Dr. Wrenn will be discussing radioactivity around sites. I would hesitate to answer all questions with regard to accidental environmental situations. But I think he is going to summarize this data for you.

Dr. Mills: On page 4, there is a matter of clarification. In the middle of the page, it reads: "Other indirect benefits of note are in the cumulative health and safety effects for both occupational and public groups."

Would you expand on that?

Dr. Yoder: Yes. As I pointed out, this is a distillation of a

number of pieces of information. Perhaps my distillation went a little too far.

The environmental statement discussed the activity associated with mining of coal, transportation of coal, and other associated options. When one compares the projected impact of the plutonium LMFBR versus these, I think that there was a clear benefit for the working population as well as the general public.

Dr. Mills: Dr. Garner?

Dr. Garner: I do not really have any serious questions. I was concerned to see that you stated there were 13 kilograms of plutonium. Are they free or encapsulated?

Dr. Yoder: They are encapsulated.

Dr. Garner: That is all.

Dr. Mills: Dr. Radford?

Dr. Radford: I have a few questions, Bob.

When you talk about plutonium, which plutonium isotopes are you talking about?

Dr. Yoder: I include the isotopes 239, 240, 241, when I refer to plutonium. I speak of plutonium 238 separately through the paper; I have tried to specifically identify that.

Dr. Radford: How is plutonium 238 separated from plutonium 239?

Dr. Yoder: How is it separated?

Dr. Radford: In these commercial applications which are using specifically plutonium 238 and, I assume, no plutonium 239, how do

they get the plutonium 238 away from it? Or do they manufacture it separately?

Dr. Yoder: I would like to ask Ray Moore who is a specialist in this area, to answer.

Mr. Moore: In producing the plutonium-238, we irradiate neptunium. Then we make a separation of the neptunium from plutonium-238. There is no separation of isotopes. Therefore, the plutonium-238 will contain some of the heavier isotopes of plutonium.

Dr. Radford: In other words, all your discussion pertaining to 238 inventories in commercial operations is because it is made specifically for that, and really does not have to do with isotope separation, while it is uses up a little bit of neptunium-Ok, well, now you have heard a little discussion earlier about which isotopes we are talking about here.

Correct me if I am wrong. Is it not correct that it is predominantly plutonium 238 that we are talking about, if you look at either the production rate of a breeder reactor fuel or the canyon stock fuel that you get, in curies not in grams now, but in curies amounts, you get more plutonium 238 than you get plutonium 239?

Dr. Yoder: I would like to ask Dr. Ed Sinclair to answer that, since he is a breeder reactor expert.

Dr. Sinclair: Dr. Radford, the material that Dr. Yoder has been talking about is material produced in the AEC complex. It is what we call production plutonium. It contains very small quantities of plutonium-238. It is largely plutonium 239.

We have calculated the plutonium 238 content of equilibrium plutonium from Liquid Metal Fast Breeder cycle. It will be about 50 percent of the alpha activity on an activity basis, or on the order of one percent of the isotopes on a mass basis.

Dr. Radford: The Liquid Metal Fast Breeder reactor. How about the garden variety light water currently operating?

Dr. Sinclair: That has higher plutonium 238 content, about two percent.

Dr. Radford: So that would be about 3/4 of the activity?

Dr. Sinclair: In initial fueling, yes, sir. But after equilibrium, it will be reduced.

Dr. Radford: Then the implication in terms of curie activity anyway would be quite different from a civilian nuclear power program, in the AEC facility. Is that correct?

Dr. Sinclair: Very much so.

Dr. Radford: That is what I wanted to get at on that one. So that would also account for the fact, Dr. Yoder, I believe, that the importance of, say, curium or americium of some of the other isotopes is much less in the AEC program than it would be for your power program.

How, I am a little confused as to what you estimate the AEC releases will be, either .1 curie per year or -

Dr. Yoder: If you look at the graph of AEC release, you will find that releases are below .1 curie per year with a few exceptions in the past.

We are trying to project those, and, since we are below that already,

we will be a little comfortable and project .1 curie per year.

Dr. Radford: If a substantial part of that were airborne in the form of small particles, that would be a lot of particles, right?

Dr. Yoder: Yes.

Dr. Radford: Because each particle may contain -

Dr. Yoder: It depends on how you want to specify particles size. You can calculate very easily the number of particles.

Dr. Radford: You mentioned that AEC began its off site montioring program in 1970. Is that correct?

Dr. Yoder: No. The program in 1970 was to improve our monitoring program to where we had a very good inventory, a much better inventory of the plutonium and other radioactive materials in the environment around our plants.

This program has been going on for a number of years, but in 1970 we made a concerted effort to continue to reduce the emissions through several mechanisms, one of which was an enhanced environmental sampling program and documentation on all releases at AEC plants-more specific documentation.

Dr. Radford: With regard to the Rocky Flats fire, did the AEC undertake environmental surveys after that fire?

Dr. Yoder: Yes, the Health and Safety Laboratory, U.S. AEC, has done environmental sampling around Rocky Flats.

Dr. Radford: How far away?

Dr. Yoder: Ed Hardy?

Mr. Hardy: Dr. Radford, the extent of our environmental program

around Rocky Flats consisted of taking soil samples as to a measure of the integrated deposition of intially airborne materials that blew off the site.

We took these samples out to about 30 miles east of the plant, and in some directions, north and south as well, we were able to isopleth these concentrations and inventory the total amount that had been dispersed from the plant site.

Dr. Radford: When was the work done?

Mr. Hardy: This work was done in February, 1970.

Dr. Radford: Are your data consistent with those of Poet and Martel?

Mr. Hardy: Dr. Poet and Dr. Martel did not inventory the entire amount of plutonium that had dispersed from the plant. What they did was to announce that there had been plutonium offsite.

Dr. Radford: They did present isopleths to them, didn't they?

Mr. Hardy: Not that I am aware.

Dr. Radford: You do not know whether your results agree with theirs or not?

Mr. Hardy: Where we had been able to compare sites that were closeby, there seems to be no difference in our data.

Dr. Radford: Were your results published in the open literature?

Mr. Hardy: Yes, sir. They were.

Dr. Radford: Where?

Mr. Hardy: In the Health Physics journal and also in the Health and Safety Laboratory reports.

Dr. Radford: When did that publication appear?

Mr. Hardy: The Health and Safety Laboratory report appeared in August of 1970; the Health Physics article appeared, I think, last December. (Added note: the article appeared in the January, 1974 issue of Health Physics.)

Dr. Radford: Turning to the Mound Laboratory releases, did the AEC sample the sediments in the canal or in the lake or pond or whatever it was?

Mr. Hardy: Mound Laboratory undertook the major environmental sampling offsite. The Atomic Energy Commission through our laboratory did do some sediment sampling, but only as a cross check on the Mound data.

Dr. Radford: The reason I am bringing this up is, Dr. Yoder in his summary statement said there have been releases of plutonium and these have been well publicized.

If one believes the press, apparently they were not well publicized until some non AEC people reported them. Is this correct? Is this a fair appraisal of the way in which the information was gotten out to the public?

Mr. Hardy: I am really not qualified to answer that question because we responded to the Rocky Flats situation at the request of the Atomic Energy Commission headquarters, our parent organization, the Division of Biomedical and Environmental Research.

Up to that time, we were not particularly aware that there was a problem offsite.

Dr. Radford: Is it your conclusion that there is not now a problem offsite and was never one?

Mr. Hardy: I do not know what you mean by problem, Dr. Radford. There is plutonium offsite from the Rocky Flats plant.

Dr. Radford: You would feel that it meets current standards, however those are defined?

Mr. Hardy: I am not qualified to respond to that question. (Added note: this question was discussed thoroughly at the EPA January 10, 1975, public hearings on plutonium in Denver, Colorado.)

Dr. Mills: Dr. First?

Dr. First: Dr. Yoder, you have already stated that your estimates of material releases apply only to AEC and AEC contractors?

Dr. Yoder: That is correct.

Dr. First: Have you also, in your calculations, made any estimate as to what this represents as a total projected release from AEC and non-AEC operations?

Dr. Yoder: No, I have not. I have only done it for AEC activities.

Dr. First: We cannot put this in a proper context, then, for total release?

Dr. Yoder: I cannot at this moment.

Dr. Liverman: Mr. Rogers will be talking in the morning about the regulatory or non-AEC operations.

Dr. First: He will be able to answer this question?

Dr. Liverman: I hope so.

Dr. First: Can you estimate what percent of cleanup is obtainable on the basis of the experience which you related for prior accidents? You indicated that only a very small amount of material remained.

Based on this experience and so on, can you predict what percentage might remain if you were to have another episode of that general nature?

Dr. Yoder: Each incident has been somewhat different. If you give me an incident, I might be able to hazard a guess on what percentage was cleaned up.

Dr. First: I am just trying to get some order of magnitude.

Dr. Yoder: It varies.

Dr. First: Between what and what?

Dr. Yoder: Sixty to ninety percent, perhaps, would be cleaned up.

Dr. First: This would represent future capability, not necessarily past?

Dr. Yoder: That is past experience.

Dr. First: Can we do better than that?

Dr. Yoder: I think so.

Dr. First: How much better, do you think?

Dr. Yoder: It is so site dependent I would hate to hazard a number and then find out we could not do it.

Dr. First: If we had to go back to Spain again, just to pick a name out of the hat, how much better would you be able to do the second time around, having had the experience of the first one which obviously was tackled?

Dr. Yoder: I would prefer to give you a written answer to that question.

Dr. First: I do not mean to push you. I just wonder so we would have some basis.

Dr. Yoder: I would just be picking a number out of the air. I would rather give you a well thought out evaluation than a guess. (Added note: an answer to this question is contained in supplemental information submitted by the AEC. See Vol. 3).

Dr. First: One last question, if I may: You have indicated there are three areas where plutonium is being used at the present time.

One of these would be in the civilian power area, eventually if it becomes commercial?

Dr. Yoder: Yes.

Dr. First: Would you give us any estimates of what percentage of plutonium usage would be in the civilian power program at some date such as 1980, 2000 or 2020?

In other words, if we did not have a civilian power program using plutonium, would there still be a large plutonium industry?

What I am trying to do, again, is to get some idea of what the implications of civilian power is in using plutonium, what it might be on a total?

Dr. Yoder: I do not have an answer. I could try to give one, perhaps, if you wish. Perhaps Mr. Rogers tomorrow will be able to shed some light on that particular question.

Dr. First: Thank you.

Dr. Mills: Dr. Taylor?

Dr. Taylor: No questions.

Dr. Mills: Dr. Yoder, there are two questions here which came from the floor which I would like to give to you and let you respond.

In regard to the stated benefits of the breeder program, does the EIS you referred to include the cost of the safeguards program? If so, what dollar value is assigned to the impact on civil liberties?

Do they include this in the safeguard program? If so, what dollar value is assigned to the impact on civil liberties?

Dr. Yoder: Dr. Sinclair.

Dr. Sinclair: I do not believe any value has been assigned to it because no one knows how to.

Dr. Mills: A ten percent financial benefit was stated for the breeder program. Is this benefit at the usual discount rate when applied to the capital cost, or must a special discount rate, as in the draft EIS, be needed to show the benefit?

Dr. Sinclair: I do not recall a 10 percent financial benefit. That term is meaningless to me. Ten percent discount perhaps was used as one of several cases analyzed.

That is the discount rate at which the extrapolated dollar benefits are brought back to present worth. The answer is, yes, with the 10 percent discount rate, the benefits are still substantial. That is, the ratio of the cost of the program to the accrued benefits, even after a 10 percent discount rate is applied remain substantial.

Dr. Mills: I think it had reference, as Dr. Radford has pointed out, on page 4, the top of the page, the second sentence.

Dr. Sinclair: That has to do with the capital requirements. The capital requirements of the electric utility industry have been estimated with and without the breeder.

The breeder is expected to be somewhat more capital intensive than non-breeding competitors such as light-water reactors; obviously more capital intensive than fossil fuel plants.

Nevertheless, it does offset the need for developing uranium mines, uranium milling, and it does offset the need for additional gaseous diffusion capacity.

These savings in capital otherwise would be lost if the breeder were not present and they would be greater than the additional capital cost estimated for the breeder.

Dr. Mills: Thank you very much, Dr. Yoder.

The next topic is "Environmental Levels" and Dr. Ed Wrenn and Dr. Bennett.

ENVIRONMENTAL LEVELS OF PLUTONIUM AND THE TRANSPLUTONIUM ELEMENTS

by McDonald E. Wrenn, Ph.D.
U. S. Atomic Energy Commission
Division of Biomedical and Environmental Research

part of the AEC presentation at the
EPA Plutonium Standards Hearings
Washington, D. C., December 10-11, 1974

Introduction

My name is McDonald E. Wrenn. I am a member of the biomedical programs staff of the Division of Biomedical and Environmental Research of the United States Atomic Energy Commission. This testimony was assembled with the assistance of the staff of the AEC Health and Safety Laboratory and the Division of Operational Safety. Supplementary written testimony from Edward P. Hardy, Jr. of the AEC Health and Safety Laboratory will also be submitted for inclusion in this presentation.

Objective

This section briefly summarizes information about the locations, amounts, origins and distributions of plutonium and transplutonium elements present in the environment, available for environmental transport, and not readily amenable for retrieval.

The summary and analysis presented here is drawn largely from AEC-generated information in the public domain and selected references are given where appropriate.

Units of measure

The total amounts of plutonium and transplutonium elements will be expressed in curies (Ci) or kilocuries (kCi), the amounts found deposited upon the earth's surface will be expressed in activity per unit area -- in millicuries per square kilometer (mCi/km^2), or activity in soil in

picocuries (10^{-12} curie) per gram (pCi/g), or in the case of air in femtocuries (10^{-15} curie) per cubic meter (fCi/m^3). It will become apparent that the range of activities to which we need to refer exceed 10^{20}.

Environmental plutonium can be described in two general categories namely that which is widely or globally distributed and that which is of limited distribution and attributable to a local source.

Globally distributed levels of plutonium and the transplutonic elements. Estimates of the amount of globally distributed plutonium are shown in Table 1. There are two sources, nuclear weapons testing and space nuclear applications. Our best estimate of the global inventory is 460,000 curies, primarily of plutonium-239 and 240, which are both alpha emitters with half lives of 24,000 years and 6,600 years, respectively. Most of the activity (about 60%) is Pu-239, but the analytical techniques commonly used to measure environmental plutonium cannot distinguish between the 239 and 240, and accordingly the reported measurements which are sometimes expressed for brevity as Pu-239 activity are generally the sum of the two alpha activities. A source of Pu-238, about 17,000 curies was released when an isotopic generator used in the space nuclear program burned up in the atmosphere in 1964.

The estimates of plutonium associated with weapons testing are essentially those made by Harley in 1971[1] updated through 1973. The estimate of globally distributed Pu was based on the results of a soil sampling program conducted in 1970-71 by the Health and Safety Laboratory of the AEC specifically designed to evaluate Pu. Cores of soils were collected around the world at locations selected to best represent the cumulative deposition. From the amount of Pu-239, 240 measured in each sample, the amount per unit area was

calculated. The global inventory in Table 1 was constructed by summing the products of the areas in given latitude bands by the areal density of Pu-239,240 present there.

The total inventory from weapons testing was deduced from multiplying estimates of all fission yields in testing to date by the known yield of Sr-90, and the measured ratio of Pu-239/Sr-90.[2] This ratio has not varied greatly over the years of weapons testing. Estimated in this manner the total Pu-238,239,240 injected into the atmosphere in weapons testing is approximately 440,000 curies. Other transplutonium elements are produced in nuclear weapons testing although relative to Pu only americium (Am-241) is significant in activity, comprising about 25% (110,000 curies) of the present Pu alpha activity. This estimate of the quantity of Am-241 is based on the relative activities measured in soils. A roughly equal amount of Am-241 will build in from already extant Pu-241. An estimate of the amount of curium (Cm-245,246) produced in all weapons tests of 90 curies has also been made using the approach of Thomas and Perkins.[3] This estimate, which is roughly a thousand fold lower than the estimates for Pu and Am, was made by applying nuclide yields determined in a single test to all tests, and is accordingly only approximate.

The great bulk of nuclear weapons testing occurred prior to 1963 and the accumulated deposition from this early testing on the earth's surface is almost complete.

Figure 1 shows the yearly deposition of Pu-239 measured in New York since 1954; 1963 was the year of peak deposition. Figure 2 shows the cumulative deposition which is now increasing slowly. 90% of the current cumulative deposition had occurred by the end of 1965.

The present stratospheric inventory is about 1% of the amount which has been deposited on the earth's surface and the concentration of Pu-239 in surface air sampled at Richland, Washington, since 1962, which is shown in Figure 3 shows that the concentration of Pu-239,240 in ground level air (expressed in disintegrations per minute per thousand standard cubic meters of air) has decreased considerably since the early 1960's.(3) The sustained concentrations of Pu-239,240 in ground level air during the last several years result from nuclear weapons testing in the atmosphere by China and France. The increased ratio of Pu-238/Pu-239 in 1966 reflects the arrival in ground level air of Pu-238 from the SNAP-9A burnup in 1964.

Accordingly the bulk of the plutonium and transplutonium elements produced in weapons testing have already deposited on the earth's surface. At any given terrestrial location, the cumulative accumulation may differ from cumulative deposition depending on the site if erosional processes are at work which may accentuate accumulation or deplete it. In addition the cumulative deposition also may vary with location at a given latitude due to variation in depositional processes such as rainfall. Accordingly, the distribution of plutonium is not uniform on the earth's surface.

Figure 4 shows how Pu-239 was distributed between the northern and southern hemispheres, as of 1970-71. About 250 kilocuries were dispersed in the northern hemisphere and 70 kilocuries in the southern hemisphere making the total global inventory 320 kilocuries. For comparison, about 16 kCi had deposited on the conterminous United States and about 3 kCi on the Australian continent which is of comparable area. The distribution of Pu-239 with latitude should be essentially the same as for Sr-90, shown in Figure 5. The highest deposition of Pu-239 is in the mid-latitudes of the northern hemisphere and it falls off toward the north pole. There is a low in the equatorial region and then a small rise in the mid-latitudes

of the southern hemisphere, again dropping toward the south pole.(2)

The total deposit of Pu-238 is about 7 percent of the Pu-239 and the SNAP-9A debris is a major contributor, particularly in the southern hemisphere. The Pu-238 from the SNAP device almost tripled the global deposit of this plutonium isotope and we know from stratospheric measurements that it has essentially all been deposited.

Figure 6 shows the Pu-239 accumulation in mCi per km^2 at various locations in the United States. Generally the drier areas are lower than the wet areas indicating that precipitation scavenging is an important mechanism for bringing nuclear debris to the surface. Fallout in some western areas is higher per unit of precipitation than in sites along the Pacific coast or east of the Mississippi. Evidence seems to indicate that these are regions where stratospheric debris preferentially enters the troposphere and is deposited. Most of the values for this limited sampling program across the U.S. vary by only a factor of 3 or 4, and within a particular constant rainfall region the variability in deposition appears to be much smaller.

Much information about the distribution and variability of Pu-239,240 in soils can be obtained by comparison with Sr-90 and Cs-137 which have been studied much more extensively.

For example, the vertical distribution of plutonium in soils has been determined at a few sites; whereas the vertical distribution of Sr-90 and Cs-137 have been studied at many. Globally deposited Pu-239,240 is deposited initially as small particles which do not remain indefinitely on the surface. Figure 7 shows the vertical distribution of Pu-239, Sr-90, and Cs-137 in a sandy loam soil sample from New England. Most of the deposited plutonium is in the top 5cm (2 inches) and its distribution is

similar to that of Cs-137. Both nuclides can be found in measurable concentrations down to 20 cm (8 inches) but the amount below 5 cm is only about 20 percent of the total. Strontium-90, by comparison, is less retained in the top soil and can be found to 30 cm (12 inches) so one can conclude that it is migrating at a faster rate than Pu-239 or Cs-137.

Accordingly, the concentration of plutonium inferred from measurements in surface soils will depend on the depth of the sample and the variation of Pu-239,240 concentration with depth. The vertical distribution will most likely change with time at varying rates in different types of soils and different environments. The factors which influence the rate of vertical migration are not well understood and are the subject of active investigation.

In Table 2 the widespread plutonium alpha activity is compared with the total alpha activity from naturally occurring actinides in soil, using the continental United States as a model and assuming that soils contain about 1 pCi/g of both uranium and thorium. Approximately 4.4 million curies of natural alpha emitters are present in the top 2 centimeters of soil of which approximately 1.6 million curies are alpha emitting actinides (Uranium and Thorium). Compared in this manner the concentration and amount of alpha activity from Pu-238,239,240 in surface soils (the top two centimeters) is about 1% of the natural background actinide activity.

Representative concentrations of Pu-239 in air, soil, ocean water, and human tissue[2,3,4,5] are shown in Table 3, all expressed in pCi/g of medium, with selected measurements chosen around 1971 and 1972.

The lowest concentration is found in surface air. This reflects the transient nature of the atmospheric content. Ocean water, soil, and human

tissue all show higher concentrations partly as a result of accumulation of material over many years. Surface ocean water was typically an order of magnitude higher than air but much lower than soil due to efficient dilution to great depths. In addition there has been some removal to the marine sediments. The concentration in human lung tissue reflects continued accumulation from air by breathing and the relatively slow removal of material from lung or lymph tissue (see Bennett's testimony).[5] The highest concentrations are observed in surface soils. These relatively higher concentrations result from the cumulative nature of the deposit on the surface and the very slow downward rate of migration into the soil.

There are to my knowledge no good estimates of the total amount of globally distributed plutonium in biota. However, this has been studied in local ecosystems[6].

Local Accumulations

Local accumulations of plutonium may occur in association with specific facilities or activities. Table 4 lists the estimated local cumulative releases and inventories in excess of 0.1 curie which are environmentally available for a selected number of AEC and AEC contractor sites. These estimates are drawn from cumulative measurements of liquid and gaseous releases, evaluations of non-routine releases such as accidents, annual routine environmental surveillance reports, and environmental measurement programs designed to provide information on environmental inventories. Because soil measurement programs, useful for estimating the amount in the environment from soil measurements alone, are still in progress at

most facilities, estimates of environmentally available amounts may change as more complete information becomes available. In Table 5 the maximum off-site surface soil concentrations which have been observed are listed. These values are drawn from the reported environmental surveillance program results for individual operational facilities and sites.(7) The results of the environmental surveillance program for all sites are reported annually in the EPA publication of Radiological Health Data. In addition, a compendium of the results of all sites and facilities programs is assembled annually as an AEC report.(8)

The sources fall in five general categories, which are nuclear weapons testing, nuclear weapons accidents, major AEC production and test sites, AEC contractor industrial type facilities, and purposeful release of wastes under controlled conditions to the environment. Nuclear weapons testing can be a source of local contamination both surface and sub-surface. The U.S. test areas include the Nevada test site and the pacific testing sites, Bikini and Enewetak. An extensive radiological survey and evaluation has been completed for Enewetak[9] where concentrations in soil range from 30 to 3000 pCi/g. This evaluation concludes that the Pu present will not seriously limit the reinhabitation of the atoll. In fact the most limiting nuclide in terms of dose is Sr-90.

The behavior of environmental Pu has been under study at the Nevada Test site for many years. Early intensive studies were conducted during and following tests, and presently intensive studies are underway to evaluate the environmental behavior of Pu which has been in situ from one to close to two decades. Under investigation are such aspects as the vertical and horizontal migration of Pu and Am in soils, the factors which affect resuspension, and the particle size of resuspended Pu.(10) An

inventory of material available from such testing at the Nevada Test Site is underway but not complete. Most of the material on the surface of the site is inside government site boundaries. Some of it is available for transport by wind but much of it has been either weathered or treated to minimize redistribution.

Nuclear weapons accidents near Palomares, Spain (1966), and Thule, Greenland (1968), resulted in local environmental contamination. Extensive decontamination was effected at each site. From the Thule accident[15,16] it may be estimated that about 25 Ci are in marine sediments and surface soils. The residual plutonium in Spain is being followed by the Junta de Energia Nuclear.[17,18] These accidents are discussed briefly in the supplementary material provided.

There has been little offsite environmental contamination at major AEC development, production and testing facilities, including Hanford, Idaho, Savannah River and Oak Ridge. The amounts of materials stored in wastes at these facilities were discussed in section B as well as releases onsite to treatment and disposal systems such as seepage basins. Only small portions of these have become environmentally available. This question is treated in environmental statements being prepared for the major AEC production and testing sites.[9] The environmentally available amounts (i.e., available on the surface for transport by wind) are not well known. However, it is probable that these numbers do not exceed a few tens of curies. For example, at Savannah River about 5 Ci has been released to the atmosphere and surface soils, of which approximately 2 Ci is estimated to be outside the site boundaries. However, the cumulative amounts measured

in soil at the site boundary (1.9 mCi/km^2 for 10 cores taken at 4 locations) are not distinguishable from the background levels from global fallout (1.8 mCi/km^2 at 160 km radius, 10 cores from 3 locations).[11]

Another category consists of industrial type facilities such as Mound Laboratories and Rocky Flats. Pu contamination of the environment around Rocky Flats has been reasonably well documented and is described in a series of HASL reports published in recent years.[12,13,14] Our best estimate is that several curies are distributed off-site and on the order of ten curies in surface soils on-site.

The following are examples of purposeful release of wastes to the environment. The U.K. for many years has made it a policy to dispose at sea of some of their intermediate level wastes which contain plutonium and americium. Upwards of 3000 curies of α activities have been disposed of in this manner from a pipe at Windscale into the Irish Sea; this activity is probably half Pu and half Am. Between 1951 and 1963 the U.S. disposed at sea of about 6400 Ci of drummed wastes described as plutonium contaminated. In 1971-72, the European Nuclear Energy Association disposed of a large number of 55 gallon drums of solid wastes containing an estimated 1300 curies of alpha-emitting wastes. Local releases in foreign countries other than the examples just cited have not been summarized here, although they may influence local radionuclide concentrations.

In summary, it may be concluded that the major transuranic activity in the environment is composed of plutonium and americium from weapons testing and that this material is detectable in surface soils around the world, although their presence raises the alpha background in surface soils

generally less than 1%. The Pu and Am activity per gram near the surface will decrease slowly with time. Finally, local sources of plutonium although much smaller in quantity than that from globally distributed weapons testing fallout can result in concentrations of Pu in soil exceeding the concentrations of the global level from weapons testing.

Selected References

1. J. H. Harley, "Worldwide Plutonium Fallout from Weapons Tests," p. 13-19, Proceedings of Environmental Plutonium Symposium LA-4756, Los Alamos, New Mexico, 1971.

2. Testimony of Edward P. Hardy, Jr., "Worldwide Distribution of Plutonium"

3. C. W. Thomas and R. W. Perkins, "Transuranium Elements in the Atmosphere," BNWL-1881 UC-48, Battelle Pacific Northwest Laboratories, presented at the ANS Meeting, Washington, D.C. 1974.

4. Testimony of Herbert L. Volchok, "Transuranic Elements in the Marine Environment"

5. Testimony of Burton G. Bennett, "Plutonium Fallout Pathways to Man"

6. F. W. Whicker, C. A. Little, and T. F. Winsor, "Plutonium Behavior in the Terrestrial Environs of the Rocky Flats Installation," IAEA Symposium on Environmental Surveillance Around Nuclear Installations, IAEA/SM-180/45, Warsaw, Poland, 1973.

7. Annual Reports of Environmental Surveillance at AEC Facilities and Contractors Facilities.

8. Environmental Monitoring at Major USAEC Contractor Sites, CY 1973, WASH-1259, 1973

9. NVO-140, "Eniwetok Radiological Survey," USAEC, Nevada Operations Office, Las Vegas, Nevada, October, 1973.

10. NVO-142, "The Dynamics of Plutonium in Desert Environments," Nevada Applied Ecology Group Progress Report, July 1974.

11. H. A. McClearen, "Plutonium in Soil at the Savannah River Plant," DPSPU 74-30-14, Second AEC Environmental Protection Conference, Albuquerque, New Mexico, 1974.

12. P. W. Krey and E. P. Hardy, "Plutonium in Soil around the Rocky Flats Plant," USAEC Report HASL-235, 1970.

13. P. W. Krey and B. T. Krajewski, "Plutonium Isotopic Ratios at Rocky Flats," USAEC Report HASL-249, 1972.

14. H. L. Volchok, R. Knuth, and M. Kleinman, "Plutonium in the Neighborhood of Rocky Flats, Colorado: Airborne Respirable Particles," USAEC Report HASL-246.

15. "USAF Nuclear Safety," AFRP 122-1, Jan/Feb/March 1970, No. 1, Vol. 65 (Part 2) Special Edition.

16. A. Aarkog, "Proceedings of the International Symposium on Radioecology Applied to the Protection of Man and His Environment," pp. 1213-1218, Rome, Italy, September 1971, (CONF 710973, EUR-4800, Vol. 1, 2).

17. "First Results from the Programme of Action Following the Palomares Accident," E. Iranzo, Junta de Energia Nuclear - Madrid, Spain, Symposium on Radiation Protection of the Public in a Mass Disaster, International Radiation Protection Association (IRPA), Interlaken 1968.

18. "Experience of an Accidental Contamination by Radioactive Materials, Palomares, Spain (1966)," E. Ramos and E. Iranzo, Junta de Energia Nuclear, Madrid, Spain, Second International Civil Defense Symposium on Nuclear Radiation Hazards, Monoco, 1966.

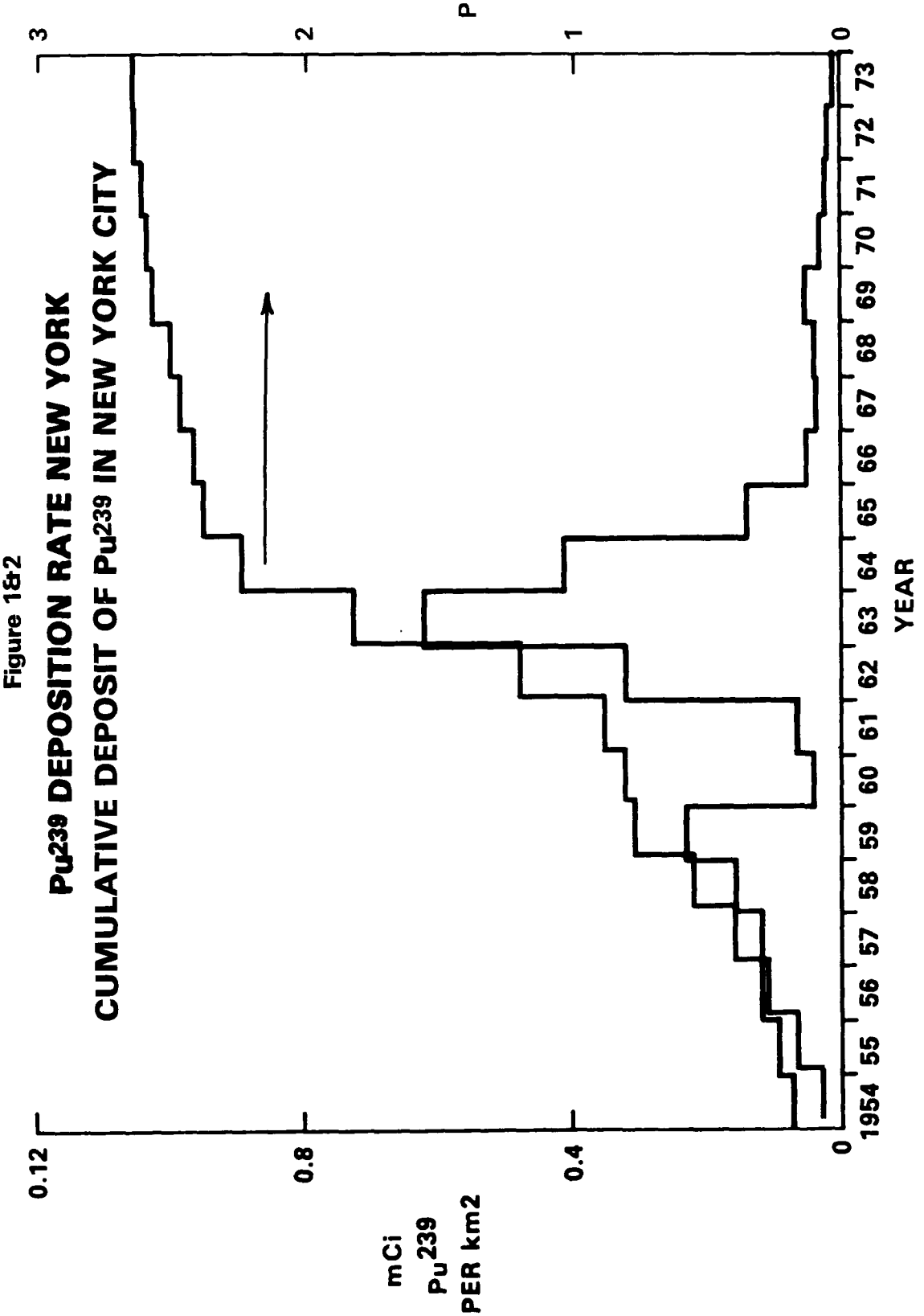
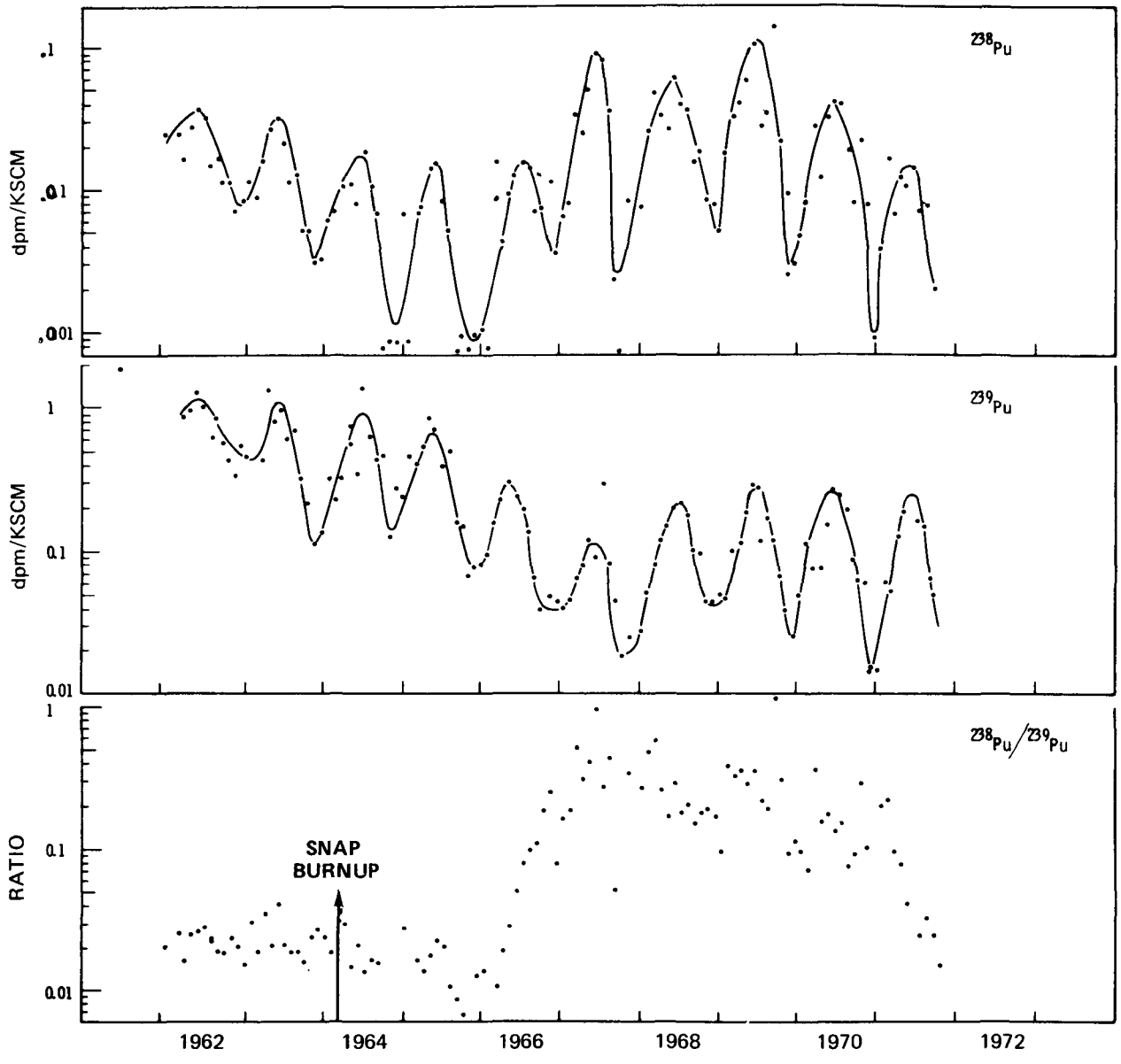

Pu239 DEPOSITION RATE NEW YORK
CUMULATIVE DEPOSIT OF Pu239 IN NEW YORK CITY
mCi Pu239 PER km2
0.12
0.8
0.4
0
1954 55 56 57 58 59 60 61 62 63 64 65 66 67 68 69 70 71 72 73
YEAR
mCi Pu239 PER km2
3
2
1
0

Figure 1&2

Figure 3. ^{238}Pu AND ^{239}Pu IN SURFACE AIR, 45°N



392

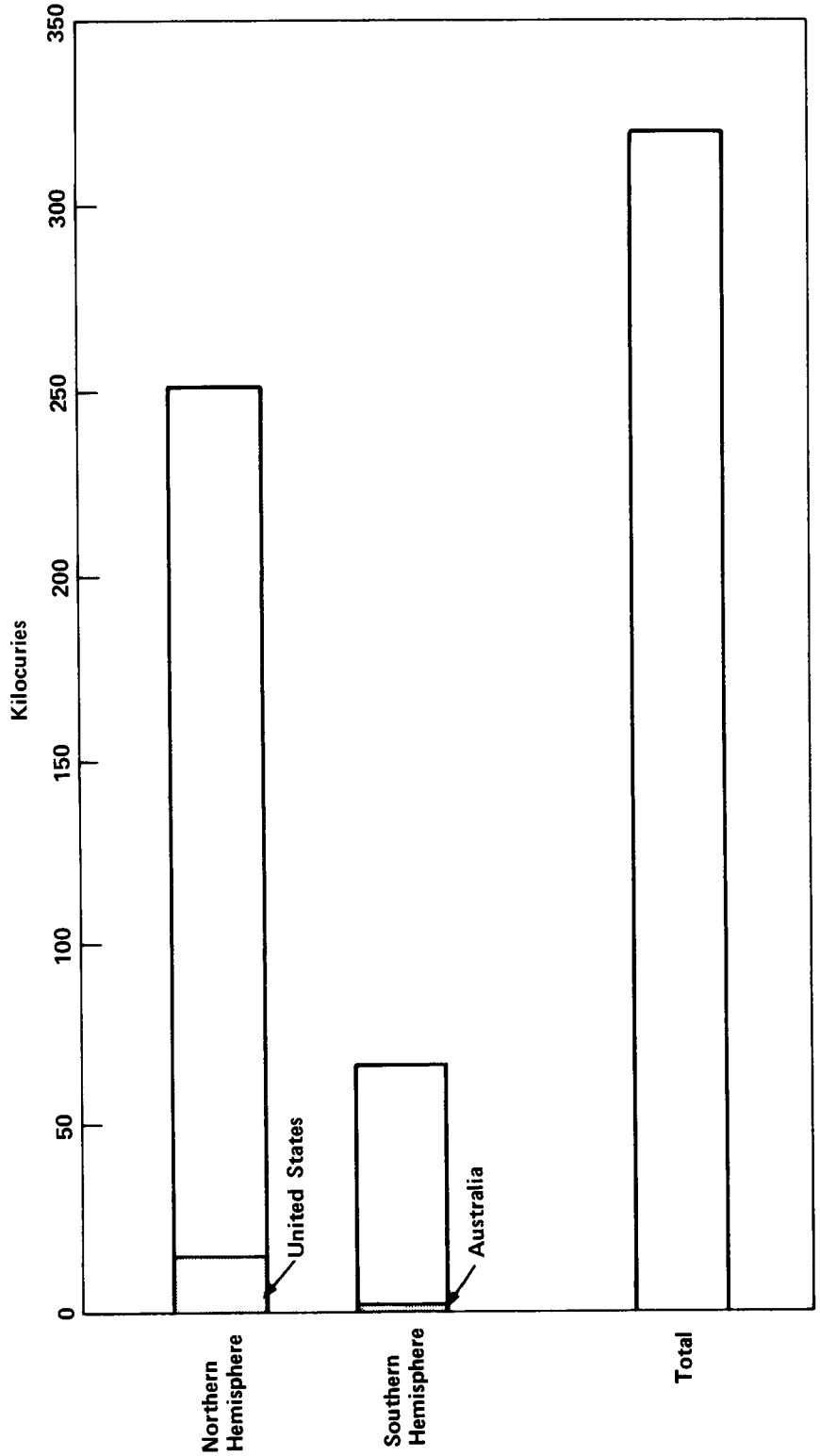


Figure 4. DISTRIBUTION OF DEPOSITED Pu^{239} 1970 – 1971

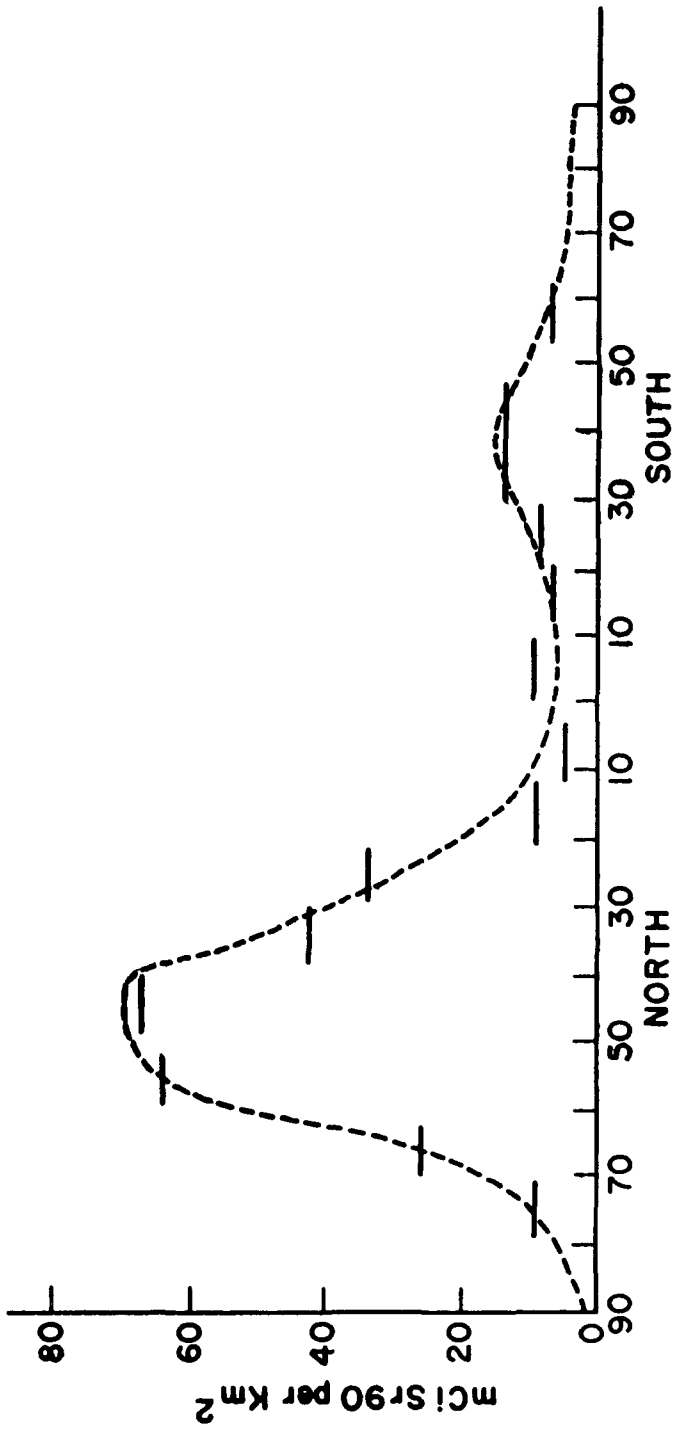


Figure 5. AVERAGE LATITUDINAL DISTRIBUTION OF DEPOSITED Sr90 FROM ANALYSES OF SOIL COLLECTED 1965–1967

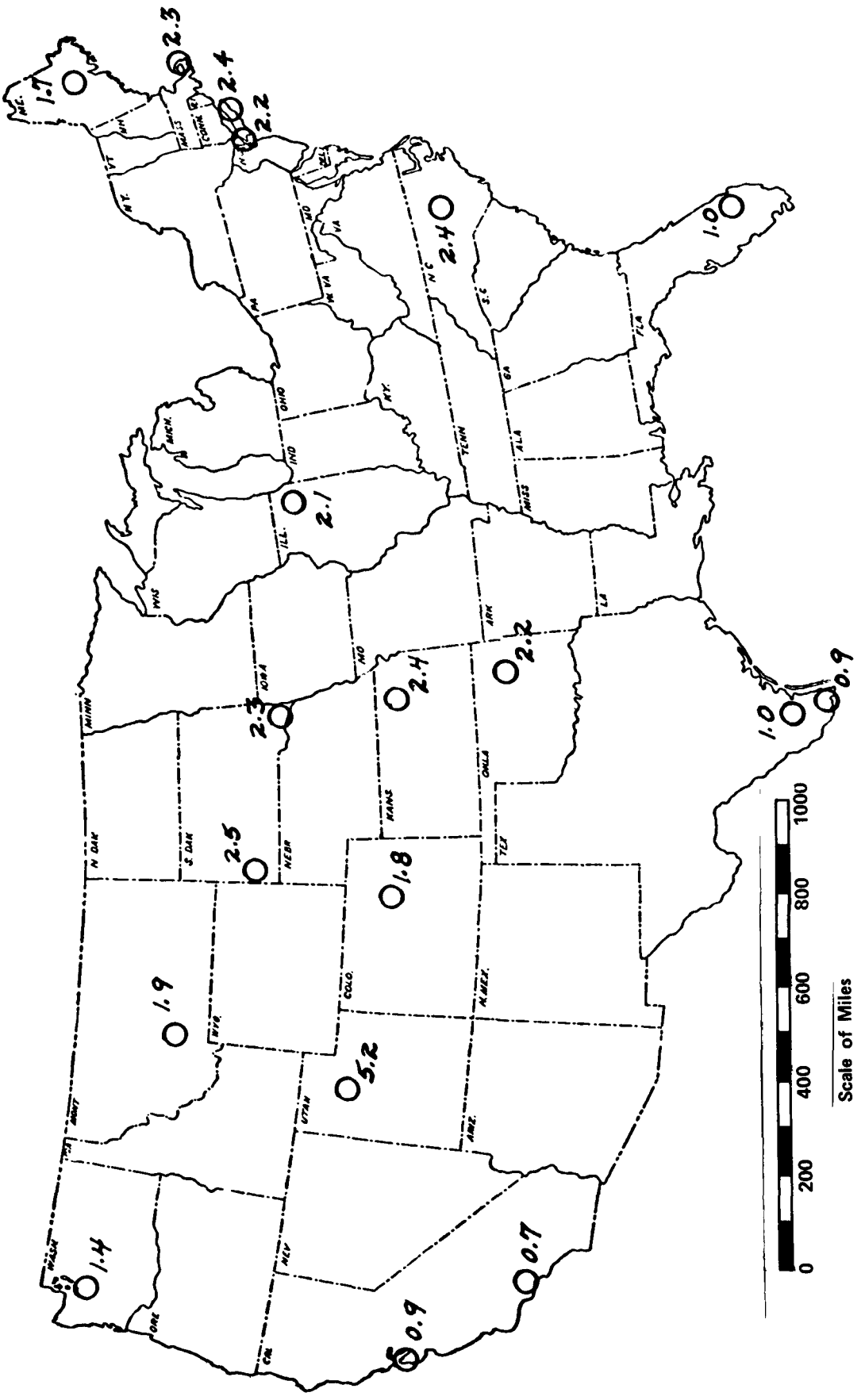


Figure 6. CUMULATIVE DEPOSIT OF Pu^{239} IN mCi PER km^2

Figure 7

DEPTH DISTRIBUTIONS OF Sr^{90}, Cs^{137}, AND $Pu^{239,240}$ IN SANDY LOAM SOIL

NORTH EASTHAM, MASS.
OCTOBER 1972

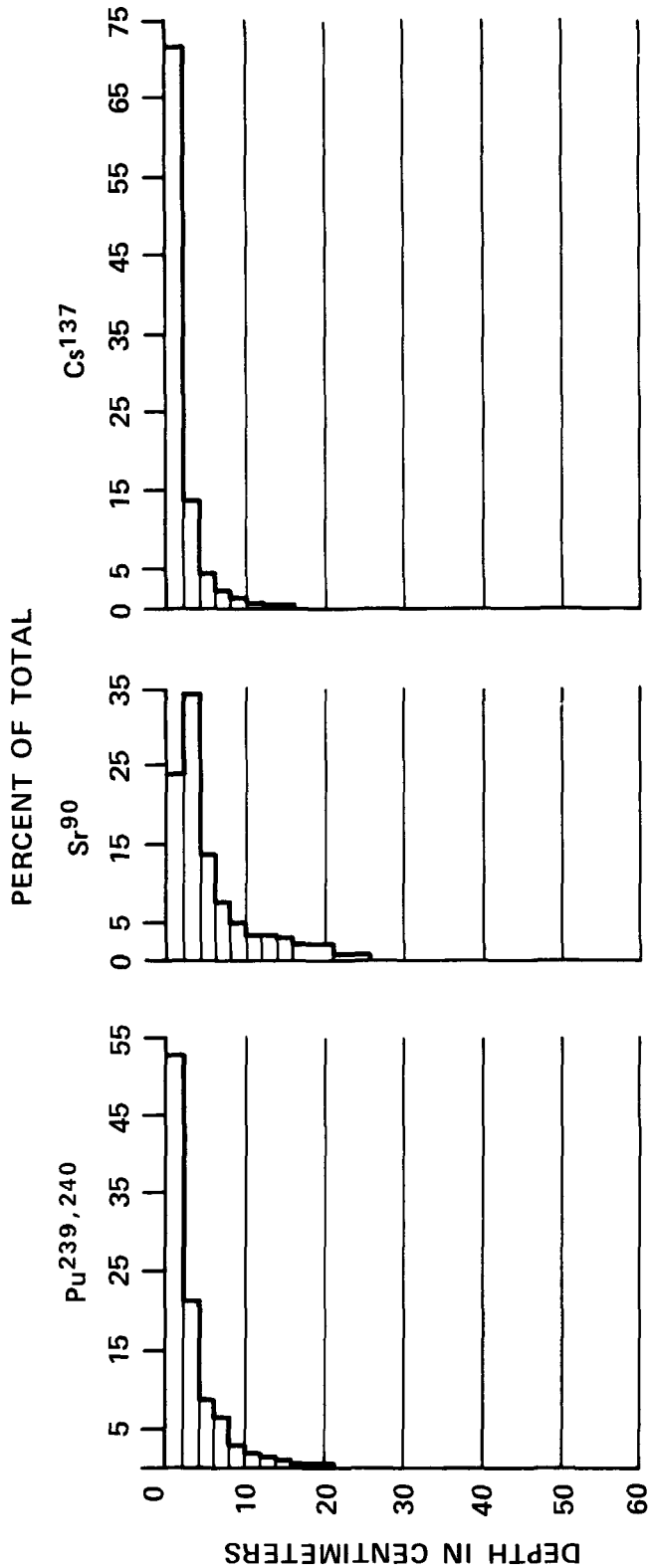


Table 1.

GLOBALLY DISTRIBUTED AMOUNTS OF ALPHA EMITTING PLUTONIUM FROM ATMOSPHERIC INJECTIONS

SOURCES	AMOUNT (CURIES)	% ACTIVITY BY ISOTOPE Pu–238	Pu–239	Pu–240
ATMOSPHERIC TESTING 1945–74				
DEPOSITED NEAR TESTING SITE	110,000	3	58	39
DEPOSITED WORLD WIDE	330,000	3	58	39
SPACE NUCLEAR	17,000	100	—	—
TOTAL	457,000			
TOTAL GLOBAL EXCLUDING NEARIN TO TESTING SITE	347,000			

Table 2.

ACTINIDES: ALPHA EMITTING CONCENTRATIONS AND AMOUNTS IN U.S. SOIL

NUCLIDES	AMOUNT (kCi)	REPRESENTATIVE CONCENTRATION IN SURFACE SOIL pCi/g
Pu–239, 240, 238	16	.05
Am–241	4	.01
Th–232, 230, 228 & U–238, 234 to 2 cm. depth	1600	5

Table 3

Representative Concentrations of Pu-239
in Various Media (Circa 1971)

Media	pCi/g
Air (Richland, Washington 1971)	1×10^{-7}
Ocean water (surface)	5×10^{-7}
Human tissue (lung - U.S. 1971)	3×10^{-4}
Soil (Northeast U.S., top 5 cm.)	5×10^{-2}

Table 4

Preliminary Estimates of Local Sources of Plutonium in the Environment (Quantities > 0.1 Ci)

Facility	Quantity	Location
NV NTS + Pacific	~ 1,000 Ci	Pu-239 to Onsite Soil
Thule	~ 25 Ci	Pu-239 in Marine Sediments and Surface Soils
Rocky Flats	0.04 Ci	Pu-239 to Atmosphere
	0.1 Ci	U + Pu-239 to Offsite Streams
	4.0 Ci	Pu-239 to Offsite Soil
	10.0 Ci	Pu-239 to Onsite Soil
Mound Laboratory	0.4 Ci	Pu-238 to Atmosphere
	0.5 Ci	Pu-238 to River - Routine Releases
	5.0 Ci	Pu-238 to Canals and Ditches
	0.5 Ci	Pu-238 to Soil
Savannah River	2.9 Ci	Pu-239 to Atmosphere
	0.6 Ci	Pu-239 to Atmosphere
	1.5 Ci	Pu-239 to Onsite Soil
	0.1 Ci	Pu-239 to Onsite Soil
LASL	1.3 Ci	Pu-239 to Atmosphere
	0.3 Ci	Pu-239 to Soil

Table 5

Concentrations of Plutonium in Soil

Location	Approximate Range (picocuries/gram)
Worldwide (Fallout)	0.0 to 0.2
Utah	0.2 to 0.45
Argonne National Laboratory	0.01 to 0.1
Hanford Plant	Offsite: 0.004 to 0.02
Lawrence Livermore Laboratory	0.0006 to 0.86
Los Alamos Scientific Laboratory	Offsite: 0.003 to 50
Mound Laboratory (Pu-238)	Offsite: 0.003 to 2.2
Rocky Flats	Offsite: 0.2 to 95
New Brunswick Laboratory	0.00009 to 0.75
Central New Mexico (Trinity)	0.13 to 10
Nevada Test Site	Offsite: 0.1 to 10
Bikini Atoll	1.3 to 190
Eniwetok Atoll	34 to 3,200
Palomares	0 to 1,800

WORLDWIDE DISTRIBUTION OF PLUTONIUM

by Edward P. Hardy, Jr.

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New York, N. Y. 10014

part of the AEC presentation at the
EPA Plutonium Standards Hearings
Washington, D. C., Dec. 10-11, 1974

Introduction

It is certainly clear that plutonium contamination of the environment on a global basis is primarily the result of atmospheric nuclear weapons testing. There are localized areas where plutonium contamination has occurred through accidents or inadvertent releases from nuclear facilities. The total amounts released are on the order of curies as compared with hundreds of thousands of curies from nuclear tests. Contamination levels in these areas are documented and studies are being carried out to follow the movement of plutonium through the eco-system pathways to man. For the future, however, it is important to know how plutonium from nuclear tests is distributed because this so-called "background" will be the baseline against which perturbations of the environment by the escalating nuclear industry must be assessed.

Nuclear Tests

Most of the plutonium now dispersed around the world was produced by nuclear tests conducted through 1962.[1] The above-ground tests carried out by the People's Republic of China in the Northern Hemisphere and France in the South Pacific since 1963 have contributed an additional ten percent

to the global inventory.[2] The principal isotopes of plutonium that have been measured are Pu-239,240 and Pu-238. These are the isotopes that have been produced in greatest abundance. With time, a daughter isotope - Am-241, will become an important contributor.

SNAP-9A

Although its contribution to the plutonium radioactivity now dispersed over the earth is relatively small it is worthwhile noting that Pu-238 was released in the high stratosphere in April 1964 when a nuclear powered satellite failed to achieve orbit and disintegrated. This Pu-238 has now settled out on the earth's surface and constitutes a substantial increment to the Pu-238 fallout from nuclear tests.[3]

Sampling Programs

The Atomic Energy Commission has traced the dispersal of plutonium from atmospheric tests and the SNAP-9A satellite through its sampling programs in the stratosphere, and at ground level. I intend to review the measured levels and show how this radioactivity has changed with time. To give some perspective to the amount of plutonium produced, the Pu-239,240 radioactivity is about 2 to 3 percent of the long-lived fission product Sr-90 radioactivity. The Pu-238 radioactivity from nuclear tests is only 2 to 3 percent of the Pu-239,240 radioactivity. From now on when I refer to Pu-239 it can be inferred that I mean Pu-239 + Pu-240 because these two isotopes cannot be distinguished by conventional alpha spectrometry.

Stratosphere

Figure 1 shows the amount of Pu-239 in the stratosphere as a function of time. The unit is kilocuries and separate curves are given for the northern and southern hemispheres. After the intensive period of testing

in 1961 and 1962, the levels of Pu-239 declined with a half residence time of 10 to 11 months. Since 1967, sporadic testing by France and the People's Republic of China has maintained relative constant or only slightly diminishing amounts of Pu-239 in the stratosphere up to the present time.

Figure 2 represents the amount of Pu-238 in the stratosphere from the satellite called SNAP-9A. This was a one-time input and it is now impossible to distinguish the level from this source against the Pu-238 from nuclear tests. The SNAP device released 17 kilocuries[4] while the total amount of Pu-238 that reached the stratosphere from weapons tests was about 9 kilocuries.

Surface Air

Throughout this period of weapons testing, it is generally agreed that human exposure to plutonium is primarily through inhalation. The surface air concentrations of Pu-239 in New York City as illustrated in Figure 3 show that at peak level in 1963 the concentration was 1.7 femtocuries per m^3 or about 9 percent of the most conservative concentration guide for populations.[5] Recent surface air concentrations attributable primarily to Chinese tests in the northern hemisphere are about 4 percent of this peak level. To assess the inhalation hazard, the fraction of the total concentration which may deposit in the nonciliated portion of the lung, must be known. Measurements of this so-called respirable fraction indicate that 80 - 85 percent of the Pu-239 aerosol is associated with particle sizes that are respirable.[6] These data refer only to plutonium from weapons tests.

Deposition

Measurements of deposited plutonium have made it possible to estimate the total amount on the earth's surface and to determine how it is distributed. A properly selected soil sample can represent the accumulated deposit, and, based on a worldwide soil program carried out in 1970-71, Figure 4 shows how Pu-239 is distributed between the northern and southern hemispheres. About 250 kilocuries is dispersed in the northern hemisphere and 70 kilocuries in the southern hemisphere making the total global inventory 320 kilocuries. For comparison, about 16 kCi has deposited on the conterminous United States and about 3 kCi on the Australian continent which is of comparable area. The highest deposition of Pu-239 is in the mid-latitudes of the northern hemisphere and it falls off toward the north pole. There is a low in the equatorial region and then a small rise in the mid-latitudes of the southern hemisphere, again dropping toward the south pole.

The total deposit of Pu-238 is about 7 percent of the Pu-239 but the SNAP-9A debris is a major contributor, particularly in the southern hemisphere (see Figure 5). The Pu-238 from the SNAP device almost tripled the global deposit of this plutonium isotope but we know from stratospheric measurements that it essentially all deposited.

Figure 6 shows how much Pu-239 in mCi per km^2 has deposited at various places in the United States. Generally the drier areas are lower than the wet areas indicating that precipitation scavenging is an important mechanism for bringing nuclear debris to the surface. Fallout in some western areas is higher per unit of precipitation than in sites along the Pacific coast or east of the Mississippi. Evidence seems to indicate that these are regions where stratospheric debris preferentially enters the troposphere and

is deposited.(7) The extremes in Pu deposition for the stratospheric source vary by only a factor of 3 or 4 and within a particular constant rainfall region, the variability in deposition is less than 15 percent.(8)

The total deposit of plutonium in the region of Salt Lake City is about two times higher than expected from global fallout. The excess plutonium probably came from the high explosive detonations involving unfissioned plutonium that were carried out at the Nevada test site in the late 1950's.(9)

The deposition rate of Pu-239 with time can be illustrated for New York City (see Figure 7). The pattern is similar to that for surface air, as expected. By integrating these rate data, the total deposit is in good agreement with the more direct measurement in soil.

Some information on the depth distribution of plutonium in soil is available which shows that most of the deposited plutonium is in the top 5 cm (2 inches) and that its distribution is similar to that of Cs-137, the most abundant long-lived fission product generated in nuclear tests. Both nuclides can be found in measurable concentrations down to 20 cm (8 inches) but the amount below 5 cm is only about 20 percent of the total. Strontium-90, by comparison, is less retained in the top soil and can be found to 30 cm (12 inches) so one can conclude that it is migrating at a faster rate than plutonium or cesium.(10)

Americium^{241}

It was mentioned earlier that Am-241 is a daughter of the isotope Pu-241 which builds up with time. Knowledge of its behavior in the environment is important because its chemical properties are different from plutonium. The few measurements that have been made of this nuclide in fallout show that its activity level is about 25 percent of that from

Pu-239. Despite elemental differences, Am-241 from global fallout shows a depth distribution in soil similar to Pu-239 but further measurements are needed.

Summary

Nuclear tests conducted in the atmosphere are the major sources of plutonium contamination on a worldwide basis. About 320 kilocuries of Pu-239 have deposited and about 4 kilocuries remaining in the stratosphere will reach the earth's surface. Measurements are being made of air concentrations at ground level and the deposition rate. Inhalation is the major route of human exposure and later testimony will be presented to show the resulting body burden. Contamination levels in foods have also been measured and the comparatively smaller body burden from ingestion will also be discussed.

References

1. Harley, J. H.
Worldwide Plutonium Fallout from Weapons Tests
USAEC Report, LA-4756, Los Alamos, pp. 13-17, Dec. 1971

2. Estimated from information provided by the news media and other unclassified sources

3. Hardy, E., P. Krey and H. Volchok
Global Inventory and Distribution of Fallout Plutonium
Nature, 241, No. 5390, pp. 444-445, Feb. 16, 1973

4. Krey, P.
Atmospheric Burn-up of a Plutonium-238 Generator
Science, 158, No. 3802, pp. 769-771, Nov. 10, 1967

5. International Commission on Radiological Protection
Report of Committee II on Permissible Dose for Internal Radiation
ICRP Publication 2 (1959)
Assuming soluble plutonium with bone as the critical organ and based on 1/30 of the occupational level for a 168 hour week

6. Volchok, H., R. Knuth and M. Kleinman
The Respirable Fraction of Sr-90, Pu-239 and Pb in Surface Air
USAEC Report HASL-278, pp. I-36 to I-40, January (1974)

7. Volchok, H. L.
High Fallout in the Western United States - An explanation
USAEC Report HASL-257, pp. I-18 to I-32, July (1972)

8. Hardy, E.
Regional Uniformity of Cumulative Radionuclide Fallout
USAEC Report HASL-288, pp. I-2 to I-9, January (1975)

9. Hardy, E., P. Krey and H. Volchok
Plutonium Fallout in Utah
USAEC Report HASL-257, pp. I-95 to I-118, July (1972)

10. Hardy, E.
Depth Distributions of Global Fallout Sr-90, Cs-137, and Pu-239,240 in Sandy Loam Soil
USAEC Report HASL-286, pp. I-2 to I-10, October (1974)

FIGURE 1

STRATOSPHERIC INVENTORY OF Pu-239

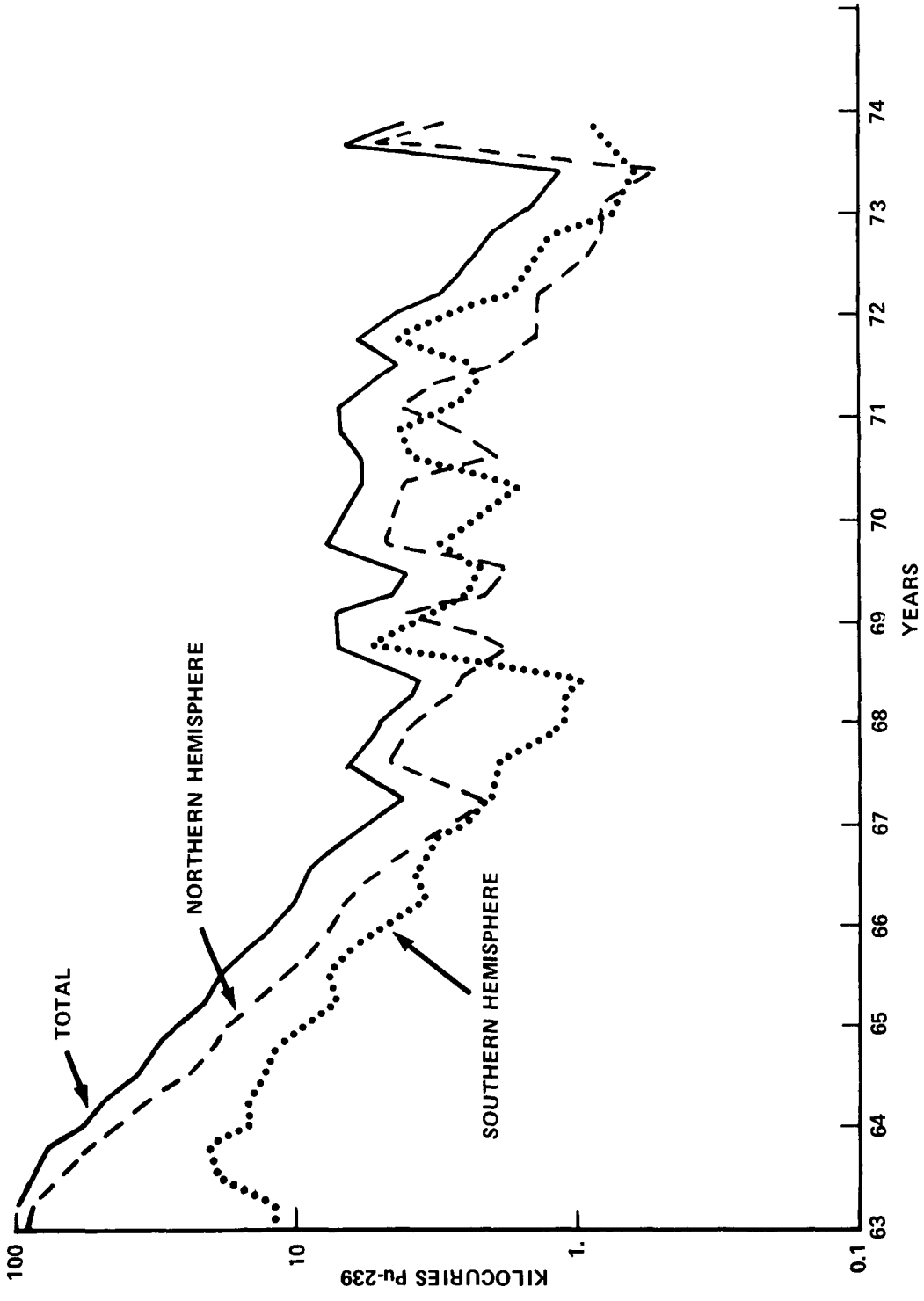
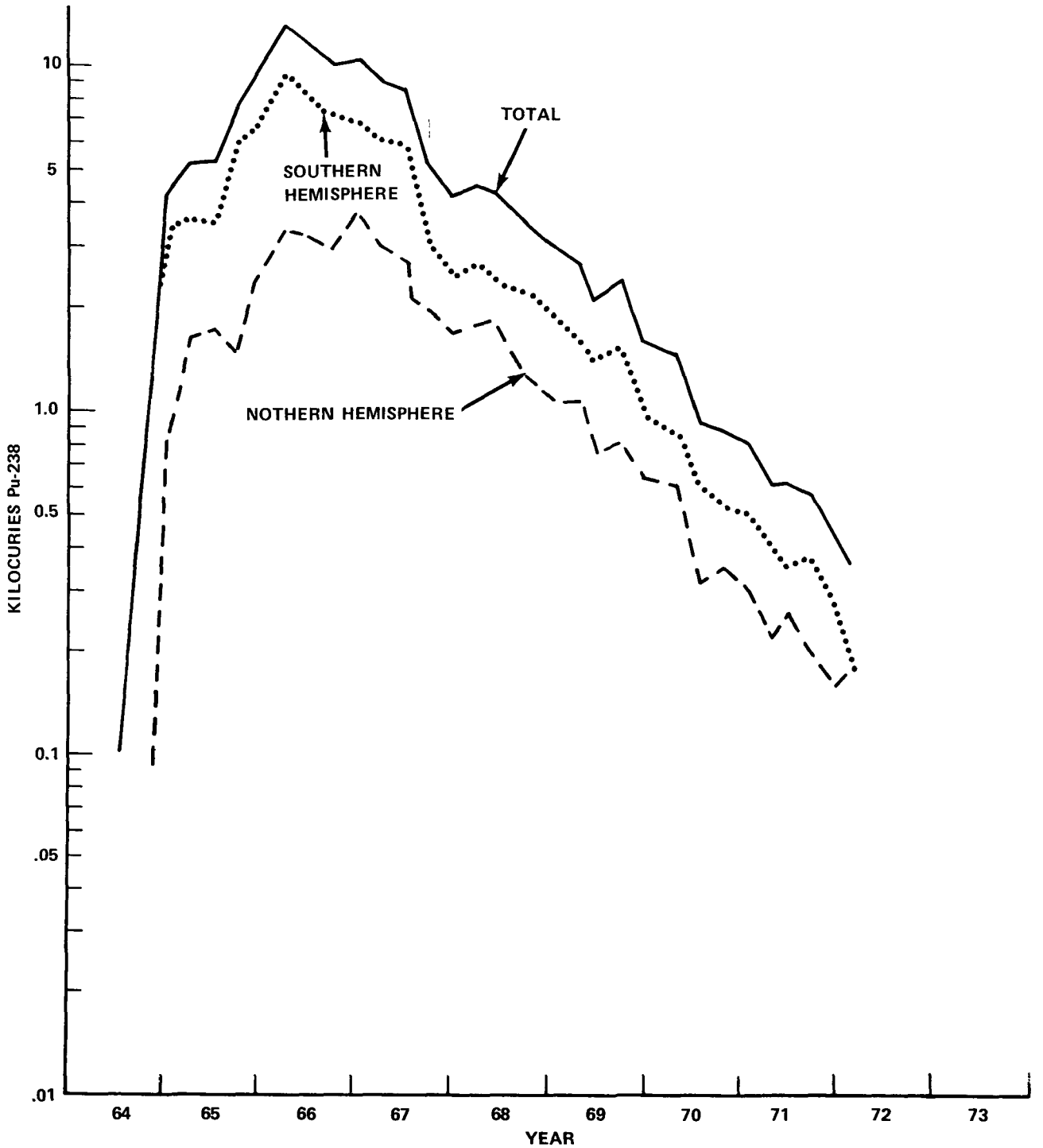


FIGURE 2
STRATOSPHERIC INVENTORY OF SNAP-9A Pu-238



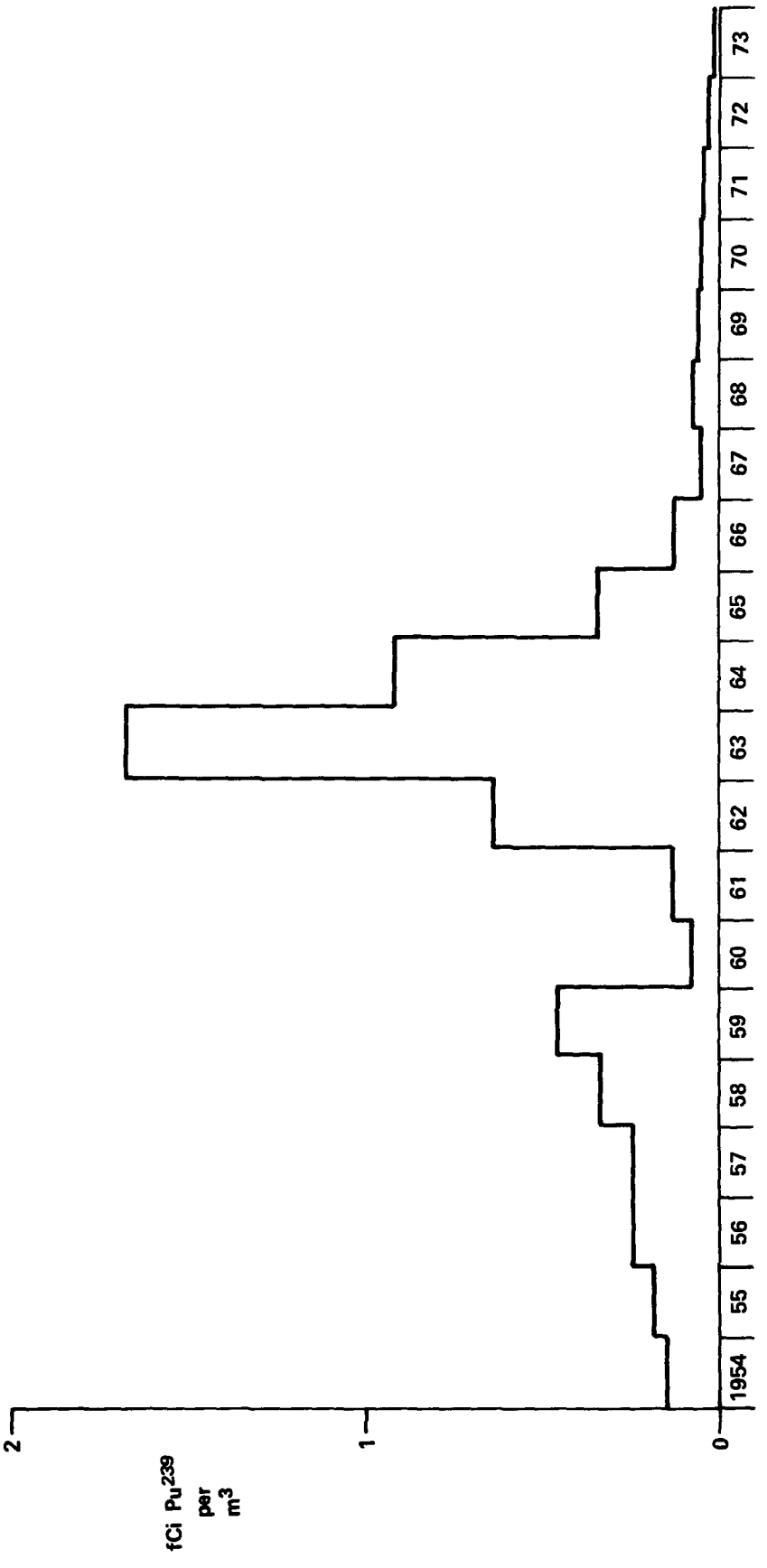
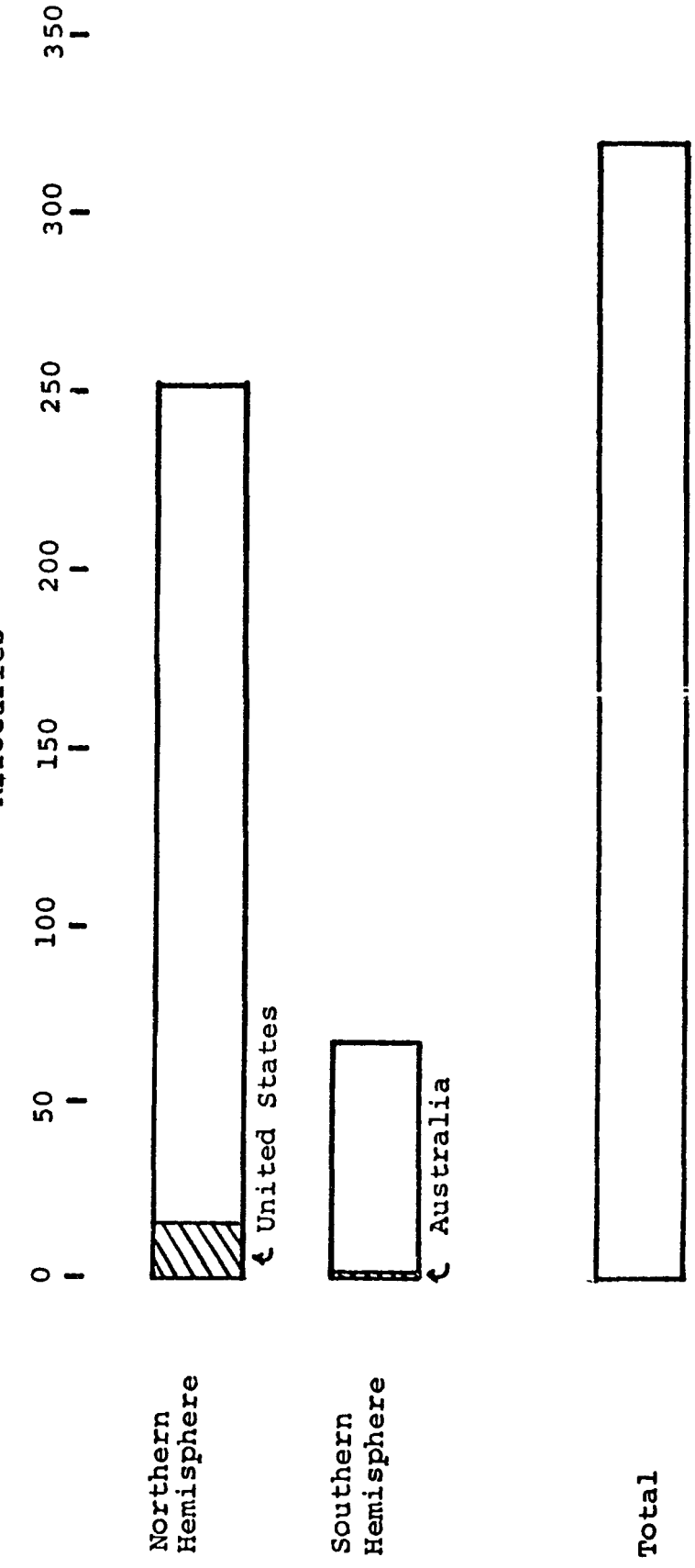


Figure 3. Pu^{239} IN SURFACE AIR
New York

Figure 4

DISTRIBUTION OF DEPOSITED Pu^{239}



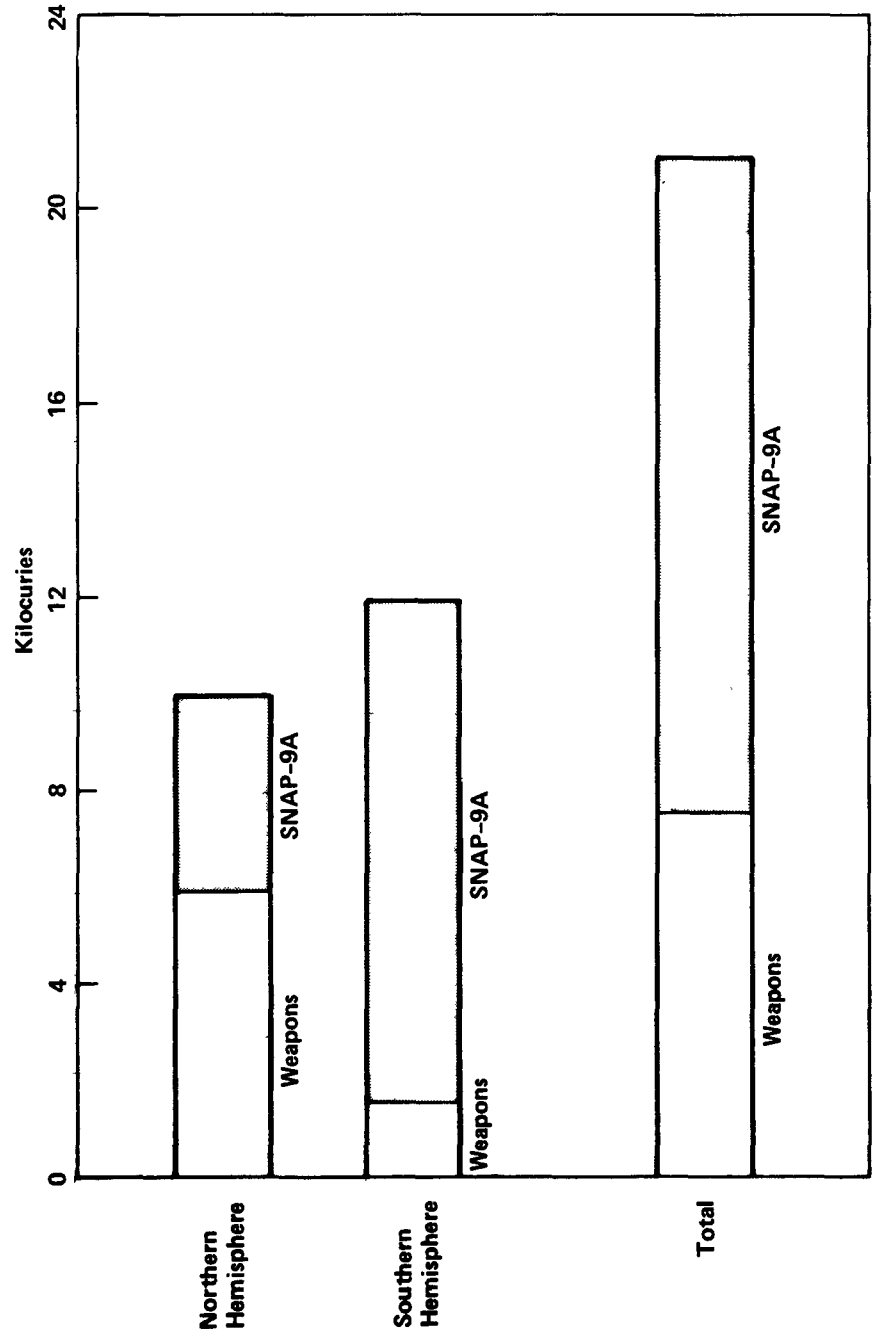


Figure 5. DISTRIBUTION OF DEPOSITED Pu^{238}

Figure 6

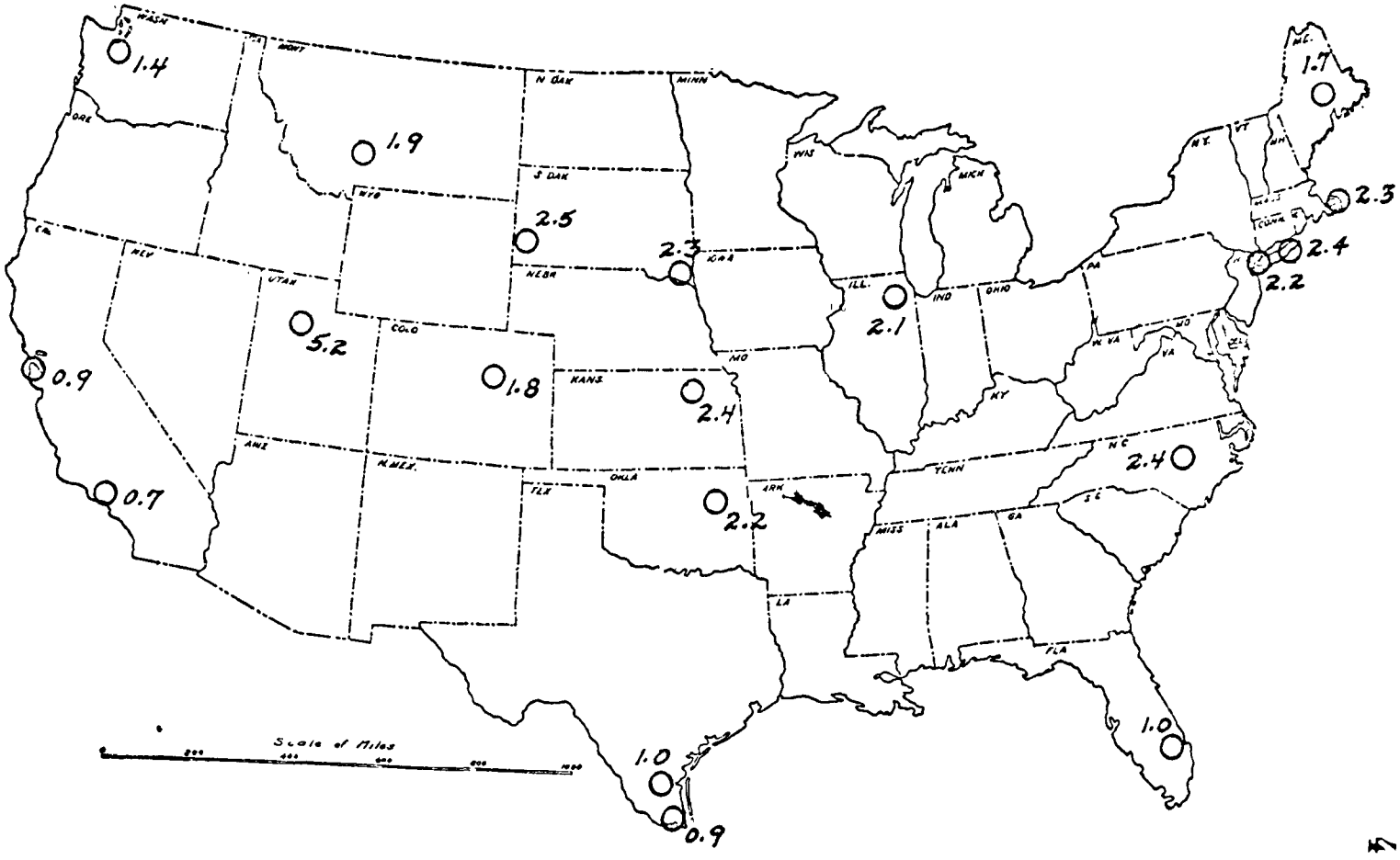
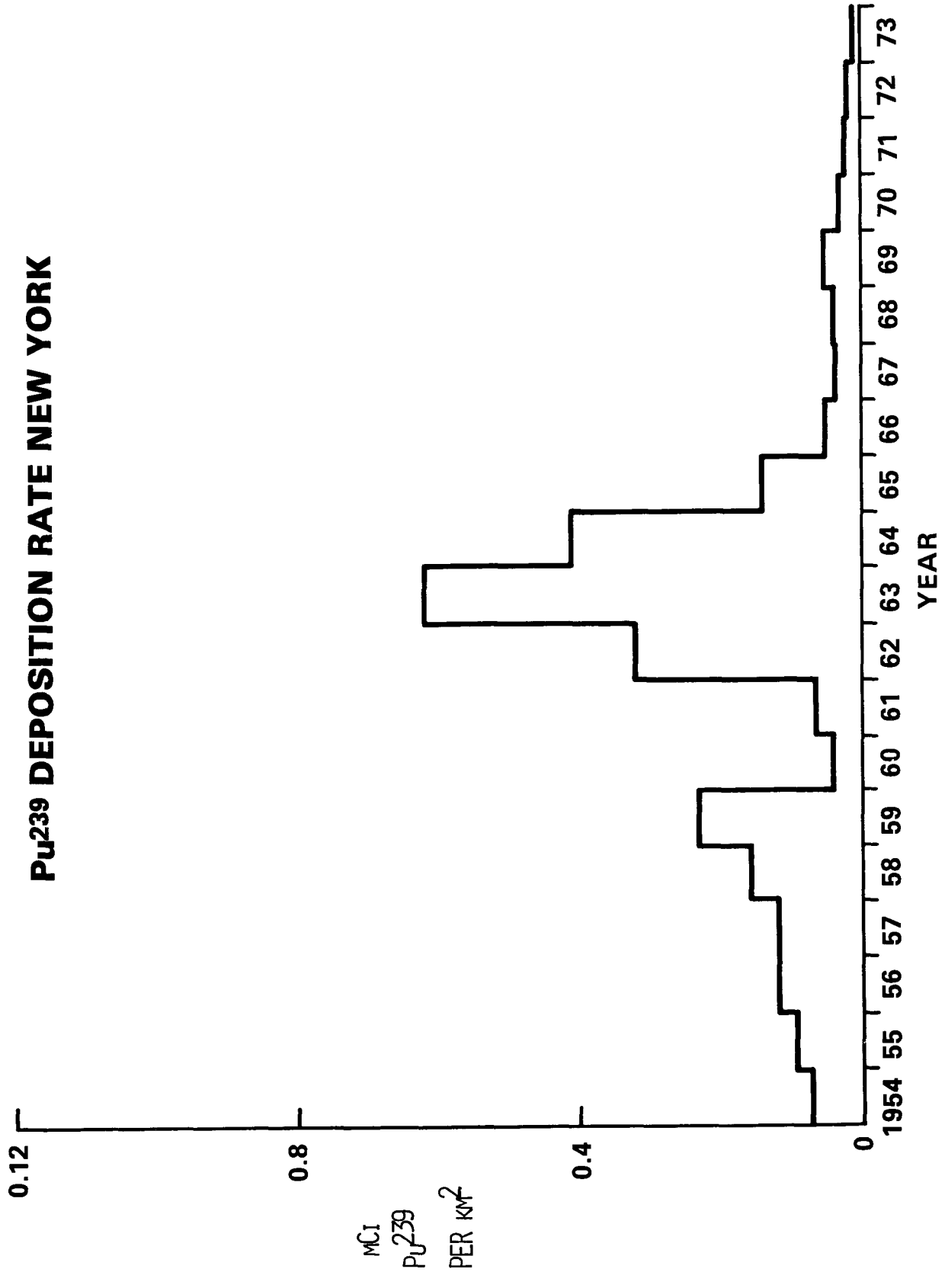

NO. 3133 OUTLINE MAP OF UNITED STATES.
CODEX BOOK COMPANY, INC. NORWOOD, MASSACHUSETTS
CUMULATIVE DEPOSIT OF Pu239 IN mCi PER km2
1.4
1.9
2.5
2.3
5.2
0.9
1.8
2.4
0.7
2.2
2.1
1.7
2.3
2.4
2.2
2.4
1.0
1.0
0.9
Scale of Miles

Figure 7.


Pu239 DEPOSITION RATE NEW YORK
0.12
0.8
0.4
0
MCi
Pu239
PER KM2
1954
55
56
57
58
59
60
61
62
63
64
65
66
67
68
69
70
71
72
73
YEAR

Dr. Radford: Dr. Wrenn, what is the ordinate on Figure 3? Can you put numbers there on the concentration?

Dr. Wrenn: The reference by Perkins does not have the numbers on them, but the units he uses are disintegrations per minute per thousand standard cubic meters. (Note added: the numerical values have been added to Figure 3 which displays the information requested by Dr. Radford.)

Dr. Radford: But he did not put numbers on his?

Dr. Wrenn: He did not have the numbers on his.

Dr. Radford: That is rather strange, to publish in a scientific journal, a graph with no numbers on it.

Dr. Wrenn: I think his point was to point out the relative change with time and the increase in the isotopic ratio at this particular point.

Also, to point out the continued input from atmospheric testing, rather than to point out the absolute values of these numbers.

Table 3 shows the average concentration of Pu-239 in air at Richland for 1971.

Dr. First: Does Table 4 list accumulated material per site, is that it?

Dr. Wrenn: Table 4 is a rough estimate of the amount available per site, yes.

Dr. First: The units you have there are quantity per what, per site?

Dr. Wrenn: Total curies per site. Roughly up to the end -- Well,

the dates on each of those are not the same, but, say, 1972 is maybe a good mean.

Dr. First: All right.

Dr. Wrenn: The Rocky Flats number, for example, is a little more up to date than that.

Dr. Mills: We will hold further questions on this until we hear from Dr. Bennett.

Dr. Parker: Dr. Wrenn, you stated you borrowed from Dr. Perkins, a former colleague of mine at Richland.

Comments were made by the panel on the competence of Dr. Perkins as a scientist. I happen to consider him one of the finest in the country.

May I ask, Mr. Chairman, that you address yourself by letter to Dr. Perkins to have him clear up the question of the graph that was shown.

Dr. Mills: Yes, sir. Surely.

Dr. Wrenn: I would like to say that I consider Dr. Perkins highly competent. I was talking with him last night rather late about this.

In my remarks, I certainly meant nothing to reflect improperly on Dr. Perkins. In fact, his is one of the finest collections on long term environmental data available.

Dr. Mills: Dr. Bennett?

Dr. Bennett: My name is Burton Bennett. I am a research scientist at the AEC Health and Safety Laboratory in New York.

I would like to present for your consideration a brief discussion of the "Environmental Pathways of Transuranic Elements."

ENVIRONMENTAL PATHWAYS OF TRANSURANIC ELEMENTS

Burton G. Bennett

Health and Safety Laboratory
U. S. Atomic Energy Commission
New York, N.Y. 10014

I. GENERAL CONSIDERATIONS

Exposure of man to transuranic element contamination may occur by the inhalation or ingestion pathways. A large number of laboratory and ecological studies have been performed or are in progress to elucidate specific aspects of these pathways, such as resuspension of deposited activity, plant uptake, and physical and biological transfers in terrestrial and aquatic environments. In addition, the measurements of fallout plutonium, tracing the course of this material in air and diet to man, provide some of the most directly appropriate data regarding the environmental pathways.

It is generally recognized that for an initially airborne release, the inhalation pathway is the dominant contributor to the body burden in man. The low solubility of the transuranic elements inhibits plant uptake and absorption from the gastrointestinal tract and minimizes the importance of the ingestion pathway. The physical mechanisms of transfer of activity are thereby emphasized instead of biological accumulation mechanisms.

Dispersion of airborne radioactivity is governed by the local and regional meteorology. For contamination which originates on the ground surface, such as leakages or spills, resuspension could be an important consideration. Radioactivity in air or in soil may reach plants by deposition on plant surfaces or by root uptake. Plant uptake is governed

by the isotope and soil chemistry and by the plant physiology. Disposition of inhaled or ingested material and the biological behavior have been studied in numerous animal study programs.

There have been a few good summaries, reviews and bibliographies of pathway considerations, as well as applications of such data in environmental statements.[1-9] I could not possibly elaborate here on all of the accumulated data. I can, at best, remind you of some of the considerations and then present the fallout experience.

Resuspension

Resuspension is a much discussed phenomenon. Although its importance is recognized in ground contamination situations, for initially airborne releases, such as fallout radioactivity, resuspension has not markedly influenced the measured concentrations in air.[9] A very large range of possible resuspension factors is often quoted - a range of 9 or 10 orders of magnitude. It is important, however, to carefully distinguish between those values which have been suggested for hazard analyses and those values that might reflect more realistic situations.

Measurements of resuspension have been conducted at contaminated areas of the Nevada Test Site. Soon after contaminating events, resuspension factors (ratios of radioactivity per unit volume of air to radioactivity per unit surface area of soil) on the order 10^{-4} to 10^{-6} m^{-1} have been obtained, decreasing subsequently with 35 to 70 day half-times.[10-12] We are often reminded of those results, 10^{-4} to 10^{-6}. Less often, however, are we reminded of the conditions under which they were obtained. Langham and his co-workers set out in 1956 to measure resuspension at the Nevada

Test Site. Having little initial success, they found it necessary to assist the micrometeorology. They arranged to have heavy trucks roar back and forth in front of the air sampler. The first value reported by Langham[11] 7×10^{-5} m^{-1} is described as obtained during "extensive vehicular traffic." A second value, 7×10^{-6} m^{-1}, was derived for "dusty rural air." Langham[11] had a feeling that 10^{-6} might be more appropriate for general usage, and Stewart[10] also suggested that value for "quiescent conditions." In later years, subsequent to weathering and downward movement of plutonium in soil, values of 10^{-9} to 10^{-10} m^{-1} have been reported.[13,14] The results for the desert environment are admittedly not easily generalized to more usually inhabited areas.

An important constraint in estimating a realistically applicable general resuspension factor is the fallout experience. Values should not be so large that when applied to the fallout deposition amounts, the measured air concentrations are exceeded. For fallout plutonium and as applied to natural uranium in soil as a tracer, most reasonably assumed is a resuspension factor of 10^{-9} m^{-1} to be applied to accessible activity in soil (activity in top 1 cm or less).[9]

It is recognized that a number of parameters are involved in describing the resuspension process, including soil conditions, moisture, wind, and vegetative cover. There may also be perturbations due to mechanical disturbances, such as digging or traffic. Activity may also be transferred to the body or clothing which may also lead to additional intake. Healy[6] has discussed many of these considerations. Research efforts under way should provide increased understanding of the resuspension phenomenon and allow better prediction of short-term effects.

Plant Uptake

A number of tracer studies have been conducted in which specific influences of plant uptake of transuranic elements have been identified. These factors include chemical form, solubility, oxidation state of the radioactive element, composition and pH of the soil, and plant species. Reviews of the various studies have recently been prepared by Price[3] and Francis[4], and Durbin[5] has given detailed treatment primarily of the chemical considerations involved. In Table 1, I have made a further attempt at synthesis. Additional effort will be required to achieve completeness and uniformity of reporting.

The laboratory "pot experiments" are limited by the sometimes unusual growing conditions or spiking methods and often involve seedling plants in quite short duration studies. One may worry about the extension of these results to the edible portions of mature plants grown under field conditions. On the other hand, the controlled experiments are better able to isolate the factors which apply, and the data on relative uptake of several isotopes are quite useful. The lowest values of uptake in Table 1 may reflect the short duration of exposure.[28] The highest values, field data from Palomares, may involve some direct contamination as well as root uptake.[26] The result for peeled potatoes from soil contaminated by global fallout fits in well with the laboratory study results.[22]

Longer term experiments have not demonstrated significant uptake changes. Neubold[21] indicated a slight increase in uptake for ryegrass in a 2 year experiment, but the data are inconclusive, since the concentrations barely exceeded minimum detection levels. Romney[32] reported a 7-fold increase

in 5 years, due possibly to increased root development. Buchholz[23] found equal or greater variations in uptake measurements over a 4 year period, but there was no time trend.

There appear to be no isotope differences in plant uptake, either for plutonium or curium isotopes, though the data are not extensive.

If one were to generalize on the basis of the data on hand, one might assign plant uptake of plutonium to be 10^{-4} (pCi/g fresh wt. per pCi/g dry soil), plus or minus an order of magnitude, with uptake of americium and curium about 30 times greater.

Uptake from foliar deposition is being studied. Very little translocation of plutonium following deposition has been found in initial laboratory experiments,[15] in agreement with fallout plutonium measurements of wheat.[22]

Ecological Studies

Ecological studies are in progress to assess the distribution of transuranic contamination in plant and animal communities.[16-18] Changes with time and any reconcentration processes will be investigated. An important contributor of plutonium contamination of plants has been shown to result from wind-borne activity deposited on plant surfaces.[17] The amounts of activity present in small mammals have not been unusual, considering the exposure pathways which exist.[6,32]

Aquatic Studies

The only evidence for concentrations of transuranics above surrounding background comes from studies of aquatic environments. There, it is as much the low retention of suspended activity in water as it is accumulations in plant or animal organisms. Plutonium is readily removed to sediments.

The highest activity levels in biota are found in marine plants, with concentration factors as great as 1000 (pCi/kg wet wt. per pCi/l water). The concentration factors decrease with increasing trophic level. The general behavior of plutonium in fresh water systems is comparable.[19] I have appended a summary of transuranics in the marine environment by Herbert L. Volchok of the Health and Safety Laboratory which includes a large literature compilation.

Biological Behavior

An excellent discussion of the entry of plutonium and other actinides into animals and man and the biological behavior is presented in ICRP Publication 19.[20] Absorption from the gastrointestinal tract and entry through intact skin and wounds are considered. The ICRP Task Group Lung Model has been formulated to be used in determining the disposition of inhaled material. Fractional deposition in the three lung regions is determined by particle size. Three classes of transfer parameters, dependent primarily on chemical form of the inhaled material, are provided to determine subsequent movement from the lung to other organs in the body or to excretion. The Lung Model provides a sound basis for considering inhalation intake.

Other Aspects

There are many other aspects of environmental pathways which can and should be considered, such as mobility in soil, chelation effects on plant uptake, wash-off from plant surfaces, and animal intake pathways with transfer to meat and milk. Much data on these topics is available and more is being accumulated. Let me go on, however, to the fallout experience.

References

1. Langham, W.H., "The Biological Implications of the Transuranium Elements for Man," Health Phys. 22, 943 (1972)

2. Bair, W.J., R.C. Thompson, "Plutonium: Biomedical Research," Science, 183, 715 (1974)

3. Price, K.R., "A Review of Transuranic Elements in Soils, Plants, and Animals," J. of Environ. Quality 2, 62 (1973)

4. Francis, C.W., "Plutonium Mobility in Soil and Uptake in Plants: A Review," J. of Environ. Quality 2, 67 (1973)

5. Durbin, P.W., "Transfer of Plutonium from Soil to Plants: A Review of the Problem," Univ. of Calif. Report UCID-3689 (1974)

6. Healy, J.W., "A Proposed Interim Standard for Plutonium in Soils," Los Alamos Scientific Laboratory Report LA-5483-MS (1974)

7. Thompson, R.C., "Biology of the Transuranium Elements - A Bibliography," Battelle Pacific Northwest Lab. Report BNWL-1782 (1973)

8. Environmental Plutonium Data Base Group, "Environmental Aspects of Plutonium and Other Elements - A Selected, Annotated Bibliography, Oak Ridge National Lab. Report ORNL-ETS-73-21 and 74-21 (1974)

9. Environmental Statement, "Environmental Impact of the LMFBR," USAEC Report WASH-1535, Sec. 4G.2 (1974)

10. Stewart, K., "The Resuspension of Particulate Material from Surfaces," in Surface Contamination (B.R.Fish, ed.) Pergamon, New York pp. 63-74 (1964)

11. Langham, W.H., "Plutonium Distribution as a Problem in Environmental Science," Proceedings of Environmental Plutonium Symposium, Los Alamos Scientific Lab. Report LA-4756 (1971)

12. Anspaugh, L.R., Phelps, P.L., Kennedy, N.C., Booth, H.G., "Wind-Driven Redistribution of Surface - Deposited Radioactivity," Proceedings of Environmental Behavior of Radionuclides Released in the Nuclear Industry, IAEA, Vienna (in press)

13. Anspaugh, L.R., et al., "Resuspension of Plutonium: A Progress Report," Lawrence Livermore Laboratory Report UCRL-75484 (1974)

14. Volchok, H.L., "Resuspension of Plutonium-239 in the Vicinity of Rocky Flats," Proceedings of Environmental Plutonium Symposium, Los Alamos Scientific Lab. Report LA-4756 (1971)

15. Klepper, B.L., D.K. Craig, "Plutonium Aerosol-Foliar Interaction Program, Summary," Battelle Pacific Northwest Lab., unpublished (1974)

16. Nevada Applied Ecology Group Progress Report, "The Dynamics of Plutonium in Desert Environments," USAEC Report NVO-142 (1974)

17. Whicker, F.W., C.A. Little, T.F. Winsor, "Plutonium Behavior in the Terrestrial Environs of the Rocky Flats Installation," Proceedings of Symposium on Environmental Surveillance Around Nuclear Installations, IAEA (1974)

18. Hakonson, T.E., L.J. Johnson, "Distribution of Environmental Plutonium in the Trinity Site Ecosystem After 27 Years," Los Alamos Scientific Lab. Report LA-UR-73-1291 (1973)

19. Radiological and Environmental Research Division Annual Report, Argonne Nat. Lab. Report ANL-8060, Part III (1973)

20. International Commission on Radiological Protection, "The Metabolism of Compounds of Plutonium and Other Actinides," ICRP Publication 19 (1972)

21. Neubold, P., "Absorption of Plutonium-239 by Plants," U.K. Agricultural Research Council Report ARCRL-10 (1963)

Literature Cited - Table 1

22. Bennett, B.G., "Fallout ^{239,240}Pu in Diet," in Fallout Program Quarterly Summary Report, USAEC Report HASL-286, October (1974)

23. Buchholz, J.R., W.H. Adams, C.W. Christenson, E.B. Fowler, "Summary of a Study of the Uptake of ^{239}Pu by Alfalfa from Soils," Los Alamos Scientific Lab. Report LADC-12897 (1971)

24. Cline, J.F., "Uptake of ^{241}Am and ^{239}Pu by Plants," Battelle Pacific Northwest Lab. Report BNWL-714 (1968)

25. Cummings, S.L., L. Bankert, "The Uptake of Cerium-144, Promethium-147, and Plutonium-238 by Oak Plants from Soils," Rad. Health Data and Reports 12, 83 (1971)

26. Fowler, E.B., et al., "Soils and Plants as Indicators of the Effectiveness of a Gross Decontamination Procedure," Los Alamos Scientific Lab. Report LA-DC-9544 (1968)

27. Hale, V.Q., A. Wallace, "Effect of Chelates on Uptake of Some Heavy Metal Radionuclides from Soil by Bush Beans," Soil Science 109, 262 (1970)

28. Jacobson, L., Overstreet, R., "The Uptake by Plants of Plutonium and Some Products of Nuclear Fission Absorbed on Soil Colloids," Soil Science 65, 129 (1948)

29. Nishita, H., E.M. Romney, K.H. Larson, "Uptake of Radioactive Fission Products by Plants," in Radioactive Fallout, Soils, Plants, Food, Man, E.B. Fowler (ed.), Elsevier, New York (1965)

30. Price, K.R., "Uptake of ^{237}Np, ^{239}Pu, ^{241}Am, and ^{244}Cm from Soil by Tumbleweed and Cheatgrass," Battelle Pacific Northwest Lab. Report BNWL-1688 (1972)

31. Rediske, J.H., J.F. Cline, A.A. Selders, "The Absorption of Fission Products by Plants," Hanford Research Report HW-36734 (1955)

32. Romney, E.M., Mark, H.M., Larson, K.H., "Persistence of Plutonium in Soil, Plants and Small Mammals," Health Physics, 19, 487 (1970)

33. Thomas, W.A., D.G. Jacobs, "Curium Behavior in Plants and Soil," Soil Science 108, 305 (1969)

34. Wallace, A., "Increased Uptake of ^{241}Am by Plants Caused by the Chelating Agent DTPA," Health Physics, 22, 559 (1972)

35. Wilding, R.E., T.R. Garland, "Influence of Soil Plutonium Concentration on Plutonium Uptake and Distribution in Shoots and Roots of Barley," J. Agr. Food Chem. 22, 836 (1974)

36. Wilson, D.O., J.F. Cline, "Removal of Plutonium-239, Tungsten-185 and Lead-210 from Soils," Nature 209, 941 (1966)

Table 1

PLANT UPTAKE OF TRANSURANIC ELEMENTS

Concentration Factor (pCi/g fresh weight per pCi/g dry soil) - when necessary, data adjusted on basis of ash wt. 1% and dry wt. 20% of fresh wt.

	Conc. Factor ($\times 10^{-4}$)	Reference	Plant Species and Method
^{239}Pu	.02 - .1	Jacobson, Overstreet	barley seedlings in clay suspension for 24 hr.
	.04 - 1	Price	cheatgrass, tumbleweed - 2 mo - radioactive layer in soil.
	.001 - .3	Buchholz, Adams, Christenson, Fowler	alfalfa, barley, beans, tomatoes, lettuce - 4 yr. - nitrate, oxide and weapons contaminated soil
	.1 - .4	Cline Wilson, Cline	barley - 18d. - beans in solution
	.1 - 1	Wildung, Garland	barley shoots - 30d - factor of 2 higher in roots
	.04 - .3	Romney, Mark, Larson Nishita, Romney, Larson	clover - 5 yr. - NTS soil
	.4 - 4	Rediske, Cline, Selders	beans, tomatoes, barley, thistles - leaves - nutrient media for 20d
	3	Bennett	potatoes, peeled - fallout background soil
	1 - 300	Fowler, et al.	tomatoes, maize, beans, alfalfa - Palomeres soil - veg. samples washed but may still include external contamination.
^{238}Pu	.02 - 2	Cummings, Bankert	oat shoots - 3 wks. in 9 soils - radioactive layer in soil
^{241}Am	1 - 3	Price	(see ^{239}Pu)
	3	Buchholz, et al.	"
	4 - 6	Cline	"
	20	Hale, Wallace	bush beans - leaves
	300	Wallace	soy beans - leaves and stems - higher in roots - chelates increase uptake
^{244}Cm	1 - 4	Price	(see ^{239}Pu)
^{242}Cm	0 - 4	Thomas, Jacobs	beans - % uptake agrees with Price - forage grass - no detectable uptake
^{237}Np	25 - 220	Price	(see ^{239}Pu)
^{233}U	.5 - .7	Buchholz, et al.	(see ^{239}Pu)

Summary:

^{239}Pu	10^{-5} to 10^{-3}	^{244}Cm	same as ^{241}Am	^{233}U	10^{-4}
^{238}Pu	same as ^{239}Pu	^{242}Cm	same as ^{244}Cm		
^{241}Am	10^{-4} to 10^{-2}	^{237}Np	10^{-2}		

Relative Uptake - experiments with identical plant species and soils for each isotope

^{239}Pu	^{233}U	^{241}Am	^{244}Cm	^{237}Np	Experiment
1	6	30			Buchholz (see ^{239}Pu above)
1		20-30			Cline "
1		30	40	2000	Price "

II. FALLOUT PLUTONIUM PATHWAYS TO MAN

Fallout plutonium reaches man by the inhalation and ingestion pathways. Direct inhalation of the initially airborne weapons-produced material has been the dominant contributor to the plutonium body burden. Plutonium in air is deposited on vegetation or on soil, contaminating food by direct deposition or by root uptake. The low plutonium concentrations occurring in food and the very low transfer across the gastrointestinal tract make the importance of the ingestion pathway very minimal. Both pathways, however have been considered in detail.

Ingestion Pathway

A complete diet sampling, consisting of representative foods from 19 separate categories, was conducted in 1972 in New York by the Health and Safety Laboratory.[1] The plutonium concentrations in the various foods were determined and the annual intake estimated.

Because of the low plutonium concentrations in the foods, relatively large samples were required (100 g ash). The total sampling comprised 237 kg of fresh food. Table 1 lists the analytical results. The highest concentration was found in shellfish, followed by grain products and fresh fruits and vegetables. Lower concentrations were found in meats, eggs, peeled potatoes, and canned or processed foods. No activity above the minimum detection level (.01 dpm/sample) was found in milk.

The listing indicates that external contamination is a factor in the occurrence of plutonium in foods. The difference between fresh and canned foods indicates that some of the activity is lost through washing and processing. The plutonium concentration on potato peels exceeded the concentration in the peeled potatoes by a factor of 60. The activity on

the peels could be accounted for by the soil activity.

Separate analysis of clams and shrimp, which made up the shellfish sample, showed 8 times higher plutonium concentration in the clams. Much of the activity in clams, which are filter feeders, is no doubt associated with the gastrointestinal portion. The meat portion of the fresh fish sample had a concentration 10 times less than the shellfish sample.

The absence of detectable activity in milk had been observed earlier for milk sample in 1965.[2] A tracer study has indicated very low transfer of plutonium to milk (10^{-6} of ingested dose per liter).[3]

Analysis of the identical food samples for ^{90}Sr indicated that plutonium is deficient in all food items, relative to the deposition amounts. No unusual concentrating processes have been observed. The few plutonium analyses of food sampled some years earlier indicate that the concentrations are decreasing as the deposition rate decreases.

The concentration factor for $^{239,240}Pu$ in potatoes was determined from analysis of Long Island (New York) potatoes and representative Long Island soil.[1] The result was 3×10^{-4} (ratio of concentration in fresh peeled potatoes to that in dry soil). Tracer studies have indicated similar results for other plant species. This determination indicates that there should be no unexpected behavior for the uptake to the edible portion of plants at low environmental levels of plutonium.

Analysis of plutonium in New York tap water (.3 fCi/ℓ in 1973) indicates that plutonium, as does cesium, becomes largely removed to sediments.[1]

Ingestion intake of fallout plutonium has been determined from the concentration results and food consumption estimates. These results are listed in Table 2. The annual intake during 1972 was 1.6 pCi, due 35% to

grain products, 20% each to vegetables, fruits, and meats, and less than 4% to dairy products. The annual intake in 1965 was estimated to be 2.6 pCi.[2]

Uptake of plutonium from the gastrointestinal tract is estimated to range from 3×10^{-5} to 10^{-6}.[4] On this basis, the 1.6 pCi ingestion intake during 1972 would have contributed, at most, 5×10^{-5} pCi to the body burden. While inhalation intake during 1972 (.2 pCi) was less than the ingestion intake, the contribution to body burden was greater than the ingestion contribution by a factor of 1000.

Inhalation Pathway

Inhalation intake of fallout plutonium can be determined directly from the measured air concentrations. Estimates of retention in lung, transfer to blood, and organ distributions are obtained using the ICRP Task Group Lung Model. Details of the model and results of the computations for fallout plutonium were reported recently.[5]

Based on the measured and inferred plutonium concentrations in air in New York and a constant inhalation rate (20 m^3/d), the inhalation intake is determined. The intake, listed in Table 3, reflects weapons testing activity - a decrease in 1960 during the test moratorium, a maximum in 1963 (12.2 pCi) following the 1961-62 tests, and declining intake after the 1963 Test Ban Treaty. The cumulative inhalation intake through 1973 has been 42.2 pCi.

The lung model is shown in Figure 1. The transfer rates and fractions are the amended values accepted by ICRP Committee 2 in 1971.[4] The Class Y parameters have been assumed, the form of the fallout plutonium being most likely PuO_2. Deposition in the nasopharynx (N-P) and tracheo-bronchial (T-B)

regions is cleared rapidly and almost entirely to the G.I. tract. Elimination from the pulmonary (P) region is primarily with a 500 day half-time with 80% going to the G.I. tract (40% with a 1 day half-time, 5% to blood, and 15% to the lymph system. Some permanent retention in the lymph nodes is assumed - 10% of the amount passing through the lymph system. Equal partition (45% each) of the amount transferred from blood to bone and liver is assumed. An additional 1% transfer from blood to kidney can be assumed, the remainder going to other soft tissue and excretion. The removal half-time from bone is taken to be 100 years and from liver and kidney 40 years. Transfer of plutonium from the gastrointestinal tract to blood is quite low (10^{-6}), making negligible contribution to organ burdens from activity passing from lung to the G.I. tract.

Regional deposition in the lung depends on the particle size. From measurements of size characteristics of airborne fallout,[6,7] it has been assumed that fallout plutonium radioactivity is attached to representative 0.4 μm aerosol particles. This size results in 32% deposition in the pulmonary region. Since 60% of the deposition receives longer term retention, about 20% of the inhalation intake contributes to the initial lung burden. The lung model transfer parameters indicate that about 6% of the intake reaches blood, and with the 45-45-1 subsequent distribution to bone, liver and kidney, 2.75% of the inhalation intake can be expected to be found in bone and liver and 0.06% in kidney.

The cumulative inhalation intake of 42 pCi of $^{239,240}Pu$ could thus have resulted in about an 8 pCi body burden (42 pCi x 20%), but since the intake occurred over several years, a maximum body burden of 4 pCi was reached in 1964 (Table 3). Little activity having been removed from bone

and liver, the burdens estimated from cumulative intake (42 pCi x 2.75% $\cong$ 1 pCi) agree closely with the more detailed computations[5] of the current burdens. Table 4 lists the computed organ amounts for 1973. The total body burden is 2.5 pCi.

Comparison of the results of the lung model calculations of organ burdens of fallout plutonium are available with the human tissue autopsy analysis results of the Los Alamos Scientific Lab. The comparisons have shown good general agreement. The averages observed for 50 to 75 samples obtained during 1972-73 were recently reported.[8] The observed-computed comparisons are .3 - .2 pCi in lung, .2 - .5 pCi in lymph nodes, 1.6 - 1.0 pCi in bone, 1.1 - .9 pCi in liver, and .2 - .02 pCi in kidney.

Figure 2 shows the measured inhalation intake of fallout plutonium and the computed organ burdens, including extrapolated values which assume no further intake beyond 1974. The continuing air concentration and tissue sampling programs will provide further checks of our prediction capability following inhalation intake.

The doses due to the computed burdens have been determined, based on uniform distributions within the organs.[5] The cumulative doses through 1973 to an individual exposed throughout the entire fallout period since 1954 have been 15 mrem to lung, 8 mrem to bone and 4 mrem to liver. Longer term retention in liver and bone eventually causes the doses to these organs to exceed the dose to lung. The cumulative doses through the year 2000 to the same exposed individual are estimated to be 34 mrem to bone, 17 mrem to liver, and 16 mrem to lung. These dose commitments are less than 10% of the total dose commitments due to all other fallout radionuclides.

References

1. Bennett, B.G.
Fallout ^{239,240}Pu in Diet
USAEC Report HASL-286, October (1974)

2. Magno, P.J., P.E. Kauffman, B. Shleien
Plutonium in Environmental and Biological Media
Health Physics 13, 1325 (1967)

3. Sansom, B.F.
The Transfer of ^{239}Pu from the Diet of a Cow to its Milk
British Veterinary Journal 120, 158 (1964)

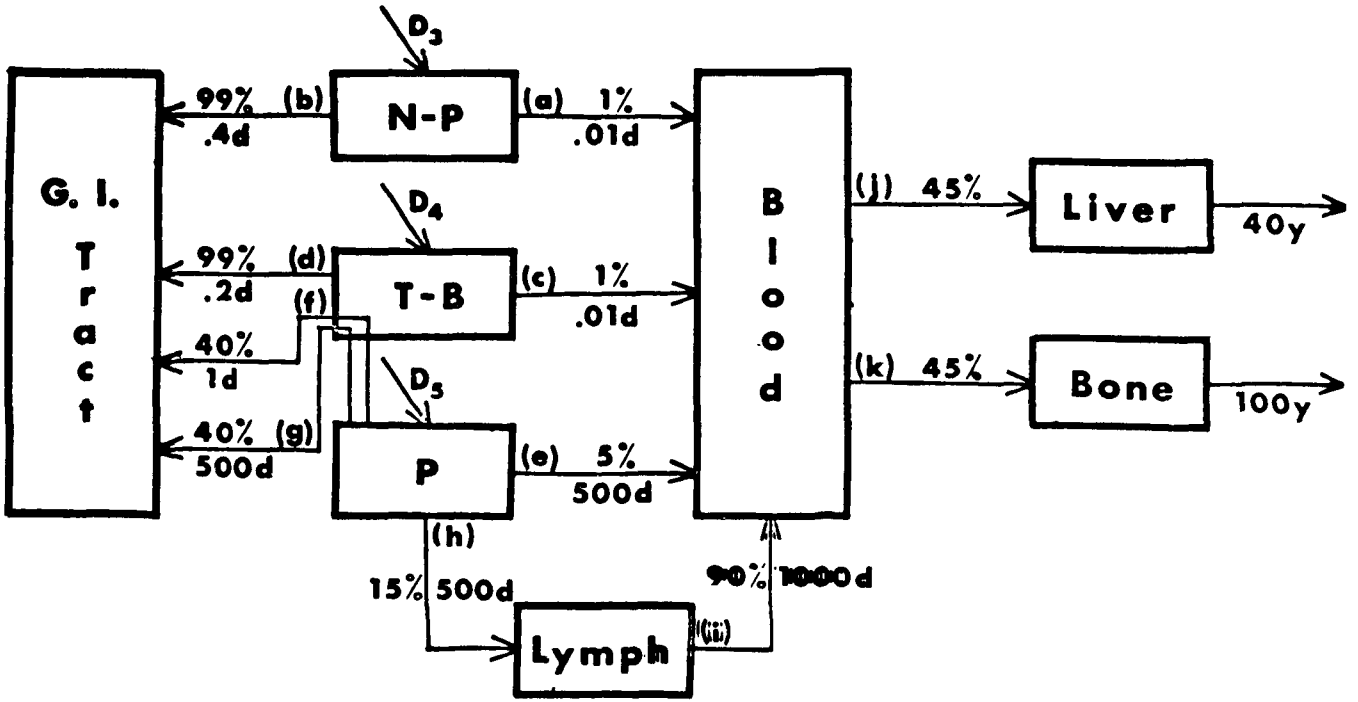
4. International Commission on Radiological Protection
The Metabolism of Compounds of Plutonium and other Actinides
ICRP Publication 19 (1972)

5. Bennett, B. G.
Fallout ^{239}Pu Dose to Man
USAEC Report HASL-278, January (1974)

6. Schleien, B., N.A. Gaeta, A.G. Friend
Determination of Particle Size Characteristics of old and Fresh Airborne Fallout by Graded Filtration
Health Physics 12, 633 (1966)

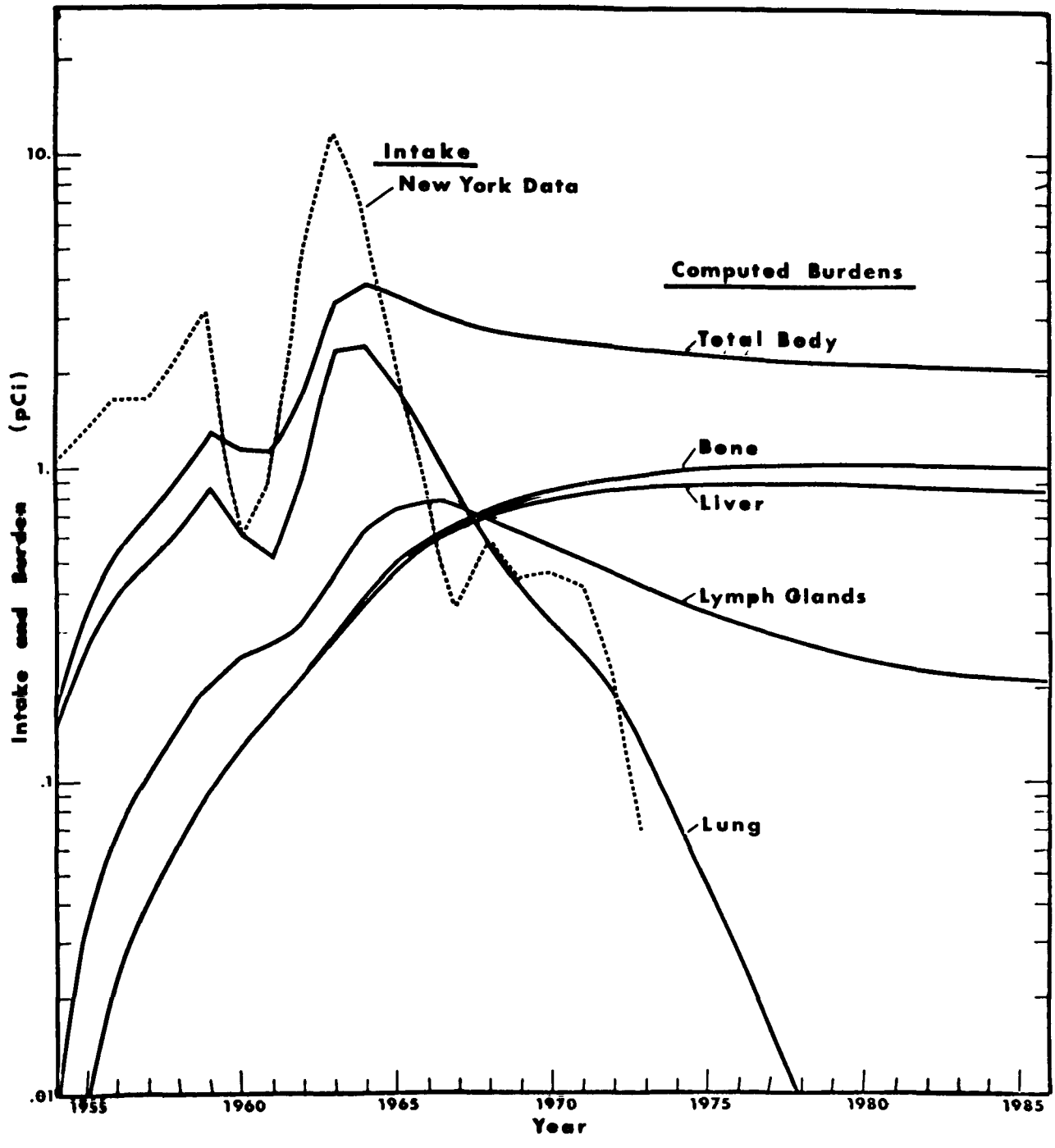
7. Lockhart, L.B., R.L. Patterson, A.W. Saunders
The Size Distribution of Radioactive Atmospheric Aerosols
Journal of Geophysical Research, 70, 6033 (1965)

8. Annual Report of the Biomedical and Environmental Research Program of the LASL Health Division, January - December 1973
Los Alamos Scientific Lab Report LA-5633-PR, May (1974)



The ICRP Task Group Lung and Blood Clearance Model for Plutonium

Figure 1



Inhalation Intake and Burden in Man of Fallout $^{239,240}Pu$

Figure 2

Table 1

^{239,240}Pu CONCENTRATION IN FOOD
NEW YORK 1972
(pCi/kg)

SHELL FISH	0.011	FRESH FISH	0.0016
BAKERY PRODUCTS	0.0085	RICE	0.0015
WHOLE GRAIN PRODUCTS	0.0060	POTATOES	0.0013
FRESH FRUIT	0.0051	EGGS	0.0012
DRY BEANS	0.0049	MACARONI	0.0012
FRESH VEGETABLES	0.0043	CANNED VEGETABLES	0.0009
ROOT VEGETABLES	0.0035	MILK	<0.0003
POULTRY	0.0033	FRUIT JUICE	<0.0003
FLOUR	0.0028	CANNED FRUIT	<0.0002
MEAT	0.0026		

Table 2

$^{239, 240}$Pu DIETARY INTAKE
NEW YORK 1972
(pCi/y)

BAKERY PRODUCTS	0.37	CANNED VEGETABLES	0.019
FRESH FRUIT	0.30	EGGS	0.019
FRESH VEGETABLES	0.21	DRY BEANS	0.015
MEAT	0.20	FRESH FISH	0.013
FLOUR	0.095	SHELL FISH	0.011
WHOLE GRAIN PRODUCTS	0.066	FRUIT JUICE	<0.0072
POULTRY	0.066	RICE	0.0046
MILK	<0.064	MACARONI	0.0036
POTATOES	0.048	CANNED FRUIT	<0.0018
ROOT VEGETALBES	0.035		

FOOD	1.5 pCi/y
TAP WATER	0.1
TOTAL	1.6 pCi/y

Table 3

FALLOUT ^{239,240}Pu INHALATION INTAKE AND COMPUTED BODY BURDENS

YEAR	INHALATION INTAKE (pCi)	BODY BURDEN (pCi)
1954	1.0	0.2
55	1.3	0.4
56	1.7	0.5
57	1.7	0.7
58	2.3	1.0
59	3.3	1.3
60	0.6	1.2
61	0.9	1.1
62	4.6	1.8
63	12.2	3.5
64	6.7	3.9
65	2.4	3.6
66	0.9	3.3
67	0.4	3.0
68	0.6	2.8
69	0.4	2.7
70	0.5	2.6
71	0.4	2.6
72	0.2	2.5
73	0.1	2.5

Table 4

FALLOUT $^{239,\ 240}$Pu IN MAN*

1973

ORGAN	BURDEN (pCi)
LUNG	0.13
LYMPH	0.44
BONE	0.98
LIVER	0.90
KIDNEY	0.02
TOTAL	2.5 pCi

*CALCULATED

TRANSURANIC ELEMENTS IN THE MARINE ENVIRONMENT

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Following is a brief summary of current information concerning transuranics in the marine environment. Most of this material was developed during a workshop convened by the Ocean Affairs Board of the National Research Council in late 1973. The workshop subject was "Assessing Potential Ocean Pollutants"; one chapter (Volchok et al., 1974) is devoted specifically to transuranics. The report of this workshop will be published in the very near future. The entire bibliography of the workshop chapter has been included here, along with the actual references cited.

In marine environments, transuranic elements have been introduced, in dispersed form, in four ways:

1. Close-in fallout from nuclear explosives testing.
2. World-wide fallout from nuclear explosives testing.
3. Atmospheric burn-up of plutonium power supplies.
4. Fluid wastes from chemical reprocessing and reactor operations.

The environmental redistributions of plutonium have been followed, to some extent, after its introduction by each of these avenues, and a small amount of information exists about americium. Unfortunately the data now at hand do not permit us to distinguish among the distributions of plutonium following its introduction in different ways. It has been assumed by Bowen and his co-workers (Wong et al., 1970a, 1970b; Bowen et al., 1971;

Noshkin and Bowen, 1973) that both plutonium and americium from world-wide fallout do pass through soluble phases in the oceans, but this has not yet been confirmed.

Pillai et al. (1964) found that plutonium concentrations in surface water, collected while fallout rates were high, were explainable by considering the precipitation exposure of the water masses sampled. More recently, samples collected while fallout rates were low showed concentrations that were explained by sedimentation of plutonium, in contrast to the conservative behavior of Sr^{90} and Cs^{137} in the same samples (Miyake and Sugimura, 1968; Miyake et al., 1970; Bowen et al., 1971; Noshkin, 1972; Noshkin and Bowen, 1973).

Profiles of Pu concentration as a function of depth in ocean water columns have been measured, primarily by Bowen and his co-workers at Woods Hole Oceanographic Institution (WHOI) in AEC-DBER and GEOSECS programs.

Noshkin and Bowen (1973) studied the relationship between the Pu^{239} in the sediment (expressed as a fraction of the estimated delivery to the latitude sampled) and the depth of the overlying water; several shallow water cores contained 100 percent of the predicted delivery, whereas their deepest core (over 5300 m) contained, in 1971, no measurable Pu^{239}. The major marine removal pathway for this transuranic is apparently biogenous sedimenting particles.

Data are insufficient to show that this behavior can be generalized for other transuranic elements, or even for Pu^{238} that was introduced by SNAP-9A. Schell and Young (1973) suggest that Am^{241} is being removed from the water column in Bikini atoll; Sugihara and Bowen (1962) and Bowen and Sugihara (1965) argued that lanthanide sedimentation was usually on inorganic

particulates, and americium is predicted to be much more lanthanide-like than is plutonium. Unpublished data (Bowen et al., unpublished manuscript) show, in one N. Atlantic water column, a steady increase with depth, of the Am^{241}/Pu^{239} ratio, from 0.16 at 200 m, to 0.38 at 3200 m; this appears to be too great an increase to be explained by generation of Am^{241} by decay of Pu^{241}, and in that case, would argue strongly for control of plutonium and americium distributions by their solution chemistry in sea water.

Aarkrog's (1971) study of the accidental release of Pu^{239} and Am^{241} near Thule, Greenland, showed that of the Pu measured, upwards of 95 percent went to the sediments; 1 percent found in the water column was fine particles (as was expected of recently formed PuO_2 particles). The biological data are not yet sufficient to show the extent of remobilization of the Pu^{239}, and no examination has yet been made of the Am^{241}. The reprocessing waste discharge into the Irish Sea from Windscale also results (Preston and Mitchell, 1973; Mitchell, 1971a, 1971b) in association of most of the Pu^{239} and Am^{241} with the sediments close to the discharge area.

Pu^{239} and Am^{241} from fallout have been found in marine organisms from a variety of places in both hemispheres (Noshkin, 1973; Cherry and Shannon, 1974). Cm^{242} has been found (Livingston, personal communication, 1973) in Fucus from the Irish Sea, and Np^{237} (at very low levels) in a variety of samples from Eniwetok (Noshkin, personal communication, 1973).

Sources in Polykarpov (1966) indicate concentration factors of about 1000 for Pu^{239} in marine plants; Noshkin (1973) has tabulated much recent data shown in Table 1, indicating that this level is often exceeded by marine benthos and zooplankton, and usually very greatly exceeded by the Atlantic Ocean species of pelagic Sargassum.

Data reported by Bojanowski et al. (1974), and by Mitchell (1971a, 1971b) show that Am^{241}, from fallout or from waste, is strongly concentrated by Sargassum or rooted algae leading to in-plant ratios of Am^{241}/Pu^{239} several times higher than those in the medium. Their data indicate that Am^{241} is more concentrated in Porphyra from the Irish Sea than Fucus (Am^{241}/Pu^{239} as high as 1.4 in Porphyra, versus 0.18 in Fucus).

Study by Wong et al. (1972) showed that in the great Pacific kelp the maximum Pu^{239} concentrations (about 2 pCi/kg) were confined to the thin outer layers of the plant, the inner parts showing concentrations only 1/200 of that near the outside surface.

In general it appears (Noshkin, 1972) that marine invertebrates exhibit higher concentrations of fallout Pu^{239} than do fish, this is also the trend of the data on close-in fallout Pu^{239} about the Pacific test sites. The fish Pu^{239} shows bone or liver-seeking behavior, as it does in mammals; liver-seeking may also be characteristic of Pu^{239} in molluscs and crustacea, but there are few data. The tendency shown by molluscs and lobster, for high concentrations of Pu^{239} associated with shells, can be explained by the well-known tendency for shell-periphyton to accumulate trace constituents from the medium, rather than by the invertebrate equivalent of bone-seeking.

The data show little evidence for any trophic level enhancement of Pu^{239} accumulation, although in the one case specifically studied (Wong et al., 1970) starfish showed consistently higher Pu^{239} (fallout) than did the mussels on which they were feeding.

By analogy one would expect Pu^{239} or Am^{241}, once incorporated in tissues of marine organisms, to show long residence half-times; in the one case studied, Hodge et al. (1973) suggested a half-time of 3.5 years for Pu^{239} in albacore liver.

It has been noted a number of times that even Pu^{239} accumulations from fallout represent higher radiobiological doses (in rems) to some marine organisms analyzed than do either their Sr^{90} or Cs^{137} contents. This is because of the relatively greater biological effectiveness of alpha particles versus the beta or gamma radiation of Sr^{90} or Cs^{137}.

Bibliography and

LITERATURE CITED

Aarkrog, A. 1971. Radioecological investigations of plutonium in an arctic marine environment. Health Phys. 20:31-47.

Adams, W.H. and E.B. Fowler. 1970. ^{238}Pu incorporated in fish living in water containing $^{238}PuO_2$. LA-DC-12899. Health Division, Los Alamos Scientific Lab., Univ. of California, Los Alamos, New Mexico. 7 pp.

Andelman, J.B. and T.C. Rozzell. 1970. Plutonium in the water environment. I. Characteristics of aqueous plutonium. In: Radionuclides in the environment (R.F. Gould, ed.), pp. 118-37. Advances in Chemistry, Series No. 93. American Chemical Society, Washington, D.C. 529 pp.

Avargues, M. and H.P. Jammet. 1966. Étude du site marin de La Hague en relation avec le rejet d'effluents radioactifs. In: Proceedings of conference on disposal of radioactive wastes into seas, oceans and surface waters, May 16-20, 1966, Vienna, pp. 787-95. International Atomic Energy Agency, Vienna. 898 pp.

Aviation Week and Space Technology. 1973. Forecast and inventory issue. 98:1-186.

Bair, W.J., J.E. Ballou, J.F. Park, and C.L. Sanders. 1973. Plutonium in soft tissues with emphasis on the respiratory tract. In: Handbook of experimental pharmacology (H.C. Hodge, J.N. Stannard, and J.B. Hursh, eds.), Vol. 36, Chapter 11, pp. 503-68. Springer-Verlag, Berlin-Heidelberg-New York. 995 pp.

Ballou, J.E., R.C. Thomason, W.J. Clarke, and J.L. Palotay. 1967. Comparative toxicity of plutonium-238 and plutonium-239 in the rat. Health Phys. 13:1087-92.

Bentley, G.E., W.R. Daniels, G.W. Knobelock, F.O. Lawrence, and D.C. Hoffman. 1971. Separation and analysis of plutonium in soil. In: Proceedings of environmental plutonium symposium, August 1971, Los Alamos. Symposium No. LA-4756, pp. 59-61. Los Alamos Scientific Lab., Univ. of California, Los Alamos, New Mexico. 119 pp.

Bishop, C.T., W.E. Sheehan, R.K. Gillette, and B. Robinson. 1971. Comparison of a leaching method and a fusion method for the determination of plutonium-238 in soil. In: Proceedings of environmental plutonium symposium, August, 1971, Los Alamos. Symposium No. LA-4756, pp. 63-71. Los Alamos Scientific Lab., Univ. of California, Los Alamos, New Mexico. 119 pp.

Bojanowski, R., H.D. Livingston, D.L. Schneider, and D.R. Mann. A procedure for analysis of americium in marine environmental samples. In: Reference methods for marine radioactivity studies. II. Ruthenium, iodine, silver and the transuranic elements. International Atomic Energy Association, Vienna. In press.

Bowen, V.T. 1973. Woods Hole Oceanographic Institution, Woods Hole, Massachusetts 02543. Personal communication, October 1973.

Bowen, V.T. and T.T. Sugihara. 1965. Oceanographic implications of radioactive fallout distributions in the Atlantic Ocean from 20° N to 25° S, from 1957 to 1961. J. Mar. Res. 23(2):123-46.

Bowen, V.T., K.M. Wong, and V.E. Noshkin. 1971. Plutonium-239 in and over the Atlantic Ocean. Talanta 29:1-10.

Bundesminister für Bildung und Wissenschaft. 1972. Umweltradioaktivitat und Strahlenbelastung: Jahresbericht 1971. Der Bundesminister für Bildung und Wissenschaft, Bonn. 174 pp.

Cherry, R.D. and L.V. Shannon. The alpha-radioactivity of marine organisms. Atomic Energy Rev. In press.

Crandall, J.L. 1971. Applications of transplutonium elements. Presented at the third international transplutonium element symposium, October 20-22, 1971, Argonne Natl. Lab., Argonne, Ill. E.I. du Pont de Nemours and Company, Aiken, South Carolina. Unpublished ms.

Durbin, P.W. 1973. Metabolism and biologic effects of the transplutonic elements. In: Handbook of experimental pharmacology (H.C. Hodge, J.N. Stannard, and J.B. Hursh, eds.), Vol. 36, Chapter 18, pp. 739-879. Springer-Verlag, Berlin-Heidelberg-New York. 995 pp.

Foster, R.F. 1973. Sources and inventory of radioactivity in the aquatic environment. Presented at the Health Physics Society meeting, June 17-21, 1973, Miami Beach, Florida. Battelle-Pacific Northwest Laboratories, Richland, Washington. Unpublished ms.

Foster, R.F. and J. Soldat. 1966. Evaluation of the exposure resulting from the disposal of radioactive wastes into the Columbia River. In: Proceedings of conference on disposal of radioactive wastes into seas, oceans and surface waters, May 16-20, 1966, Vienna. International Atomic Energy Agency, Vienna. 898 pp.

Gillette, R. 1973. Radiation spill at Hanford: The anatomy of an accident. Science 181:728-30.

Hakonson, T.E. and L.J. Johnson. 1973. Distribution of environmental plutonium in the Trinity Site ecosystem after 27 years. LA-UR-73-1291, Conf. 730907-14. Los Alamos Scientific Lab., Univ. of California, Los Alamos, New Mexico. 6 pp.

Hanford Biology Symposium, Eleventh. 1972. The biological implications of the transuranic elements. Health Phys. 22:533-954.

Hardy, E.P., P.W. Krey, and H.L. Volchok. 1973. Global inventory and distribution of fallout plutonium. Nature 241:444-45.

Hodge, V.F., T.R. Folsom, and D.R. Young. 1973. Retention of fallout constituents in upper layers of the Pacific Ocean as estimated from studies of a tuna population. In: Radioactive contamination of the marine environment. Proceedings of a symposium on the interaction of radioactive contaminants with the constituents of the marine environment, July 10-14, 1972, Seattle, Washington, STI/PUB/313, pp. 263-76. International Atomic Energy Association, Vienna. 786 pp.

ICRP - See International Commission on Radiological Protection.

International Commission on Radiological Protection (ICRP). 1972. The metabolism of compounds of plutonium and other actinides. ICRP Publication Series No. 19. Pergamon Press, Oxford-New York-Toronto. 59 pp.

Janes Weapons Systems. 1972. 1971-1972 Vol. Institute for Strategic Studies, London, U.K. 586 pp.

Jeffries, D.F., A. Preston, and A.K. Steele. 1973. Distribution of caesium-137 in British coastal waters. Mar. Pollut. Bull. 4(18): 118-22.

Johnson, L.J. 1972. Los Alamos land areas environmental radiation survey, 1972. LA-5097-MS. Los Alamos Scientific Lab., Univ. of California, Los Alamos, New Mexico. 27 pp.

Joseph, A., P.F. Gustafson, I.R. Russell, E.A. Schuert, H.L. Volchok, and A. Tamplin. 1971. Sources of radioactivity and their characteristics. In: Radioactivity in the marine environment (Report of the Panel on Radioactivity in the Marine Environment, Committee on Oceanography, National Research Council), pp. 6-41. National Academy of Sciences, Washington, D.C. 272 pp.

Krey, P.W., D. Bogen, and E. French. 1962. Plutonium in man and his environment. Nature 195:263-65.

Krey, P.W. and B.T. Krejewski. 1972. Plutonium isotopic ratios at Rocky Flats. HASL-249, April 1, 1972, pp. I-67 - I-94. Health and Safety Lab., New York Operations Office, U.S. Atomic Energy Commission, New York, New York.

Kubose, D.A., M.G. Lai, H.A. Goya, and H.I. Cordova. 1967. Radioactivity release from radionuclide power sources. VI. Release from plutonium dioxide to seawater in the presence of ocean-bottom material. Technical Release 67-71. U.S. Naval Radiological Defense Lab., U.S. Department of the Navy, Washington, D.C. 9 pp.

Langham, W.R. 1971. Plutonium distribution as a problem in environmental science. In: Proceedings of environmental plutonium symposium, August, 1971, Los Alamos. Symposium No. LA-4756, pp. 3-11. Los Alamos Scientific Lab., Univ. of California, Los Alamos, New Mexico. 119 pp.

Leitenberg, M. 1970. So far, so good. Environment 12(6):26-35.

Livingston. 1973. Woods Hole Oceanographic Institution, Woods Hole, Massachusetts 02543. Personal communication.

Magno, P.J., P.E. Kaufman, and B. Shleien. 1967. Plutonium in environmental and biological media. Health Phys. 13:1325-30.

Marzocchi, A., G. Cassano, F. Gera, G. Lenzi. 1971. Lo smaltimento dei rifiuti radioattivi al centro di Ricerche Nucleari della Trisaia. Minerva Fisico Nucleare 15:38-45.

Mitchell, N.T. 1970. Radioactivity in surface and coastal waters of the British Isles 1970. Technical Rpt. FRL 6. Ministry of Agriculture, Fisheries and Food, Fisheries Radiobiology Lab. Lowestoft, U.K. 34 pp.

Mitchell, N.T. 1971a. Radioactivity in surface and coastal waters of the British Isles 1969. Technical Rpt. FRL 7. Ministry of Agriculture, Fisheries and Food, Fisheries Radiobiology Lab., Lowestoft, U.K. 33 pp.

Mitchell, N.T. 1971b. Radioactivity in surface and coastal waters of the British Isles 1970. Technical Rpt. FRL 8. Ministry of Agriculture, Fisheries and Food, Fisheries Radiobiology Lab., Lowestoft, U.K. 35 pp.

Miyake, Y. and Y. Sugimara. 1968. Plutonium contents in the western north Pacific waters. Meteorol. Res. Inst. Tokyo 19(3):481-85.

Miyake, Y., Y. Katsuragi, and Y. Sugimara. 1970. A study on plutonium fallout. J. Geophys. Res. 75:2329-30.

Morin, M., J.C. Nenot, and J. Lafuma. 1972. Metabolic and therapeutic study following administration to rats of Pu^{238} nitrate: A comparison with Pu^{239}. Health Phys. 23:475-80.

Mott, W.E., D.W. cole, and W.S. Holman. 1972. The U.S. Atomic Energy Commission nuclear-powered artificial heart program. Address presented in Madrid, May 15, 1972. Unpublished ms.

Noshkin, V.E. 1972. Ecological aspects of plutonium dissemination in aquatic environments. Health Phys. 22:537-49.

Noshkin, V.E. 1973. Lawrence Livermore Lab., Livermore, California. Personal communication, 1973.

Noshkin, V.E. and V.T. Bowen. 1973. Concentrations and distributions of long-lived fallout radionuclides in open ocean sediments. In: Radioactive contamination of the marine environment. Proceedings of a symposium on the interaction of radioactive contaminants with the constituents of the marine environment, July 10-14, 1972, Seattle, Washington, IAEA STI/PUB/313, pp. 671-86. International Atomic Energy Agency, Vienna. 786 pp.

Olafson, J.H. and K.H. Larson. 1963. Plutonium, its biology and environmental persistence. In: Radioecology (V. Schultz and A.W. Klement, eds.), Proceedings of the first national symposium on radioecology, September 10-15, 1961, Colorado State Univ. Rheinhold Publishing Company, New York. 746 pp.

Olivier, J.P. 1974. Nuclear Energy Agency/Organization for Economic Cooperation and Development, 38 Boulevard Suchet, 75016 Paris. Personal communication, January 9, 1974.

Patin, S.A., V.A. Pechkurenov, and I.A. Shekehnova. 1971. Kinetics and mechanisms of accumulation of plutonium by Misgurnus fossilis spawn. Radiobiologya 11:742-46. Translated in AEC-Tr-7306:157-59.

Pillai, K.C. 1973. Atomic Energy Establishment, Trombay, Bombay 73, India. Personal communication, 1973.

Pillai, K.C., R.C. Smith, and T.R. Folsom. 1964. Plutonium in the marine environment. Nature 203:568-71.

Pillai, K.C. and P.R. Kamath. 1971. Control of radioactive pollution in India. Mar. Pollut. Bull. 2(5): 74-75.

Polykarpov, G.G. 1966. Radioecology of aquatic organisms. Rheinhold Publishing Company, New York.

Polzer, W.L. 1971. Solubility of plutonium in soil-water environments. Health Services Lab. Rpt., April 16. Health Services Lab., Idaho Falls, Idaho.

Preston, A. and N.T. Mitchell. 1973. Evaluation of public radiation exposure from the controlled marine disposal of radioactive waste (with special reference to the United Kingdom). In: Radioactive contamination of the marine environment. Proceedings of a symposium on the interaction of radioactive contaminants with the constituents of the marine environment, July 10-14, 1972, Seattle, Washington, IAEA STI/PUB/313, pp. 575-93. International Atomic Energy Agency, Vienna. 786 pp.

Price, K.R. 1973. A review of transuranic elements in soils, plants, and animals. J. Environ. Qual. 2(1):62-66.

Raabe, O.G., G.M. Kanapilly, and H.A. Boyd. 1973. Studies of the in vitro solubility of respirable particles of Pu^{238} and Pu^{239} oxides and an accidentally released aerosol containing Pu^{239}. Inhalation Toxicology Research Institute Annual Report 1972-1973, LF-46, UC-48, pp. 24-30. Lovelace Foundation, Albuquerque, New Mexico.

Richmond, C.R., J.E. London, J.S. Wilson, and J. Langham. 1968. Biological response to small, discrete, highly radioactive sources. I. Observations on gastrointestinal transit, histological change, and tissue deposition in beagles fed one-half curie $^{238}PuO_2$ for six months. Health Phys. 15:487-92.

Richmond, C.R., J. Langham, and R.S. Stone. 1970. Biological response to small, discrete, highly radioactive sources. II. Morphogenesis of microlesions in rat lungs from intravenously injected $^{238}PuO_2$ microspheres. Health Phys. 18:401-08.

Romney, E.M., H.M. Mork, and K.H. Larson. 1970. Persistence of plutonium in soil, plants, and small mammals. Health Phys. 19:487-91.

Seaborg, G.T. 1963. Man-made transuranium elements. Prentice-Hall, Englewood Cliffs, New Jersey. 120 pp.

Seaborg, G.T. and J.J. Katz. 1954. Actinide elements. National Nuclear Energy Series, Vol. 14A, McGraw-Hill, New York. 870 pp.

Schreiber, B., L. Tassi Pelati, and M.G. Mazzadri. 1972. Radioecology research in the Gulf of Taranto: Annual report 1971. In: Studies on the radioactive contamination of the sea (M. Bernhard, ed.), pp. 148-60. Euratom Rpt. EUR 4865 3, or CNEN Rpt. RT/B10(71) 7(1972). Commission of the European Communities, Luxembourg.

Stockholm International Peace Research Institute (SIPRI). 1972. SIPRI yearbook of world armaments and disarmament - 1972. Humanities Press, New York.

Stannard, J.N. 1973a. Biomedical aspects of plutonium. In: Handbook of experimental pharmacology (H.C. Hodge, J.N. Stannard, and J.B. Hursh, eds.), Vol. 36, Chapter 8, pp. 309-22. Springer-Verlag, Berlin-Heidelberg-New York. 995 pp.

Stannard, J.N. 1973b. Plutonium in the environment. In: Handbook of experimental pharmacology (H.C. Hodge, J.N. Stannard, and J.B. Hursh, eds.), Vol. 36, Chapter 15, pp. 669-88. Springer-Verlag, Berlin-Heidelberg-New York. 995 pp.

Stover, B.J. and W.S.S. Jee, eds. 1972. The radiobiology of plutonium. Univ. of Utah Press, Salt Lake City. 539 pp.

Sugihara, T.T. and V.T. Bowen. 1962. Radioactive rare earths from fallout for the study of particle movement in the sea. In: Radioisotopes in the physical sciences and industry, pp. 57-65. International Atomic Energy Agency, Vienna.

U.S. Atomic Energy Commission. 1971. Siting of fuel reprocessing and waste management facilities. ORNL-4451. Oak Ridge Natl. Lab., U.S. Atomic Energy Commission, Oak Ridge, Tennessee. 415 pp.

U.S. Atomic Energy Commission. 1972. Nuclear power: 1973-2000. WASH-1139 (72). Forecasting Branch, Office of Planning and Analysis, U.S. Atomic Energy Commission, Washington, D.C. 43 pp.

Vaughan, J., B. Bleaney, and D.M. Taylor. 1973. Distribution, excretion, and effects of plutonium as a bone-seeker. In: Handbook of experimental pharmacology (H.C. Hodge, J.N. Stannard, and J.B. Hursh, eds.), Vol. 36, Chapter 10, pp. 349-502. Springer-Verlag, Berlin-Heidelberg-New York. 995 pp.

Volchok, H.L. 1973. U.S. Atomic Energy Commission, Health and Safety Lab., 376 Hudson Street, New York, N.Y. 10004. Personal communication, October 1973.

Volchok, H.L., R.H. Knuth, and M.T. Kleinman. 1972. The respirable fraction of plutonium at Rocky Flats. Health Phys. 23:395.

Volchok, H.L., V.T. Bowen, R. Dyer, W. Forster, J. Herring, J. Perkowski, T. Rice and J. Stannard. Chapter 3 "Transuranic Elements" In: "Assessing Potential Ocean Pollutants" Ocean Affairs Board, National Academy of Sciences. In press.

Washington Post, July 16, 1973, p. 10.

Webb, G.A.M. and F. Morley. 1973. A model for the evaluation of the deep ocean disposal of radioactive waste. NRPB-R14, June 1973. National Radiological Protection Board, Harwell, Didcot, Berkshire, U.K.

Wick, O.J., ed. 1967. Plutonium handbook: A guide to the technology, Vols. 1 and 2. Gordon and Breach, Science Publishers, New York. 966 pp.

Wong, K.M., V.E. Noshkin, and V.T. Bowen. 1970a. Radiochemical procedures of Wong (now used as WHOI) for the analysis of strontium, antimony, rare earths, cesium, and plutonium in sea water samples. In: Reference methods for marine radioactivity studies, Tech. Series No. 118, pp. 119-26. International Atomic Energy Agency, Vienna. 284 pp.

Wong, K.M., V.E. Noshkin, L. Surprenanat, and V.T. Bowen. 1970b. Plutonium-239 in some organisms and sediments. In: Fallout program: Quarterly summary report, March 1, 1970-June 1, 1970 (E.P. Hardy, Jr., ed.), HASL-227, pp. I-25 - I-33. New York Operations Office, Health and Safety Lab., U.S. Atomic Energy Commission, New York, New York. 190 pp. + Appendix.

Wong, K.M., V.F. Hodge, and T.R. Folsom. 1972. Plutonium and polonium inside giant brown algae. Nature 237:460-62.

Zlobin, V.S. 1966. Accumulation of uranium and plutonium by marine algae. Radiobiologya 6(4) [Translation on pp. 219-27; Russian, pp. 613-17].

Zlobin, V.S. 1971. Active phase of assimilation of Pu-239 by the marine algae Ascophyllum nodosum. Proc. Sci. Res. Planning Inst. Sea Fisheries Oceanogr. 29:169-75. Translated in AEC-Tr-7418:207-17.

Zlobin, V.S. and Mokanu, O.V. 1970. Mechanisms of accumulation of Pu^{239} and Po^{210} by the brown algae Ascophyllum nodosum and marine phytoplankton. Radiobiologya 10:584-89. Translated in AEC-Tr-7205:160-69.

Zlobin, V.S. and M.F. Perlyuk. 1971. Photosynthesis and the mechanism of the action of cyanide on cell respiration and Pu-239 accumulation by marine algae. Proc. Sci. Res. Planning Inst. Sea Fisheries and Oceanog. 29:159-68. Translated in AEC-Tr-7418:195-206.

TABLE 1. PLUTONIUM IN MARINE ORGANISMS - 14 -

Organisms	Collection Date	Location	Tissue and Number Samples	Mean Pu 239 pCi/kg wet	Pu238/Pu239	Range of Conc. Factors
Plants						
Algae(attached)	1964	California Coast	Whole (4)	0.47	--	660-1570
	1970-71	Cape Cod, Mass.	" (6)	0.53	--	100-1600
	1971	California Coast	" (19)	0.64	--	260-3500
Sargassum(attached)	1971	California Coast	" (2)	0.28	--	325-450
Sargassum(pelagic)	1965-70	Atlantic Ocean	" (6)	20.7	--	3000-100,0(
Animals						
Plankton(mixed)	1950	California Coast	" (1)	0.023	--	--
"	1961	Atlantic Ocean	" (1)	2.03	--	2300
"	1964	California Coast	" (1)	1.08	--	2600
Sponge	1970	Cape Cod	" (1)	1.80	0.07	2100
Annelid Worm	1970	" "	" (1)	3.50	0.06	4100
Starfish	1970	" "	" (1)	0.87	0.09	1020
Gastropods	1970	" "	Body (2)	0.35	0.05	140-660
"	1970	" "	Shell (2)	0.42	0.09	300-690
Bivalves	1964	California Coast	Body (2)	0.22	--	230-290
"	1968	Danish Coast	? (1)	7	--	8200
"	1970	Cape Cod	Body (5)	0.31	0.07	300-520
"	"	"	Shell (2)	0.47	0.08	490-600
Salpa	1958	Atlantic Ocean	Whole (3)	1.40	--	900-2400
Crustacea	1968	Danish Coast	" (5)	1.5	--	1060-4500
Fish	1964	California Coast	" (1)	0.001	--	3
"	1969	Cape Cod	Muscle(1)	0.005	--	1-5
"	"	"	Liver (1)	0.03	--	--
"	"	"	Bone (1)	0.6	--	--
"	1970	Cape Cod	Muscle(3)	0.003	--	1-2
"	"	"	Liver (3)	0.05	--	14-60
"	"	"	Gut (3)	0.68	--	40-1100
"	"	"	Bone (3)	0.11	--	50-600
"	1970	Cape Hatteras	Muscle(3)	0.003	--	4
"	"	"	Liver (3)	0.15	--	175
"	"	"	Bone (3)	0.02	--	21
"	1971	Cape Hatteras	Muscle(2)	0.006	--	10-15
"			Bone (2)	0.03	--	30-50

Dr. Mills: Thank you, Doctor. You and Dr. Wrenn have given us a great deal of technical information which will take quite a lot of time to digest.

I have two quick questions, one to you and one to Dr. Wrenn.

In regard to the question of plutonium uptake to include the food chain for humans, has there been any information that came from the Palomares episode which would lead us in a determination of what plutonium might do by way of transport to humans?

Dr. Bennett: Yes. There have been some studies of plant uptake for edible foods at Palomares, and also laboratory tests and experiments using Palomares soil. Some of these data, reported by the Los Alamos Scientific Laboratory, are included in the comprehensive summary table of plant uptake included in my written testimony.

Dr. Mills: Other than the inhalation problem, does the depth of the soil -- did there seem to be a critical depth of plutonium in the soil uptake, or the food chain? That is, the growth and transport of materials, is it all within the first centimeter?

Dr. Bennett: For cultivated fields, that of course would not be the case. It would be more uniformly distributed. That should be considered.

Even for uncultivated areas, there is some downward mobility, as Dr. Wrenn pointed out. It does not remain on the surface forever.

Dr. Mills: I have one question for Dr. Wrenn.

In your Table 3, where you show representative concentrations of plutonium 239 in various means, you have 4×10^{-8} picocuries per gram, I recognize the sample size is an important consideration but would you

comment on the ability to make measurements at these levels?

That is, keeping in mind that one can only work with a reasonable size sample. Are these pretty close to the detectability, do you feel?

Just a comment is all that I am looking for.

Dr. Wrenn: Yes.I would say they are. They represent generally research type measurements in which one takes a great deal of trouble to collect a very large sample and to process that sample and analyze it.

For example, in seawater samples, there was .1 picocuries per 100 liters, so you have to collect 100 liters to get a tenth of a piocurie of plutonium.

To answer your question, yes. You have to stretch to do that. On a research basis, you can.

Dr. Mills: Do you have any questions, Dr. Taylor?

Dr. Taylor: I want to ask one question of Dr. Bennett, if I may.

You pointed out that the uptake of plutonium in foodstuffs seems to be very low relative to the amounts deposited in comparison with other radio elements.

What is the explanation for that?

Dr. Bennett: I notice that in wheat, very little translocating to the inner part of the kernal takes place. That might be one explanation, since there is little translocation, there is more opportunity for washoff.

The explanation for low levels in other foods in terms of plant uptake is explained by the chemistry.

Dr. Mills: Dr. First?

Dr. First: You have gone through a great deal of data in your two presentations in a short time. It is obvious you have concentrated them quite a bit.

I am going to ask you to concentrate still more, if you can. Could you tell us, either/or both of you, what is the significance of the data which you have presented to us this afternoon in terms of the objective of this conference?

What should they mean to us?

Dr. Bennett: The fallout measurements, I think, are directly appropriate to your consideration in that they are actual measurements of plutonium in the environment.

To that extent, it is not speculation; and to that extent, I think it will be important in your consideration of standards.

Dr. First: I do not think I have made my question clear. What should I think about it now that you have presented it? What am I supposed to deduce from this information?

Dr. Bennett: Whatever a scientist would care to deduce from it. It is your prerogative.

Dr. First: I realize this, but I would like to know what the significance is in your mind. Why did you present the particular things you did? Why did you highlight the particular items? They must have had some significance in the context of this particular meeting.

What I am asking you for, really, is to help me decide what this all means by not having to go through all the references.

Dr. Bennett: I am not sure I understand you.

I presented what I believe is objective scientific data. I think it does give you some indication of the behavior of plutonium in the environment.

I cannot really say anything further.

Dr. Mills: Perhaps I can read one of the specific items in the Federal Register. Information was asked for on the environmental levels. It was to include consideration of available data of the procedure, and accurateness and completeness of available data, a theoretical model developed on transport through the ecosystem, and experimental verification of such a model.

I would assume that some of this information some where down the road could be interpreted in this context.

Dr. Bennett: Yes. I would certainly hope so.

Dr. Mills: That was a very big job.

Dr. Wrenn: I guess I can have a crack at it quickly. It seems to me that one needs to discuss the existing amounts of given types of material in the environment when considering environmental type standards.

Secondly, they teach us an awful lot about the way the material will behave in the future.

One of my reasons for pointing out the americium 241 amounts is that we are going to learn from environmental studies in the next few years a lot of things about the translocation of this particular element that we do not know yet.

Dr. First: I hope nobody is interpreting this as being critical of the papers or of the information presented.

I am very much interested in it. I think it is a very fine job. I would like to know what it means.

Dr. Liverman: It seems to me that with the information on hand you can conclude the following sorts of things.

Here is fallout. You can measure what is on the top of the soil and at different levels. You can grow plants on it and find out how much they take up, how much is in the food chain, how much gets to bones, lungs.

It begins to tell you, then, something about what should be permissible to be allowed on the surface or at different levels in the soil in different regions of the country, so that you have a better feeling for saying OK, you cannot get that dirty there; you are in real trouble. It then begins to tell you something about the levels at which one should set permissible standards in different environmental conditions.

At least to me, that is what this would say.

Dr. First: Yes. I agree.

What are the levels?

Dr. Liverman: What should the levels be?

I thought that was the purpose of all of these explorations, to help us try to arrive at what these should be.

Dr. First: Yes. I agree. I thought each one might have some estimate.

Dr. Liverman: I have not. Perhaps others do.

Dr. Taylor: This will help us set flexible standards, will it?

Dr. Liverman: It should tell you how much flexibility is needed.

Dr. First: This is a do it yourself project, I take it.

Dr. Radford: I have a few questions for both the speakers.

You heard, first, about the AEC facilities and Dr. Yoder indicated those are not necessarily typical of distribution of radionuclides that occur from civilian power development.

Now we have heard about weapons testing fallout which also probably is not typical. I guess you can say flatly it is not typical.

In particular, for example, would either of the speakers comment on the importance of curium versus americium or plutonium in waste now rather than just total? I realize plutonium is the big item, but when we get into the waste system, we are dealing with curium, too. Right?

Dr. Wrenn: I pointed out in my slide number three that curium is a trivial input in weapons testing.

Dr. Radford: It may not be trivial when we get into wastes for nuclear power plants?

Dr. Wrenn: It may not be. The relative abundance will be quite different.

Dr. Radford: So the contribution that curium isotopes might have to this problem are not inferrable from this information. I would like just to ask Dr. Bennett first with regard specifically to this lung model, I take it that as far as the fallout material is concerned the principal conclusion that I would draw from your data is that inha-

lation exposure to lung tissues is essentially the principal problem.

There may be some uptake into other tissues, but it is predominantly in the lung tissues. Is that right?

Dr. Bennett: Yes. Initially it is, and subsequently some transport to G.I. tract and to blood; subsequently, to other organs. Yes.

Dr. Radford: But the dose calculated in the method you used came out pretty small for those other organs. Is that right?

Dr. Bennett: Yes, initially.

Dr. Radford: Initially, and integrated over the whole?

Dr. Bennett: Long term retention is assumed for bone and liver, so those doses do exceed the lung dose eventually.

Dr. Radford: Now, the principal concern as I understand it of the panel and this discussion is the possibility of cancer production in man. Is that your understanding too? Or genetic effects?

Dr. Bennett: Health effects, yes.

Dr. Radford: Health effects. And those are predominantly cancer effects by alpha emitters. Is that what we are talking about predominantly?

Dr. Bennett: I am not talking about it. My studies end with the estimated burdens in man. I have not directed any of my comments on health effects-

Dr. Liverman: I think we will go into that area in great depth in the morning, Dr. Radford.

Dr. Radford: All right. I just wanted to make a point pertient to Dr. Bennett's presentation, since you did present the lung model and

the derivations therefrom.

The radiogenic cancers that occur in man occur in what tissues specifically within the lung? Are you familiar with that?

Dr. Liverman: I do not think he can be expected to answer that.

Dr. Bennett: I am an environmental scientist. I am not a biologist.

Dr. Radford: Oh, I see. Well, never mind, then. For the sake of an interest in time, I will take that it is predominantly in the bronchial epithelium or the substructures to that, and the ICRP lung model does not include this as a compartment, nor are there very good data on the transfer rates in and out of that compartment.

So that the application of modelling by the ICRP model is not particularly germane to this issue today.

Dr. Wrenn, would you care to speculate on the lung concentrations that have been observed, that you reported in your Table 3, and which I guess were similar to those Dr. Bennett presented in relation to the air concentrations?

Dr. Wrenn: Dr. Bennett went over this in detail for New York. I just took essentially the highest concentration and -- it will be talked about later in Dr. Richmond's paper -- I stuck that in as a representative example.

The function of this Table is merely to allow you to rank the amount of activity.

Dr. Radford: What is the form of the alpha emitting elements in fallout? Are they in submicron particles, dust particles, or how? Is this known?

Dr. Bennett: Yes. They are submicron particles attached to the aerosol particles. Yes. You can understand that from the production method in the weapons test, dispersion in the stratosphere.

Dr. Radford: Would expect a particle size distribution to be the same in a weapons test fallout as it would be, say, in material coming out of a fuel reprocessing plant?

Dr. Bennett: It could well be different, but it could also be quite similar.

Dr. Mills: Dr. Garner?

Dr. Garner: Dr. Bennett, we have in our written testimony a statement from William B. Lipton, who describes himself as a doctoral candidate who has been working on uptake of plutonium by plants.

He states, "If you use plutonium chelating agents...the uptake factor is increased by about 50."

Also, recently, there was a paper in the Journal of Agricultural and Food Chemistry, Pacific Northwest Lab, describing an increase in uptake of plutonium from soil.

Do you think this will modify the conclusions you will have to make when we start talking about plutonium with other things coming out of it, from nuclear plants as opposed to fallout?

Dr. Bennett: Yes, I am aware of these studies. I mentioned some of the effects in that table of chelation treatment. It will increase plant uptake; it is not often sustained, however. It is possible to increase plant uptake using certain chelating agents.

I am aware of that. Whether these will be of widespread use in

agriculture would be hard to say.

Dr. Garner: What about the Pacific Northwest results that showed a gradual increase in uptake by kilogram?

Perhaps someone will comment on that tomorrow?

Dr. Bennett: I think it was a gradually increasing uptake by plants with decreasing concentration in soil. However, there was only a factor of about two difference, really not significant; if you extrapolate to background levels to fallout levels, you do not find a corresponding extrapolated increase in uptake at these levels.

Uptake is not radically different from the levels that Wildung obtained.

Dr. Garner: So you think there is no reason to suspect in the future that major exposure of man will change from inhalation to ingestion?

Dr. Bennett: Yes. I have stated that there should be no surprising plant uptake at the low levels such as we have experienced with fallout plutonium.

Dr. Garner: Thank you.

Dr. Mills: Are there any more questions or comments?

Thank you, gentlemen.

I would suggest we adjourn until the morning.

We will reconvene at nine o'clock tomorrow morning.

(Whereupon, the hearing in the above entitled matter recessed at 5:30 p.m., to reconvene the following day, on Wednesday, December 11, 1974, at 9:00 a.m. o'clock.)

Dr. Mills: We will start off this morning with the area of Biomedical Effects, testimony given by the Atomic Energy Commission.

The first speaker this morning is Dr. Bill Bair.

The Biological Effects of Transuranium Elements in Experimental Animals

by W. J. Bair, Ph.D.
Director, Life Sciences Program
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part of the AEC presentation at the
EPA Plutonium Standards Hearings
Washington, D. C., December 10-11, 1974

INTRODUCTION

The toxicity of plutonium has been of concern since milligram quantities were first produced in the Oak Ridge reactor starting in late 1943. In 1944 milligram quantities were allocated for biomedical studies. In 1947 and 1948 the first biological experiments were completed with americium and curium. Since then, biological research has been in progress at several laboratories in the United States and abroad. Most of the research effort has been directed towards the compounds of the most common isotope of plutonium, ^{239}Pu. Within the past 10 years as the concept of plutonium recycle and the fast breeder program developed, recognition of the potentially increasing abundance of the transplutonium elements has led to expanded biomedical research on neptunium, plutonium, americium, curium, californium, berkelium, and einstinium.

The purpose of these animal experiments is to enable us to predict the health consequences of transuranium elements in man. These studies have considered two different kinds of contamination events. One of

these, occupational exposures to transuranics released into the work environment, involves relatively small numbers of people. Such exposures can be simulated reasonably well in the laboratory with the expectation of observing unmistakable effects in statistically significant numbers of animals. The second kind of contaminating event of concern is the exposure of large populations to very low levels of the transuranium elements. Such low level exposures cannot be directly simulated in the laboratory because exceedingly large numbers of experimental animals are required to yield meaningful results. Therefore, an understanding of the mechanisms of the biological action of low levels of transuranics is required to predict what cannot be measured in the laboratory.

An overriding concern of all the animal experimentation is the confidence with which the results can be extrapolated to man. While sophisticated experiments can be performed with rodents, dogs, cats, swine, and primates, questions regarding the applicability of the results to man will be settled only as data from human exposure cases become available.

The major health effects of the transuranic elements are due to their emission of alpha radiation and the nature of the effects depends upon which tissues are irradiated. This is determined by the disposition of these radioactive elements in the body which in turn is determined by their chemical and physical properties and their route of entry into the body. Thus, in this presentation, I will review in a general way the

absorption of the transuranic elements into, and the distribution within the body following ingestion, deposition on skin, and inhalation. Then I will summarize the biological effects which have been observed in experimental animals, in particular the late effects resulting from relatively low level radiation exposures. The emphasis will be on plutonium because it is the transuranic element we know most about.

Much of the information included in this presentation has appeared in several recent reviews (Hodge, Stannard, Hursh, 1973; Bair and Thompson, 1974; Bair, 1974; Thompson, 1974; Bair, Richmond, and Wachholz, 1974; Dolphin et al., 1974; Buldakov et al., 1969; Sanders et al., 1970; Healy, 1974; Thompson, 1974; Park, 1974; Stover, 1974).

DISPOSITION OF TRANSURANICS IN THE BODY

Transuranium elements released to the environment may reach man through three pathways. Transuranics which become incorporated into foodstuffs may be ingested and absorbed from the gastrointestinal tract, while those dispersed in air may be either deposited on the skin and absorbed, or inhaled and deposited in the respiratory tract. Occupational exposures may include entry through a wound.

ABSORPTION FROM THE GASTROINTESTINAL TRACT

Experiments confirm that most transuranic element compounds are not readily absorbed from the gastrointestinal tract. Table 1 gives values for the gastrointestinal tract absorption of uranium and several transuranic elements in newborn rats and adults. In rats, neptunium nitrate was most readily absorbed, nearly 1 percent. The least absorbed was PuO_2, 0.0001

percent. Gastrointestinal tract absorption was one or two orders of magnitude greater in the newborn rat than in the adult. Americium, curium, berkelium, and einstinium show at least a 10-fold greater absorption than plutonium.

ABSORPTION THROUGH INTACT SKIN

Although percutaneous absorption of all available transuranic elements has not been thoroughly studied, results from experiments with plutonium indicate that absorption through intact skin is a relatively minor route of entry into the body, Table 2. The highest value, 2 percent, was obtained in rat skin exposed to $Pu(NO_3)_4$ in 10 N HNO_3 for 5 days. All other experiments gave values of less than 1 percent. About 0.05 percent of einstinium, the only other transuranium for which data are available, was absorbed over a period of 7 days through rat skin. Results from animal experiments and human contamination incidents indicate the intact skin to be an effective barrier to the entry of plutonium and einstinium, and probably the other transuranium elements.

RETENTION AND TRANSLOCATION FROM LUNG

Airborne transuranic particles are similar to most other particles when they are inhaled in that deposition in the respiratory tract is primarily dependent upon the physical properties of the particles and the respiratory characteristics of the individual inhaling the particles.

Clearance From Lung

Animal experiments and limited human data provide a range of values for the retention half-times of several plutonium compounds. These are

summarized in Figure 1 for ^{238}Pu and ^{239}Pu. The retention half-times for organic complexes of plutonium, plutonium nitrate and fluoride range from less than 100 days to about 300 days in rats and dogs. The retention half-times for PuO_2 are substantially longer, ranging from 200 to 500 days in rats, 300 to 1000 days in dogs, and 250 to 300 days in human beings. The wide range of values for dogs is largely due to extensive experimentation with a variety of plutonium oxides with different particle size characteristics. The relatively low retention values for human beings, compared with dogs, suggests either that man clears plutonium particles from his lungs more rapidly than do dogs or that the materials inhaled in the human accident cases were more soluble than plutonium dioxide. Studies with $^{238}PuO_2$ in dogs indicate a much shorter lung retention time than is observed for $^{239}PuO_2$. This appears to be due to instability of $^{238}PuO_2$ particles, possibly caused by radiolysis in tissue fluids.

Figure 2 illustrates the effect of the physical properties of the inhaled particles on retention of plutonium in lung. Retention half-times are given in days for several plutonium oxides. Each bar represents data from one dog. Plutonium oxide prepared by calcining the oxalate at 1000°C was retained with a half-time of 650 to 950 days compared with 300 to 400 days for an oxalate calcined at 350°. Oxides prepared from metal powder at temperatures of 123° to 450° were retained in lung longer than the low fired oxalate. Particle size is also important.

The small particle size high-fired oxide was retained with a half-time of 400-500 days, compared with half-times up to 900 days for the larger particle size high-fired oxide. Retention of the small particle size $^{238}PuO_2$ was less than for the comparable $^{239}PuO_2$.

Pulmonary retentions of inhaled transuranic compounds have been compared in rats and dogs. In rats, both ^{241}Am and ^{242}Cm nitrates were cleared much more rapidly than ^{238}Pu and ^{239}Pu nitrates, Figure 3. Autoradiograms from this study indicated ^{241}Am and ^{242}Cm to be dispersed much more throughout the lung than ^{238}Pu and ^{239}Pu. In another experiment the rate of clearance of intratracheally instilled einstinium chloride was found to be much like that reported for ^{242}Cm nitrate.

The retention rates of several inhaled transuranics in beagle dogs, Figure 4, compare favorably with the results from rat experiments. Plutonium oxide, nitrate and fluoride were retained in the lung much longer than curium and americium oxides.

Spatial Distribution of Transuranics Within Lung

From the moment transuranic elements are deposited in the respiratory tract, biological and physical forces are at work to cause their removal. Thus, it is difficult to visualize plutonium and the other transuranics remaining static throughout their residence time in lung. It is not possible to document the course of individual particles and aggregates of particles in lung. However, the temporal and spatial characteristics of radioactive particles within tissues can be inferred from autoradiographs of tissue sections prepared from animals exposed to radioactive aerosols.

The first observation is that radionuclides are nonuniformly deposited throughout lung. Further, the radionuclides may deposit unequally among the lung lobes or among portions of lung lobes. Studies of inhaled plutonium nitrate in both rats and dogs show that immediately following the inhalation exposure, plutonium is present in both particulate and nonparticulate forms, as evidenced by the presence of alpha stars and single tracks in autoradiographs, Figure 5. Einstinium nitrate, Figure 6, and einstinium hydroxide also show particulate and nonparticulate forms a few days after deposition in the lung. Autoradiographs prepared from dogs exposed to inhaled $^{239}PuO_2$ show an initial relatively diffuse distribution of particulate plutonium throughout the entire lung.

A fraction of the amount of transuranics deposited in the lung may be dissolved and absorbed into the blood. The remaining transuranic particles and aggregates may be engulfed by macrophages. This has been demonstrated in studies with plutonium. Phagocytized plutonium dioxide particles are rapidly localized in the cells, Figure 7.

The alveolar macrophage appears to be capable of transporting transuranic particles and aggregates from the alveoli to the ciliated epithelium lining the bronchioles. These phagocytic cells containing particles and aggregates can then be removed from the lung in the mucous blanket which is propelled up the respiratory passage by ciliary action. Transuranium elements removed from the lung by this route are swallowed and excreted in the feces.

Both soluble and insoluble transuranics not immediately cleared from the lung tend to become further aggregated. This mobility and aggregation of transuranics may have large effects on the temporal and spatial distribution of the alpha radiation dose. A few days after inhalation of plutonium nitrate and other relatively soluble compounds single tracks in autoradiographs decrease and after several weeks nearly all of the radioactive material appears to be aggregated. Figure 8 shows aggregation of ^{238}Pu in rat lung 100 days after inhalation of $Pu(NO_3)_4$. Curium tends to aggregate less than plutonium (LaFuma et al., in press).

Particles of transuranium elements are transported via lymphatic vessels in the lung and collected in the thoracic lymph nodes. Autoradiographs of lung tissues taken from dogs several weeks and months after inhalation of PuO_2 show alpha stars concentrated in subpleural areas, apparently in lymphatic vessels, Figure 9. Autoradiographs also suggest that radioactive particles become immobilized in scar tissue in subpleural areas. Figure 10 is an example of a $^{238}PuO_2$ particle located in scar tissue of a dog 5 years after exposure. Areas around the scar tissue appeared to be normal.

Radioactive particles transported to lymph nodes eventually appear sequestered in "hot spots" of scar tissue and do not appear to be mobile. The residence time for plutonium in lymph nodes appears to be very long.

There is ample evidence that transuranic particles deposited in lung are subjected to biological and physical forces. This argues against either particles or aggregates of transuranium elements remaining

static indefinitely, except for that which becomes immobilized in scar tissue. To the contrary, while the rates may be low, movement of transuranic particles within lung tissue by several mechanisms certainly occurs as the lung attempts to expel the radioactive particles and other foreign material which may have been inhaled. The migration of deposited radioactive particles in lung partially compensates for the nonuniformity of the radiation exposure from the particles.

Translocation From Lung to Other Tissues

The relative distribution among body tissues of the transuranics translocated from lung by the circulating blood is essentially the same for all transuranic compounds, but may differ quantitatively depending upon the chemical and physical state of the inhaled material.

In beagle dogs within several months after inhalation of relatively soluble plutonium nitrate, the fraction remaining in lung decreased to 40 percent or less of the amount deposited in the lower respiratory tract, Figure 11. Translocation of plutonium from lung resulted in bone accumulating about 30 percent, and liver about 10 percent. A small percentage was found in spleen, lymph nodes, and other soft tissues and the remainder was excreted in urine and feces.

When plutonium dioxide is inhaled, the lymphatic system accounts for a large fraction of plutonium cleared from lung, Figure 12. Data from a 11-year study with beagle dogs shows that after 5 years lung and thoracic lymph nodes each contained 30 percent of the plutonium

initially deposited in the lower respiratory tract. After 11 years the amount in the lung had decreased to about 10 percent and the thoracic lymph nodes had accumulated 40 percent. Translocation of plutonium from lung resulted in levels in liver of about 10 percent, in bone of about 5 percent, and in the abdominal lymph nodes of about 7 percent.

The average radiation doses to these tissues bear the same relationship as the plutonium concentration in the tissues, Table 3. The average concentration of plutonium was highest in the thoracic lymph nodes and next highest in the abdominal lymph nodes. Average concentrations in lung and liver were over 1000 times less than those in the thoracic lymph nodes. The concentrations in spleen and bone were about one-fifth to one-tenth those in lung. Thus, the lymph nodes received a much higher average radiation exposure than other tissues in the body.

Data were presented showing that $^{238}PuO_2$ may be cleared from lung more rapidly than $^{239}PuO_2$. It has also been found that translocation of ^{238}Pu from lung to other tissues in the body may be greater than for ^{239}Pu, Figure 13. Distributions of plutonium in tissues of beagle dogs 5 years after inhalation of $^{238}PuO_2$ and $^{239}PuO_2$ are compared. After 5 years only 10 percent of the body burden of the ^{238}Pu was in lung compared with 46 percent for ^{239}Pu. Accumulation in thoracic lymph nodes was three times greater for ^{239}Pu than for ^{238}Pu; however, the bone burden of ^{238}Pu was 12 times that of ^{239}Pu. This illustrates that the behavior of $^{238}PuO_2$ in the body may differ significantly from that of $^{239}PuO_2$.

All of the transuranics tend to translocate from lung to bone and liver and, to a lesser extent, to spleen and kidney. However, the rate at which translocation from lung to these other tissues occurs differs considerably among the transuranics, depending mostly on the in vivo solubility of the compound inhaled. For example, $^{244}CmCl_3$, $^{244}CmO_{1.73}$, and $^{241}AmO_2$ are readily translocated to the bone, similar to plutonium nitrates, Figure 14. Translocation of plutonium occurs very slowly after inhalation of plutonium fluoride and plutonium dioxide.

In dogs exposed to aerosols of oxides of transuranium elements, ^{244}Cm was almost equally distributed among lung, liver, bone, and muscle after one month, Table 4. The translocation of ^{241}Am was predominately to the liver while translocation of a relatively soluble form of ^{238}Pu, the hydrated oxide, was mainly to bone. More stable ^{238}Pu oxides and $^{239}PuO_2$ showed little translocation from lung to other tissues, but showed greater accumulation in the thoracic lymph nodes than occurred after inhalation of $^{241}AmO_2$ and $^{244}CmO_x$.

The tissue distribution of transuranium elements absorbed through the skin, from wounds or from the gastrointestinal tract is similar to that observed after translocation from the respiratory tract. The rate of translocation may vary, however, because deposition in a wound or in the lung provides a reservoir for continuous absorption into the blood stream. Absorption from skin or the gastrointestinal tract will be of short duration, until the skin has been decontaminated or the GI tract cleared, except in cases of continuous exposure.

The quantitative differences in translocation of different transuranic elements and compounds from the lung and other deposition sites can lead to significant differences in biological effects which may occur.

DEPOSITION IN GONADS

Because of the concern for possible genetic effects of radionuclides deposited in the body, measurements have been made of the amounts of radionuclide which accumulate in the gonads of experimental animals. This is summarized for plutonium in Table 5. About 0.05 percent of the plutonium in the circulating blood may deposit in testes and only about 0.01 percent in ovaries. In the testes about half of the plutonium appears to be associated with germinal tissue. Few data are available on the deposition of the other transuranics in gonadal tissue but preliminary results suggest that the fractional uptake will be about the same as that for plutonium.

CROSS PLACENTAL TRANSFER

The transfer of transuranics and other radionuclides across the placenta have been studied in rats, Table 6. Neptunium, plutonium, and einstinium show significantly less transfer to the fetus as well as to the placenta and the placental membranes than uranium, cesium, and cerium. Preliminary results from studies of ^{241}Am and ^{244}Cm suggest less transfer than has been observed for plutonium. These results show that the placenta is an effective barrier to transuranium elements, and

that extremely high levels of contamination would have to occur in the pregnant female before appreciable quantities of transuranium elements would occur in the fetus.

BIOLOGICAL EFFECTS

It has been shown that the distribution of the transuranium elements among the tissues in the body varies depending upon the route of entry, the chemical compound and the radioisotope. The biological effects which may occur will depend upon the radiation exposure and the relative radiation sensitivity of each tissue into which the radionuclide is deposited. These are primarily blood, bone, liver, lung, and the lymphatic system. The biological effects of greatest interest are those that might occur at low doses. Animal experiments have identified neoplasia as the most sensitive response to the long-term effects of transuranic elements deposited in the body.

BLOOD

Transuranic elements are cleared from the circulating blood within a few days after absorption from the site of deposition such as the gastrointestinal tract and lung. Therefore, the major effects seen in blood cells will be due to irradiation of the hematopoietic tissue in which the radionuclides are deposited or to irradiation of blood circulating through tissues containing deposits of the radionuclide.

Most of the hematologic effects observed after deposition of the transuranics in the body occur at relatively high doses, doses above those which have resulted in cancer, Table 7. A variety of hematologic

effects have been reported in all animal species studied. Summarized in this table are only data from dog and pig experiments. The erythrocyte levels are only reduced at the highest doses. Elements of white blood cells show transient reductions following intravenous injections of all of the transuranics studied similar to those seen after exposure to external radiation. Although the transuranics deposit in bone and lymph nodes, leukemia has not been a common finding in animal experiments. It has been reported in less than a dozen rats after intravenous injection of plutonium and americium, in a few rats after intratracheal injection of einstinium, and in one dog (which also had osteosarcoma) after inhalation of ^{238}Pu.

The most consistent hematologic response seen after injection and inhalation of the transuranics is lymphopenia. This is well documented after inhalation of ^{238}Pu, ^{239}Pu, and ^{241}Am. In current experiments with dogs this is the most sensitive indication of a biological effect, occurring at dose levels of inhaled $^{239}PuO_2$ which have not yet shown cancer, Figure 15. The possible health consequences of a plutonium-reduced level of circulating lymphocytes are not yet known. One cannot rule out the possibility of a relationship between the reduction of circulating lymphocytes, lymph node pathology, decreased immunological competence, and the pathogenesis of transuranic-induced cancer.

BONE

Osteogenic sarcomas appear to be the most sensitive effect following the skeletal deposition of plutonium, americium, curium, and einstinium in mice, rats, and dogs. In most of these experiments the solutions of

the transuranics were injected intravenously. However, osteogenic sarcomas have occurred after pulmonary deposition of ^{244}Cm and ^{253}Es in rats and ^{238}Pu in rats and dogs. In these experiments the ^{244}Cm, ^{253}Es, and ^{238}Pu were largely translocated to the skeleton.

The most informative experiment on the effects of transuranics in bone is a beagle dog study with plutonium at the University of Utah. This experiment began in 1952 to compare the long-term effects of intravenously injected plutonium and radium. The objective was to determine the toxicity ratio between plutonium and radium in dogs, so that the radium toxicity data available from human exposures can be used to infer the toxic response to plutonium in man. The results from the plutonium animals in this experiment are shown in Table 8. There were 9 to 13 animals per exposure group, injected at levels differing by about a factor of three, and ranging from 2.9 μCi/kg to 0.016 μCi/kg. There was a substantial incidence of osteosarcoma, 31 percent at the lowest level. When it became evident that effects were occurring in the lowest exposure groups, additional groups were added to the experiment at levels down to 0.0006 μCi/kg, which is equivalent to the occupationally permissible body burden for man.

A number of long-term studies in rodents have also pointed to osteosarcoma as the most sensitive indicator of plutonium in the skeleton, Figure 16. The incidence of osteosarcoma is plotted against cumulative radiation dose to bone. For each datum point 95 percent binomial confidence limits are shown. Each point represents a group of animals at a given dose level; each type of symbol represents a given experiment. The

open circles represent the Utah dogs and are quite clearly a separate population from the rodents. From these kinds of data, Mays and Lloyd, assuming a time-independent linear dose-response relationship, have calculated an increased incidence per rad of 0.38 percent for beagles, 0.10 percent for mice, and 0.06 percent for rats. Although few data are available, it appears that doses greater than those which caused bone cancer in dogs do not cause bone cancer in miniature swine.

Of more interest than absolute incidence figures and their uncertain extrapolation to man, is the finding in the Utah studies that plutonium-239 is 5 to 10 times more toxic than radium-226, on the basis of the same total energy delivered to bone. This difference is attributed to the more hazardous localization of plutonium on bone surfaces, whereas radium is distributed more uniformly throughout bone. The cells from which bone tumors originate are located near bone surfaces.

The inhalation of $^{239}PuO_2$ has not led to the development of osteogenic sarcomas in experimental animals. However, osteogenic sarcomas have occurred in dogs after inhalation of $^{238}PuO_2$, Table 9. These occurred as a result of the translocation of ^{238}Pu from the lung to bone, which received a higher radiation dose than the lungs. Lung cancer was a secondary finding in one of these dogs. Another dog had leukemia and fibrosarcoma as well as osteosarcoma.

LIVER

Liver is comparable to bone and lung in terms of transuranic content and radiation exposure. However, the liver appears to be less sensitive than bone and lung to the carcinogenic action of alpha radiation.

Malignant liver tumors were the primary cause of death in two of 96 plutonium dogs at risk in the Utah experiment. Small, benign bile duct tumors were incidental findings at autopsy in eight other dogs, but these were also seen in controls at a somewhat lower incidence. The liver tumors had a longer latent period than bone tumors which might explain the lower incidence. Because of this, the possibility remains that liver tumors might predominate at lower doses.

LUNG

Inhalation of relatively soluble plutonium compounds such as organic complexes, plutonium nitrate, and $^{238}PuO_2$ has resulted in primary lung cancer in rodents, rabbits, and dogs in addition to the bone cancer already mentioned. Lung cancer has also occurred in rats given $^{253}EsCl_3$ by intratracheal instillation and in rats after inhalation of $^{244}CmO_x$, $^{244}Cm(NO_3)_3$, $^{238}Pu(NO_3)_4$, $^{241}Am(NO_3)_3$, or $^{241}AmO_2$. Lung cancer has also been observed in beagle dogs, baboons, and rodents after inhalation of $^{239}PuO_2$.

The experimental data on plutonium-induced lung cancer are shown in Figure 17, with tumor incidence in percent plotted against the lung dose in rads. These are rat, mouse, and rabbit data except for the results from one dog study represented by the square symbols. The dogs seem to be more susceptible than the rodents; however, there are no dog data below about 1000 rads. Some of the low incidence data are of uncertain significance because there was a low incidence of lung tumors

in the controls of some of the experiments. For both lung and bone tumors, the lowest dose at which a clearly significant affect has been observed is about 30 rads.

In rats given $^{253}EsCl_3$ by intratracheal instillation, the malignant lung tumor incidence was 4 percent for a lung dose of 38 rads and 12.5 percent for a lung dose of 1900 rads. The incidence of osteogenic sarcomas in these animals was 42 percent at 230 rads and zero at 5 rads. In comparison with soluble forms of the 24,000 year half-life ^{239}Pu, the 20.5 day half-life ^{253}Es was less efficient in producing lung cancer and more efficient in causing bone cancer, providing some basis for speculating on the dose rate effects of alpha radiation (Ballou et al., in press).

Other experiments are in progress in the United States and abroad to determine the carcinogenic response of inhaled curium and americium relative to ^{238}Pu and ^{239}Pu. Squamous cell carcinomas and bronchiolo-alveolar carcinomas are being observed in these experiments.

Preliminary results from several laboratories indicate that the transuranics readily induce lung cancer in rats. However, these same laboratories find that Syrian hamsters tend to be much less sensitive to the carcinogenic action of the alpha-emitting transuranium elements than rats. This is in contrast to results being obtained in other laboratories with ^{210}Po introduced by intratracheal injection which show a high incidence of lung cancer.

The available data on plutonium-induced lung cancer has been analyzed to describe mathematically the relationship between cancer incidence and radiation dose. Although other models may have equal merit, a logarithmic probit curve was selected based on its long usage in toxicology. In Figure 18, arithmetic representations of the fitted function are shown by heavy lines for probit curves and linear regressions. Dotted lines show a limited extrapolation of the fitted functions.

This analysis indicates the current status of information on plutonium-induced lung cancer. Studies now in progress are adding substantially to our understanding of the dose-effect response.

LYMPH NODES

It was shown that plutonium accumulates in lymph nodes following deposition of plutonium in the respiratory tract. Months or years after the contaminating event, lymph nodes may attain concentrations of plutonium many times the average concentrations remaining at the site of deposition and consequently the accumulated radiation dose to some lymph nodes may be greater than to any other tissue. The fact that the biomedical significance of plutonium concentrations in lymph nodes is unknown is a major concern in establishing permissible limits for plutonium.

Although dogs have been studied for 11 years after inhaling $^{239}PuO_2$ and rodents have been studied in life span experiments after inhalation of a variety of plutonium and other transuranic compounds, primary cancer of lymphatic tissue has not occurred. In dogs which had primary

cancer, metastasis to mediastinal lymph nodes and lymphatics occurred, but only one dog had a possible malignant lymphoma and this was confined to the mesenteric and mandibular lymph nodes. Therefore, it can be concluded that the lymph nodes are not especially susceptible to the carcinogenic action of alpha radiation from plutonium.

RELATIVE SENSITIVITY OF DIFFERENT SEGMENTS OF THE POPULATION

An important question relevant to the establishment of exposure standards for radiation or other potentially hazardous agents is whether all segments of the population are equally sensitive. Research on this question relative to the transuranics has not been extensive; however, some information has been gained from experiments with rats.

Effect of Age on Osteogenic Sarcoma Response to Plutonium

Studies of rats given plutonium intravenously indicate that the newborn and weanling may be slightly more sensitive than the adult to plutonium-induced osteosarcoma, Figure 19. The decreased incidences at the higher doses for the weanlings and newborns are probably due to shortened life spans for these groups which did not allow the full cancer potential to be expressed. However, the high dose adult group also showed a significantly shortened life span and still had a high incidence of bone cancer (50 percent).

A similar study with ^{253}Es did not indicate a difference in the incidence of osteogenic sarcoma between the adult and weanling groups at bone doses of 100, 500, and > 2000 rads (D. D. Mahlum, personal communication).

The Effect of Iron Deficiency

Iron deficiency is common in the human being particularly in pregnant women, pre-menopausal women, and in young children. Because of the metabolic relationship between iron and the transuranics in the blood, iron deficiency could have a bearing on the distribution and subsequent biological effects of the transuranics. In an experiment with mice rendered iron deficient it was found that deposition of intravenously injected plutonium in bone of the iron deficient mice was much greater than in the controls. This suggests that persons deficient in iron could have an increased susceptibility to plutonium-induced osteosarcoma. Iron deficiency did not affect the deposition of plutonium in gonads (H. A. Ragan, personal communication).

THE "HOT PARTICLE" ISSUE

It was recognized in the early 1940's that plutonium particles deposited in the lung would irradiate cells in the immediate vicinity of the particle rather than the entire lung. This gave rise to the concern that plutonium particles might be exceptionally efficient in causing lung cancer. Research during the past nearly 30 years has provided no evidence for an enhanced effect of the localized radiation dose from plutonium. Although not conclusive, experimental results to date suggest that plutonium particles might be less hazardous than the same amount of plutonium distributed throughout the lung because many fewer cells would be exposed to alpha radiation. However, experiments to resolve this question are technically difficult because inhaled plutonium does not

distribute throughout the lung but tends to aggregate. Also, such experiments require life time studies with large numbers of animals. A few experiments which bear on the issue have been completed with several transuranic compounds, others are still in progress.

Rats exposed to relatively non-particulate soluble ^{238}Pu which was highly dispersed during its relatively short residence time in the lung developed a higher incidence of lung cancer than has been observed for more particulate ^{238}Pu and ^{239}Pu sources (Sanders, 1973). The implication is that the dispersed ^{238}Pu exposed more cells to the carcinogenic action of the alpha radiation than particulate plutonium.

In France the influence of non-uniform distribution of alpha radiation in lung is being studied in about 700 rats exposed to $^{238}Pu(NO_3)_4$, $^{239}Pu(NO_3)_4$, $^{239}PuO_2$, $^{241}Am(NO_3)_3$, $^{241}AmO_2$, or $^{244}Cm(NO_3)_3$. Of these transuranics, ^{244}Cm was the most uniformly distributed throughout the lung and was most effective in reducing survival time followed in descending order by ^{238}Pu, ^{241}Am, $^{239}Pu(NO_3)_4$, and $^{239}PuO_2$ which was the most heterogenously distributed (LaFuma et al., in press).

The relatively uniform distribution of ^{244}Cm in lung is illustrated by the autoradiogram in Figure 20. This can be compared with the more aggregated $^{239}Pu(NO_3)_4$ in Figure 21. Although the experiment is not yet completed, nearly 200 squamous cell carcinomas and bronchiolo-alveolar carcinomas have been observed. The authors report that the results to date indicate that for lung cancer induction, ^{244}Cm, the most widely

dispersed alpha emitter, is more effective than the more particulate transuranics. Again, the implication is that more cells are exposed to the alpha radiation from the dispersed ^{244}Cm than from the other less-dispersed transuranics.

Another experiment was designed specifically to address the "hot particle" issue at the Los Alamos Scientific Laboratory (Richmond and Voelz, 1972, Anderson et al., 1974). It is impossible to distribute alpha emitting sources uniformly throughout the lung by inhalation exposure due to the tendency for such material to be mobilized and aggregated by clearance processes. Therefore, 10 μm zirconium oxide microspheres containing PuO_2 at specific activities corresponding to respirable particles were given intravenously to hamsters. The microspheres were observed to be firmly fixed in the lung vasculature and were highly dispersed throughout the lung. By varying the quantity of Pu in the microspheres the microdistribution of the radiation dose could be controlled. A total of over 2000 hamsters have been given 2000 to 1,600,000 microspheres ranging in activity from 0.07 to 59 pCi per microsphere. Total lung burdens range from 0.14 nCi to 354 nCi. This study is still in progress. However, nearly 1200 animals have lived their full life span or have been sacrificed. These animals were given a total of about 5.7×10^6 microspheres, each containing in excess of 0.07 pCi. Three malignant tumors were observed. This suggests a tumor risk of about 10^{-7} per particle. The preliminary results from this study do not suggest that particulate sources are more hazardous than equivalent less-particulate sources.

In this experiment and in other experiments with plutonium particles, the lack of significant histopathology in areas adjacent to the particles is a common finding. An example is shown in Figure 22 which is an autoradiograph of a section from a lung of a rat given $^{239}PuO_2$ by intraperitoneal injection (Sanders, in press). From 0.2 percent to 2 percent of the plutonium was phagocytized and transported to the lung where the particles lodged in the vasculature similar to the microsphere experiment with hamsters. The lungs of these rats surprisingly showed little evidence of pulmonary pathology that could be attributed to the plutonium. The radiation doses to the lungs of the several groups of a total of 151 rats were 10, 20, 40, 170, and 600 rads. Only one lung tumor occurred; this was observed after 823 days in one rat of 36 which had a lung dose of 10 rads.

Another example of Pu particles residing in lung which shows no evidence of histopathology is illustrated in Figure 23. This is an autoradiograph of a histologic section from a lung of a dog about 2 years after inhalation of $^{239}PuO_2$ showing several particles in areas of normal lung. Other sections of the lung from this dog showed evidence of plutonium-induced changes. However, normal appearing areas such as this containing plutonium particles, are not uncommon in animal experiments.

The pathogenesis of plutonium induced neoplasia is not fully understood. However, observations made during the past 10 years, suggest that phagocytosis of the plutonium particle is one of the steps leading to necrosis and a connective tissue response such as fibrosis and/or an epithelial response such as hyperplasia, metaplasia, and eventually neoplasia.

In agreement with the observations from studies of plutonium and other transuranics deposited in lung are the results from a recent study of the incidence of chromosome aberrations in the liver as a function of the size of the $^{239}PuO_2$ particle administered. For the same total quantity of plutonium administered, the more uniform dose was more effective in producing chromosome aberrations than the more localized doses (Brooks et al., 1974).

The "hot particle" issue continues to be the subject of controversy and will not be settled to everyone's satisfaction until more of these difficult and expensive experiments are completed. However, the results of relevant experiments at laboratories in the United States, France, and the United Kingdom have led the scientists conducting the experiments to believe that particulate alpha emitting transuranics in the lung do not represent a higher risk of lung cancer than the equivalent quantity of relatively non-particulate transuranium elements distributed throughout the lung (LaFuma et al., in press; Dolphin et al., 1974).

COUNTERMEASURES FOR INHALED PLUTONIUM

An important consideration in evaluating the potential health effects of plutonium is the availability of effective countermeasures for plutonium exposures. Since no acceptable therapy exists for radiation exposures, the only really effective countermeasure for inhaled transuranics is their removal from the body. Inhaled insoluble plutonium is not effectively mobilized by a wide variety of agents which have been tested.

The most effective method for removing plutonium from the lung is lavage with isotonic saline. In rats, dogs, and baboons about 50 percent of the lung burden can be removed by lavage.

A chelating agent, Diethylenetriaminepentaacetic acid (DTPA), has had wide application for treating persons occupationally exposed to plutonium. It reduces the liver burden and, to a lesser extent, the bone burden causing an increased urinary excretion of plutonium. DTPA has also been found to be effective in reducing the systemic burden of Am, Cm, and Es. However, it is not effective in removing insoluble transuranics from lung or lymph nodes.

Therefore, it must be recognized that truly effective countermeasures for transuranic contamination have not yet been found, and that for all practical purposes transuranics deposited in the body will remain there until removed by natural processes, most of which are very slow. The development of therapeutic procedures for removing transuranics from the body are high priority research projects in several laboratories.

SUMMARY AND CONCLUSIONS

STATUS OF CURRENT RESEARCH

Research relevant to the problem of low level exposures to transuranium elements has increased significantly during the past 10 years. Life span animal studies of the biological effects of the transuranium elements have greatly expanded. The current status of our knowledge of plutonium is shown in Figure 23. The dose levels at which major biological effects have been observed in experimental animals are shown relative to the

maximum permissible lung burden of 0.016 μCi for occupational exposures. Lung cancer has been observed at dose levels equivalent to about 100 times the maximum permissible lung burden. Current experiments are directed towards determining whether health effects will occur at lower levels. However, because of the cost in terms of time and money of such experiments, the most productive research may be that which is directed towards understanding the mechanisms by which alpha emitters induce cancer. Some of these studies are in progress and more are anticipated.

RESEARCH IN PROGRESS

Research is in progress in several laboratories in the United States and abroad to examine the late effects of low levels of transuranic elements. Three dog studies are in progress in the United States. At the University of Utah the late effects of transuranics are being studied after intravenous administration, Table 10. This study is primarily directed at effects in bone and liver. At the Lovelace Foundation dogs are being exposed to monodisperse aerosols of ^{238}Pu and ^{239}Pu, Table 11. A total of 360 dogs are being given single exposures to plutonium aerosols with particle sizes ranging from 0.75 to 3 μm aerodynamic diameter. Initial lung burdens range from 0.1 to 5.6 μCi.

At Battelle-Northwest 221 dogs have been exposed to polydispersed aerosols of $^{238}PuO_2$ and $^{239}PuO_2$, Table 12. Initial lung burdens ranged from 0.002 μCi to 5 μCi.

In addition to these major dog experiments, all of the available transuranics are being studied in thousands of rats and hamsters following inhalation, ingestion and intravenous injection. These long term animal

experiments are being supplemented by increasing levels of research to develop a better understanding of how alpha radiation from the transuranium elements causes cancer and other possible health effects.

No significant surprises are expected from this intensified research effort. However, the results will help us sharpen our predictions of the health consequences of the expected increased utilization and availability of the transuranium elements.

References

Anderson, E. C., Holland, L. M., Prine, J. R., and Richmond, C. R., "Lung Irradiation with Static Plutonium Microspheres," In: Experimental Lung Cancer, Carcinogenesis and Bioassays, Springer-Verlag, Heidelberg, in press, CONF-740648-1, 1974.

Bair, W. J., and Thompson, R. C., "Plutonium: Biomedical Research," Science Vol. 183: 715-722, 1974.

Bair, W. J. , "Toxicology of Plutonium," In: Advances in Radiation Biology, Vol. 4 (J. T. Lett, H. Adler, and M. Zelle, Eds.), Academic Press, 1974.

Bair, W. J., Richmond, C. R., and Wachholz, B. W., "A Radiobiological Assessment of the Spatial Distribution of Radiation Dose from Inhaled Plutonium," USAEC, WASH-1320, Sept., 1974.

Bair, W. J., "Consideration of Reactor Accident Exposure Guides for Plutonium," In: Conference on Fast Reactor Safety (CONF-740401). NTIS, Springfield, VA, 1974.

Bair, W. J., "The Effects on Populations of Exposure to Low Levels of Ionizing Radiation." Health Phys. 26, 588-591. (book review).

Ballou, J. E., Dagle, G. E., and Morrow, W. G., "The Long-Term Effects of Intratracheally Instilled $^{253}EsCl_3$ in Rats," Radiation Res. (in press).

Buldakov, L. A., Lyubchansky, E. R., Moskelev, Y. I., and Nifatov, A. P., (1969), In "Problemy Toksikologii Plutoniya," Atom Publications, Moscow (translated as "Problems of Plutonium Toxicology," U.S. Atomic Energy Commission LF-tr-41, 1970).

Brooks, A. L., Retherford, J. C., and McClellan, R. O., "Effect of $^{239}PuO_2$ Particle Number and Size on the Frequency and Distribution of Chromosome Aberrations in the Liver of the Chinese Hamster," Radiation Res. 59, No. 3, Sept., 1974.

Dolphin, G. W., Smith, H., Popplewell, D. S., Stather, J. W., Adams, N., Spoor, N. L., Brightwell, J., and Bulman, R. A., "Radiological Problems in the Protection of Persons Exposed to Plutonium," Document NRPB-R29, National Radiological Protection Board, Harwell, England, 1974.

Healy, J. W., (1974), "Contamination Limits for Real and Personal Property," Los Alamos Scientific Laboratory Report No. LA-5482-PR.

Hodges, H. C., Stannard, J. N., and Hursh, J. B. - Editors, Uranium, Plutonium, Transplutonic Elements Handbook of Experimental Pharmacology XXXVI, Springer-Verlag, New York, 1973.

Hungate, F. P., Ballou, J. E., Mahlum, D. D., Kashima, M., Smith, V. H., Sanders, C. L., Baxter, D. W., Sikov, M. R., and Thompson, R. C., "Preliminary Data on ^{253}Es and ^{249}Bk Metabolism in Rats," pp. 653-656. In: Biological Implications of the Transuranium Elements, R. C. Thompson and W. J. Bair (eds.), Health Physics, Vol. 22, June 1972.

LaFuma, J., Nenot, J. C., Norin, D., Masse, R., Detivier, H., Nobile, D., and Skupinski, W., "Respiratory Carcinogenesis in Rats after Inhalation of Radioactive Aerosols of Actinides and Lanthanides in Various Physicochemical Forms," Symposium on Experimental Respiratory Carcinogenesis and Bioassays, Seattle, WA, 1974 (in press).

Mahlum, D. D., Sikov, M. R., "Influence of Age on the Late Effects of Plutonium-239 in Rats," Radiat. Res. 59, 171, (abstract), 1974.

Mahlum, D. D., and Sikov, M. R., "Distribution and Toxicity of Monomeric and Polymeric ^{239}Pu in Immature and Adult Rats," Radiat. Res. 60, 75-88, 1974.

McClanahan, B. J., Ragan, H. A., and Mahlum, D. D., "Plutonium Metabolism in Newborn and Weanling Pigs," Radiat. Res. 59, 171, (abstract), 1974.

McClellan, R. O., Boyd, H. A., Gallegos, A. F., and Thomas, R. G., "Retention and Distribution of ^{244}Cm Following Inhalation of $^{244}CmCl_3$ and $^{244}CmO_{1.73}$ by Beagle Dogs," Health Physics, Vol. 22, pp. 877-885, 1972.

McClellan, R. O., "Progress in Studies with Transuranic Elements at the Lovelace Foundation, Health Physics, Vol. 22, pp. 815-822, 1972.

Park, J. F., Catt, D. L., Craig, D. K., Olson, R. J., and Smith, V. H., Solubility Changes of ^{238}Pu Oxide in Water Suspension and Effect on Biological Behavior after Inhalation by Beagle Dogs, pp. 719-724, In: Third International Congress of the International Radiation Protection Association, Vol. 1, W. S. Snyder (ed.), (CONF-730907). NTIS, Springfield, VA, 1974.

Park, J. F., Lund, J. E., Ragan, H. A., Hackett, P. L., and Frazier, M. E., "Inhaled $^{238}PuO_2$-Induced Bone Tumors in Dogs," presented at Bone Tumor Conference, Dusseldorf Germany, 1974.

Park, J. F., "Late Effects of Inhaled Plutonium in Dogs," Fifth International Congress of Radiation Research, Seattle, WA, July 14-20, 1974 (in press).

Richmond, C. R., Langhan, J., and Stone, R. S., "Biological Response to Small Discrete Highly Radioactive Sources," Health Physics Vol. 18, pp. 401-408, 1970.

Richmond, C. R. and Voelz, G. L., eds., Annual Report of the Biological and Medical Research Group (H-4) of the LASL Health Division, January through December 1971, Los Alamos Scientific Laboratory report LA-4923-PR, pp. 18-34, April, 1972.

Richmond, C. R., and Voelz, G. L., eds., Annual Report of the Biological and Medical Research Group (H-4) of the LASL Health Division, January through December 1972, Los Alamos Scientific Laboratory report LA-5227-PR, pp. 1-11, March, 1973.

Richmond, C. R., and Sullivan, E. M., eds., Annual Report of the Biomedical and Environmental Research Program of the LASL Health Division, January through December 1973, Los Alamos Scientific Laboratory report LA-5633-PR, pp. 1-9, May, 1974.

Richmond, C. R., and Thomas, R. L., "Plutonium and other Actinide Elements in Gonadal Tissue of Man and Animals." Accepted for publication in Health Physics (in press).

Sanders, C. L., and Adee, R. R., "The Ultrastructure of Mononuclear Phagocytes following Intraperitoneal Administration of $^{239}PuO_2$ Particles," J. of the Reticuloendothelial Soc. Vol. 6, No. 1, Feb., 1969.

Sanders, C. L., "Carcinogenicity of Inhaled Plutonium-238 in the Rat," Radiat. Res. 56, 540-553, 1973.

Sanders, C. L., Thompson, R. C., and Bair, W. J. (1970), "Lung Cancer: Dose Response Studies with Radionuclides," In: Inhalation Carcinogenesis, (M. G. Hanna, Jr., P. Nettesheim, and J. R. Gilbert, eds.), CONF-691001: 285, AEC Symposium Series No. 18, U.S. Atomic Energy Commission, Office of Information Services, Springfield, VA.

Sanders, C. L., "Effects of PuO_2 Particles Deposited in the Lung Following Intraperitoneal Injections," Health Physics (in press).

Sanders, C. L., and Dagle, G. E., "Studies of Pulmonary Carcinogenesis in Rodents Following Inhalation of Transuranic Compounds," Symposium on Experimental Respiratory Carcinogenesis and Bioassays, Seattle, WA, 1974, (in press).

Sikov, M. R., and Mahlum, D. D., "Influence of Age on ^{239}Pu Distribution, Dosimetry, and Effects." Trans. Amer. Nuclear Soc. 18, 389, (abstract) 1974.

Smith, V. H., "The Biological Dispostion of $Es(No_3)_3$ in Rats after Intravenous, Intramuscular and Subcutaneous Administration," pp. 725-730, In: Third International Congress of the International Radiation Protection Association, Vol. 1, W. S. Snyder (ed.), (CONF-730907). NTIS, Springfield, VA, 1974.

Stover, B. J., "Dose-Response Relationships for Beagles Injected with $^{239}Pu(IV)$ or $^{241}Am(III)$," Fifth International Congress of Radiation Research, Seattle, WA, July 14-20, 1974 (in press).

Thomas, R. G., McClellan, R. O., Thomas, Randi L., Chiffelle, T. L., Hobbs, C. H., Jones, R. K., Mauderly, J. L., and Pickrell, J. A., Health Physics Vol. 22, pp. 863-871, 1972.

Thompson, R. C., "Effects of Plutonium in Animals," Presentation before the ad hoc Committee of the USAEC Advisory Committee on Reactor Safeguards, Los Alamos, NM, January 4, 1974.

Thompson, R. C., Summary and Speculative Interpretation Relative to Exposure Limits, Fifth International Congress of Radiation Research, Seattle, WA, July 14-20, 1974 (in press).

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RETENTION OF PLUTONIUM IN PULMONARY REGION OF LUNG

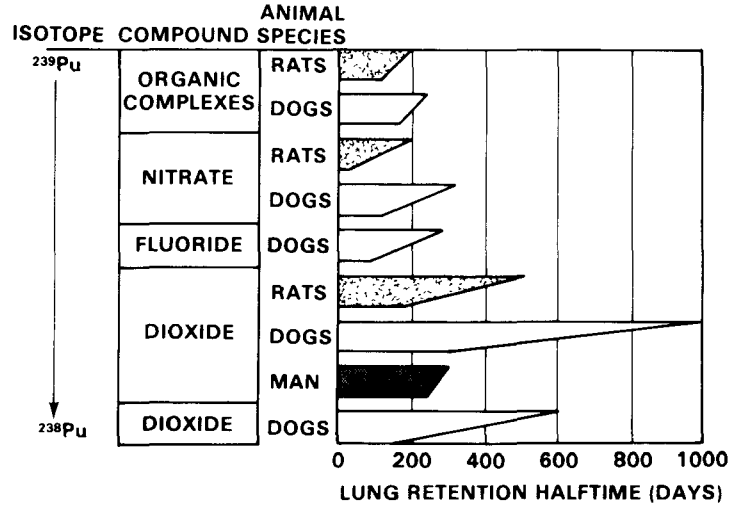

Figure 1

The attached tables were inadvertently omitted from the original printing of the AEC testimony. They are included here in the record however.

TABLE 1

Gastrointestinal Tract Absorption of Transuranics in Rats

(percent of Administered Dose)

Transuranic	Compound	Newborn	Adult
^{233}U	Nitrate	7	0.2
^{237}Np	Nitrate	1	0.9
^{238}Pu	Nitrate	2	0.03
^{239}Pu	Nitrate	0.3	0.003
	Chloride	-	0.007
	Oxide	-	0.0001
^{241}Am	Nitrate	9	0.07
	Chloride	-	0.03
	Oxide	0.5	0.01
^{244}Cm	Nitrate	6	0.2
	Chloride	-	0.05
	Oxide (aged in H_2O)	2	0.1
	Oxide (fresh)	0.3	0.03
^{249}Bk	Chloride	-	0.01
^{252}Cf	Nitrate	4	0.1
^{253}Es	Nitrate	4	0.03
	Chloride	-	0.06

Information in this Table was developed from published reports and from results of current research at PNL by M. F. Sullivan.

TABLE 2

Absorption of Pu and Es through Intact Skin

^{239}Pu or ^{253}Es Compound	Animal Species	Duration of Exposure	Percent Absorbed
$Pu(NO_3)_4$ in 10 N HNO_3	rat	1 hour	0.05
Pu-tributyl phosphate in CCl_4	rat	15 min	0.04
$Pu(NO_3)_4$ in 0.1 N HNO_3	rat	5 days	0.1-0.3
$Pu(NO_3)_4$ in 10 N HNO_3	rat	5 days	1-2
$Pu(NO_3)_4$	rabbit	14 days	0.15
Pu citrate	swine	10 days	0.25
Pu in 9% HCl + EDTA	man	-	0.01
$Pu(NO_3)_4$ in 0.4 N HNO_3	man	1 hour	0.002
$Es(NO_3)_3$ in 0.01 N HNO_3	rat	7 days	0.05

TABLE 3

Relative Concentrations of Plutonium in Tissues of Dogs 7-9 Years After Inhalation of $^{239}PuO_2$

Tissue	Relative Concentration of Plutonium
Lung	1
Thoracic Lymph Nodes	1400
Abdominal Lymph Nodes	100
Liver	0.5
Spleen	0.2
Bone	0.06

TABLE 4

Translocation in Dogs 30 Days After Inhalation
of Oxides of Transuranium Elements

Transuranic Oxides	Particle Size AMAD (μm)	Particle Size GSD	Tissue Content: Percent of Final Body Burden — Lung	Thoracic Lymph Nodes	Liver	Bone	Muscle	All Other
$^{244}CmOx$	0.5	2.1	20	0.5	25	25	22	9
$^{241}AmO_2$	1.3	2.	55	-	19	11	11	4
^{238}Pu(hydrated oxide)	0.9	2.6	64	0.5	8	23	2	3
$^{238}PuO_2$ (750°)	2.2	2.3	96	0.8	0.3	0.5	3	0.3
$^{238}PuO_2$ (PPO)	1.9	1.7	96	1	0.2	1	1	1
$^{238}PuO_2$ (PMC)	2.	1.9	94	1	0.6	1.4	1.4	2
$^{239}PuO_2$	2.	2.	97	2	0.01	0.01	0.01	0.2

(Unpublished data provided by D. K. Craig, PNL)

TABLE 5

Deposition of Plutonium in Gonads

	Percent of Pu in Blood
Testes	0.05
Ovaries	0.01

From C. R. Richmond and R. L. Thomas - in press

TABLE 6

Cross-Placental Transfer of Transuranic Elements in Rats

(Percent of Injected Dose per Gram)

Time of Injection (Day of Ingestion)		^{233}U	^{237}Np	^{238}Pu	^{239}Pu	^{239}Pu*	^{253}Es	^{137}Cs	^{144}Ce
15	Fetus	0.01	0.01	0.01	0.01	0.0002	0.002	0.09	0.02
	Placenta	0.01	0.04	0.22	0.40	0.01	0.02	0.16	0.36
	Membranes	0.13	0.81	3.80	1.93	0.03	0.04	0.08	1.79
19	Fetus	0.03	0.02	0.01	0.01	0.0004	0.008	0.08	0.02
	Placenta	0.05	0.18	0.51	0.91	0.02	0.08	0.14	0.39
	Membranes	0.33	1.24	4.30	3.20	0.07	0.05	0.07	1.60

*Polymeric

(Summary of published and unpublished data provided by D. D. Mahlum and M. R. Sikov, PNL)

TABLE 7

Hematologic Effects of Transuranic Elements

Isotope	Species	Dose (μCi/kg)	RBC	Neutro	Lymph	Mono	EOS
I.V.							
^{226}Ra	dog	.06-10.4	±	↓ ↑	↓	↓ ↑	↓ ↑
^{239}Pu	dog	.02-2.9	±	↓ ↑	↓	↓ ↑	↓ ↑
^{228}Th	dog	.02-2.8	±	↓	↓	↓ ↑	↓
^{228}Ra	dog	.05-8.5	±	↓	↓	↓ ↑	↓
^{241}Am	dog	.02-2.8	±	↓	↓	↓ ↑	↓
^{249}Cf	dog	2.8	-	↓ ↑	↓	↓ ↑	↓ ↑
^{253}Es	dog	2.9	↓ ↑	↓ ↑	↓ ↑	↓ ↑	↓ ↑
^{253}Es	pig	3.0	-	↓ ↑	-	↓ ↑	↓ ↑
^{242}Cm	dog	2.6	↓ ↑	↓ ↑	↓	↓ ↑	↓
Inhaled							
^{239}Pu	dog	.08-5.8*	-	-	↓	-	-
^{238}Pu	dog	.14-5.4*	-	±	↓	-	-
^{241}Am	dog	∿ 25	-	↓	↓	↓	↓

*Initial Lung Burden (μCi)
±Depression at highest doses only
↓Sustained depression
↓↑Depression with evidence of recovery
-No effect
(Summary of published and unpublished data provided by H. A. Ragan, PNL)

TABLE 8

Plutonium-Induced Bone Cancers
in Utah Dog Study

Injected Dose (μCi/kg)	Cancer Incidence	Dose to Bone of Cancer Dogs (RAD)
2.9	7/9 = 78%	4900
0.9	12/12 = 100%	1300
0.3	12/12 = 100%	600
0.1	10/12 = 83%	310
0.05	9/13 = 69%	190
0.016	4/13 = 31%	78
Controls	0	

TABLE 9

Osteosarcoma in Dogs after Inhalation of $^{238}PuO_2$

$^{238}PuO_2$	Survival Time (Months)	Terminal Body Burden (μCi)	Plutonium Distribution (% of Body Burden)				Osteosarcoma
			Lungs	Thoracic Lymph Nodes	Liver	Bone	
Calcined at 350°C	23-70	2.6-3.0	17	9	23	47	5/8*
Crushed microspheres	22-76	0.2-3	20	12	16	24	4/8**

* 1 lung tumor

** 1 myelogenous leukemia and 1 fibrosarcoma
(Park et al., in press)

TABLE 10

Life Span Studies of Intravenously Injected
Transuranium Elements in Dogs at University of Utah
(Numbers of Dogs*)

Nuclide	Age Group of Dogs	Injected Doses, μCi/kg										
		0	.0006	.0016	.005	.01	.015	.05	.1	.3	.9	2.8
^{239}Pu	Juveniles	5					1			4		12
	Young adults	31	26	42	25	36	12					
	Aged									2		3
^{241}Am	Young adults			13	13		12	13	10	16	1	
^{249}Cf	Young adults	6	6		6		6		6	6		
^{252}Cf	Young adults	6	6		6		6		6	6		
^{253}Es	Young adults									3		4

*August, 1974 - 356 dogs

TABLE 11

Life Span Study of Inhaled Plutonium

in Dogs at Lovelace

	Particle Size* (μm)	Initial Lung Burden (μCi)	Number of Dogs
$^{238}PuO_2$	1.5	5.6, 3, 1.4, 0.7, 0.3, 0.1	72
$^{238}PuO_2$	3.0	"	72
$^{239}PuO_2$	0.75	"	72
$^{239}PuO_2$	1.5	"	72
$^{239}PuO_2$	3.0	"	72
			360 + 60 controls

*Aerodynamic diameter of monodisperse aerosols

TABLE 12

Life Span Study of Inhaled Plutonium in
Dogs at Battelle-Northwest

$^{238}Pu^{16}O_2$		$^{239}PuO_2$	
Initial Lung Burden (μCi)	No. of Dogs*	Initial Lung Burden (μCi)	No. of Dogs*
.002	20	.004	20
.02	20	.02	20
.08	20	.08	20
.35	20	.3	20
1.3	20	1.1	20
5.2	13	5.8	8
	113		108

*Half male and half female + 40 controls

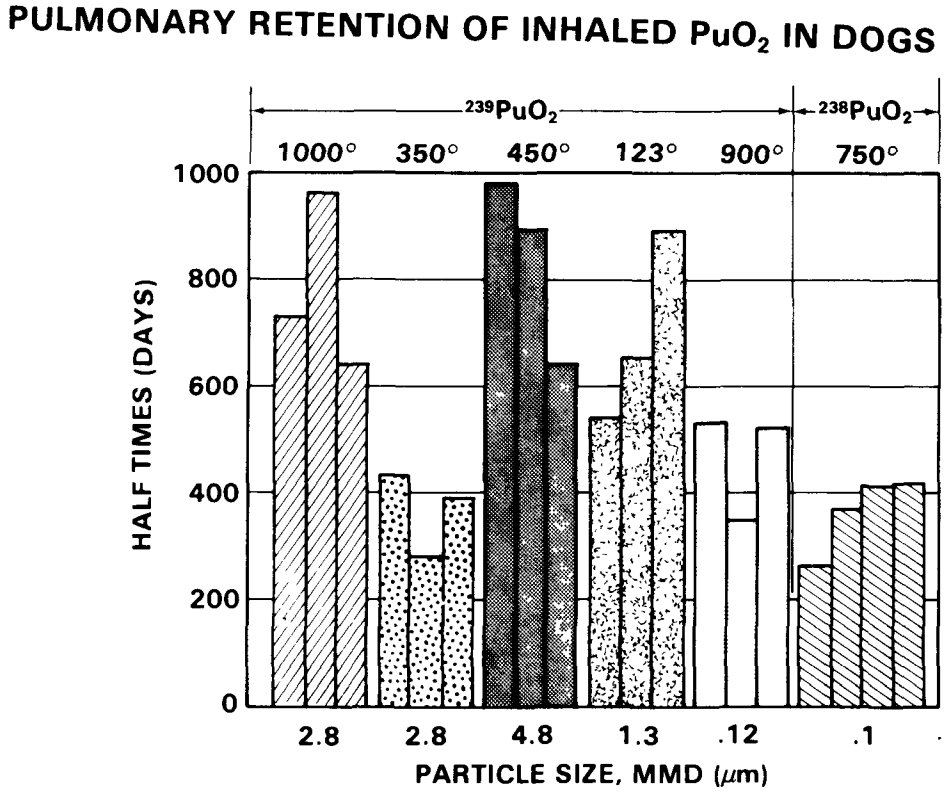

Figure 2

Pulmonary Retention of Inhaled PuO_2 in Dogs

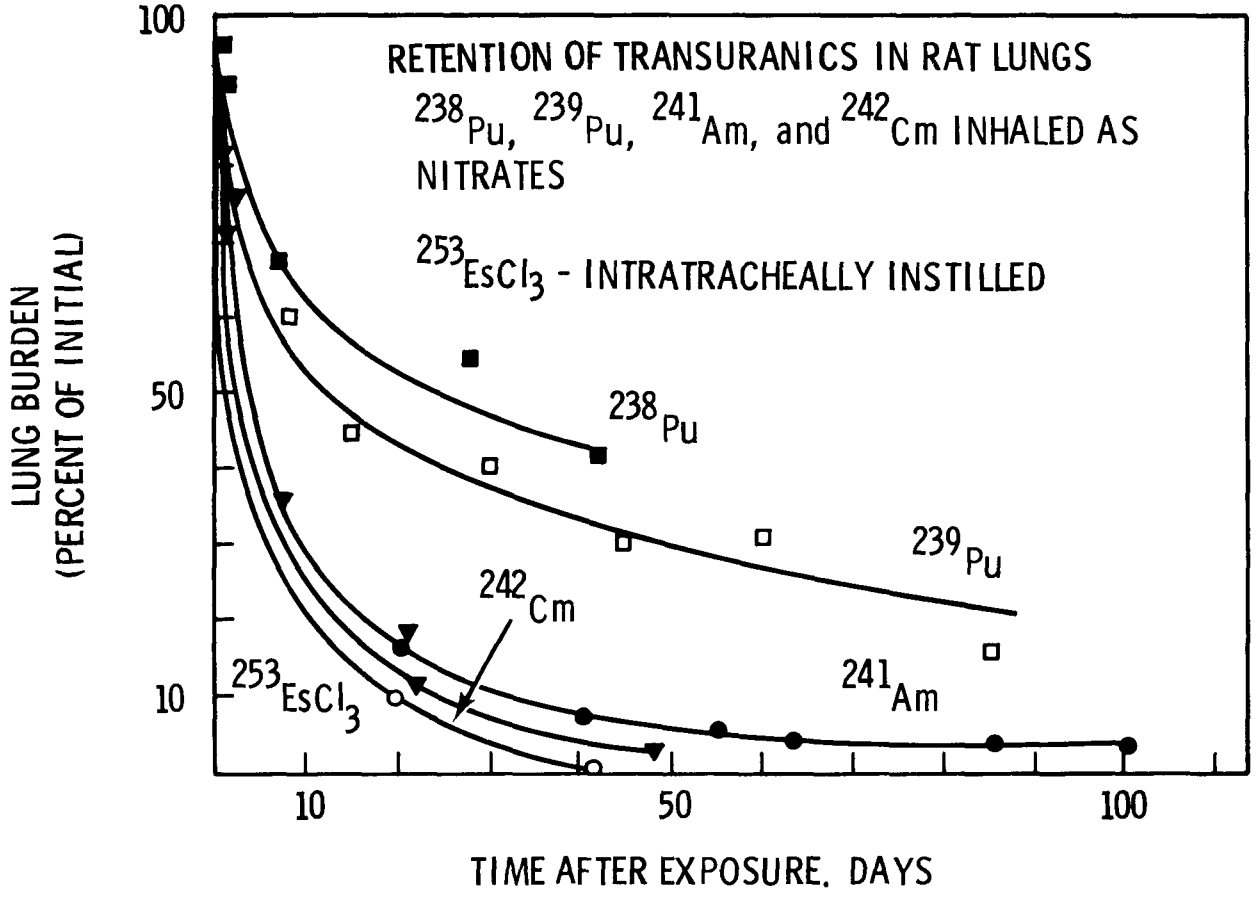

Figure 3

Retention of transuranium elements in rat lungs (^{238}Pu, ^{239}Pu, ^{241}Am and ^{242}Cm - Nenot et al., 1972; $^{253}EsCl_3$ - Ballou et al., submitted for publication)

LUNG RETENTION OF INHALED
TRANSURANIC ELEMENTS IN BEAGLE DOGS

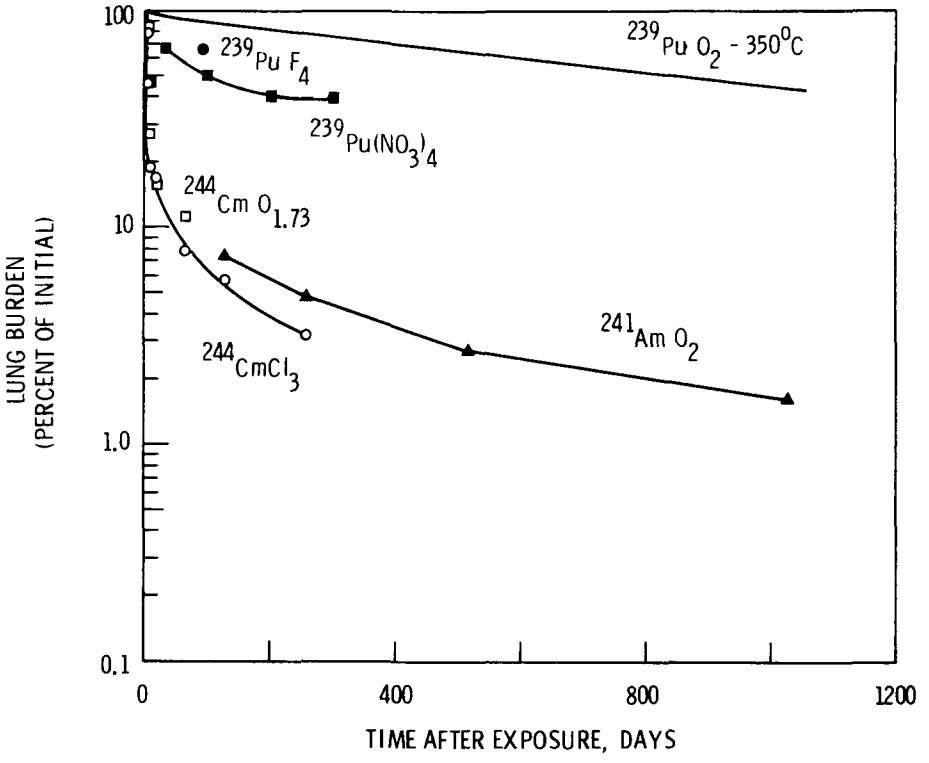

Figure 4

(Redrawn from R. O. McClellan, 1972)

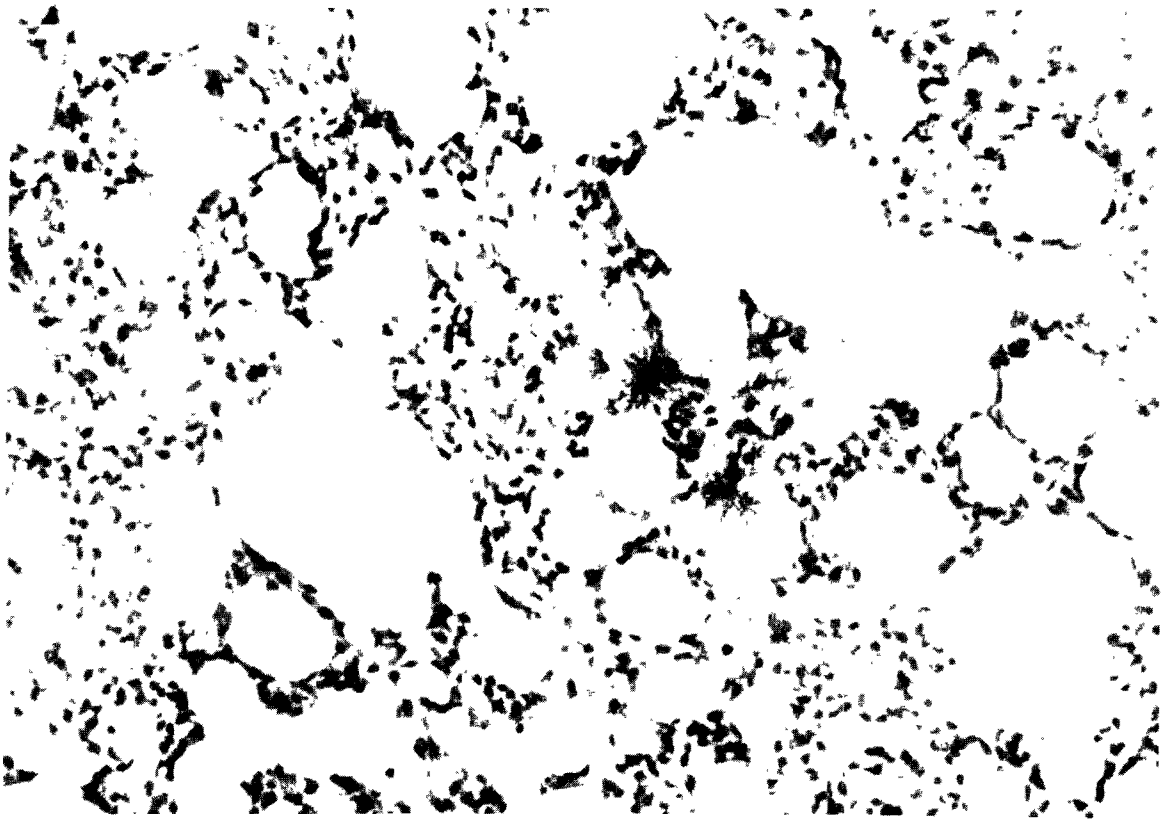

Figure 5

Autoradiograph showing particulate and non-particulate plutonium in lung of a rat immediately after inhalation of $^{239}Pu(NO_3)_4$
(Provided by J. E. Ballou, PNL)

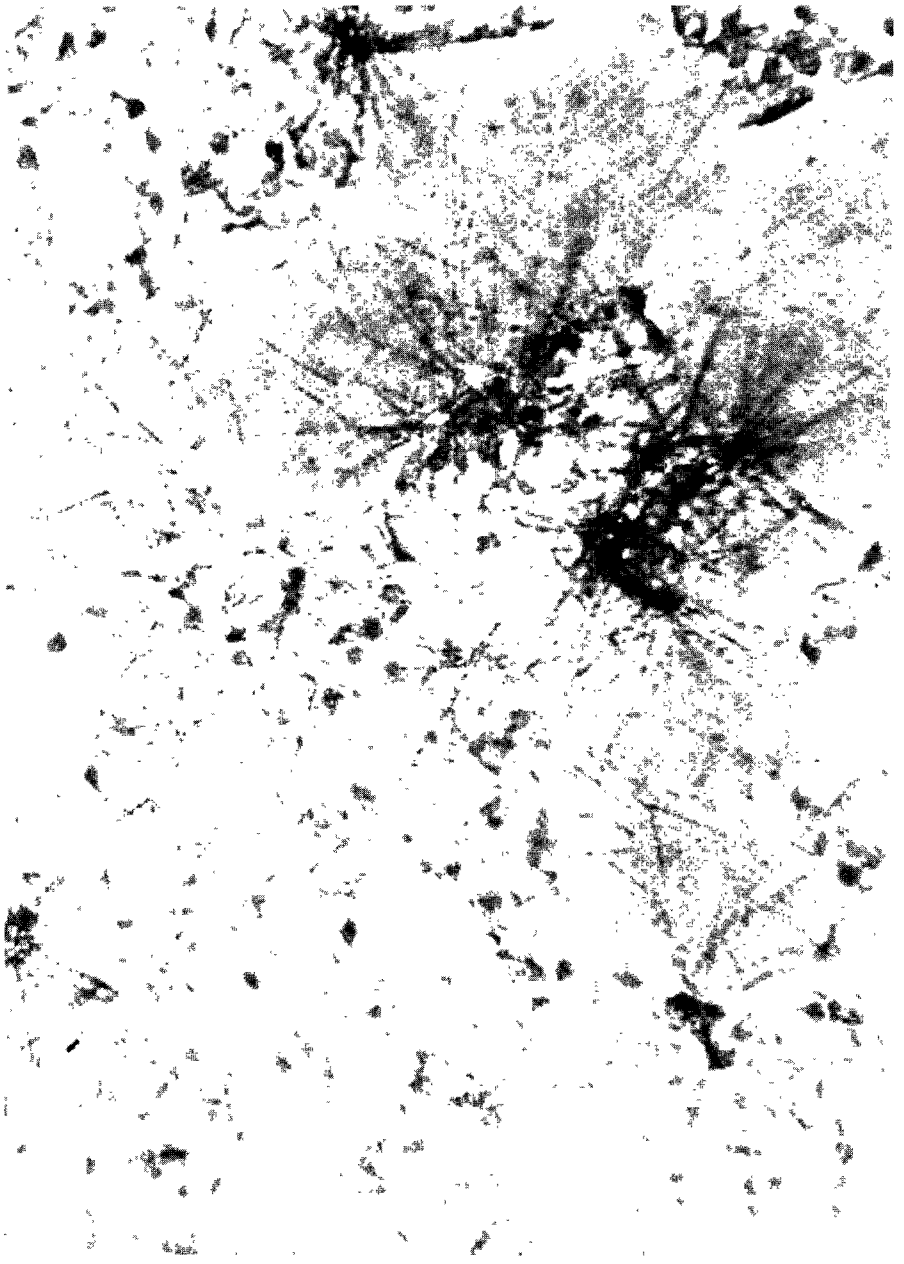

Figure 6

Autoradiograph of a histologic section from a rat lung 7 days after inhalation of $^{253}Es(NO_3)_3$ (Provided by J. E. Ballou, PNL) PNL747349-7

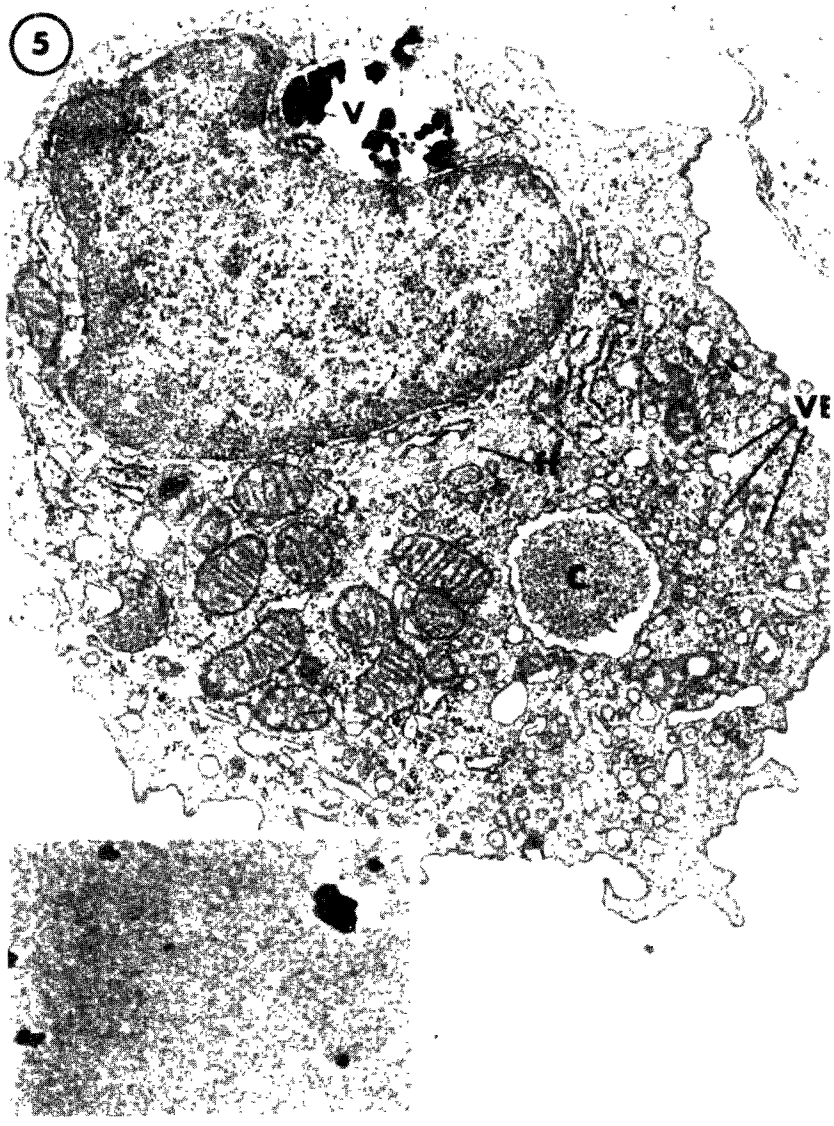

Figure 7

Electromicrograph of plutonium dioxide particles (inset) from an aerosol inhaled by rats and of a cell from the lung of an exposed rat. The dense appearing material in the cell is plutonium dioxide which had been engulfed by the cell. (Provided by C. L. Sanders and R. P. Adee, PNL) PNL0673470-5

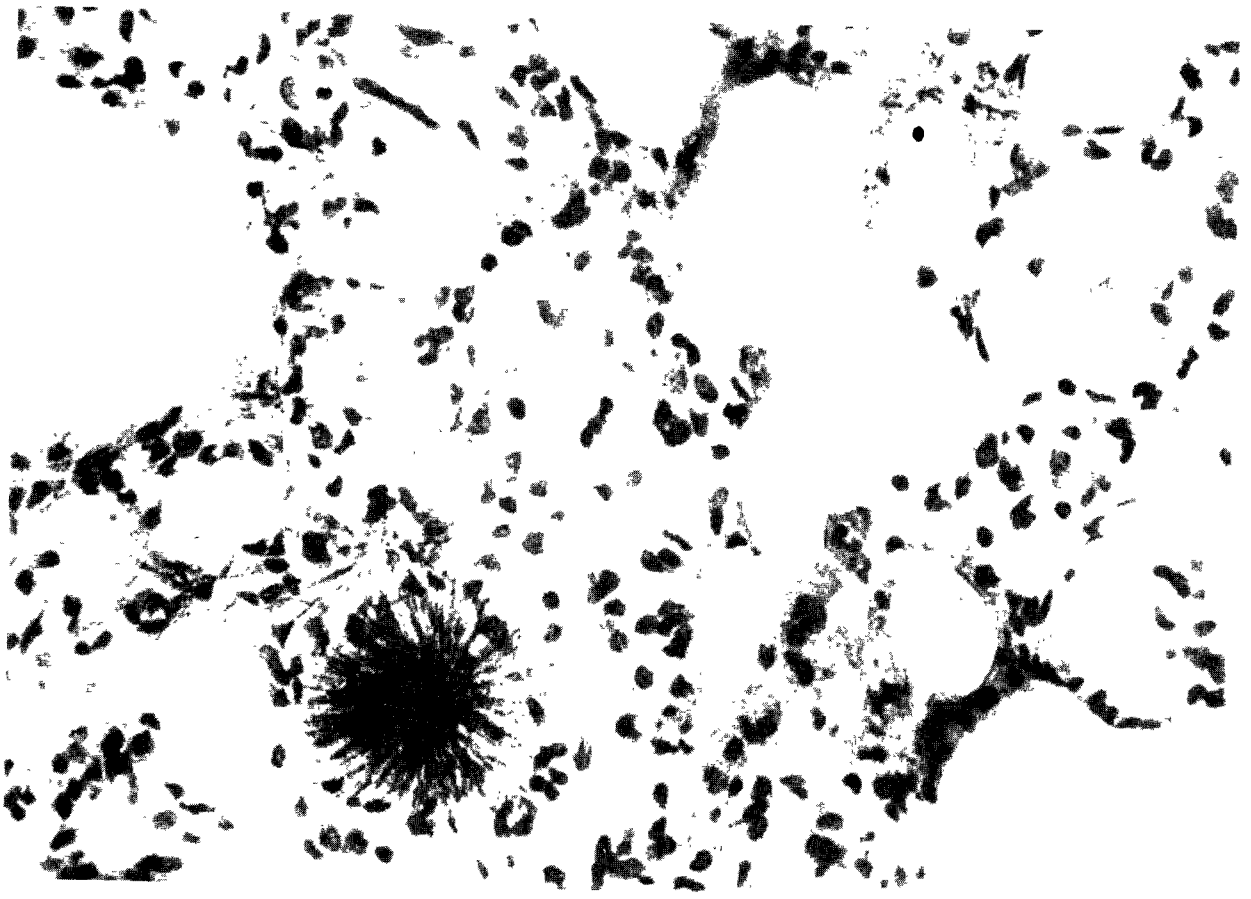

Figure 8

Autoradiograph showing aggregation of ^{238}Pu in a lung of a rat 100 days after inhalation of $^{238}Pu(NO_3)_4$. (Provided by J. E. Ballou, PNL) PNL747349-3

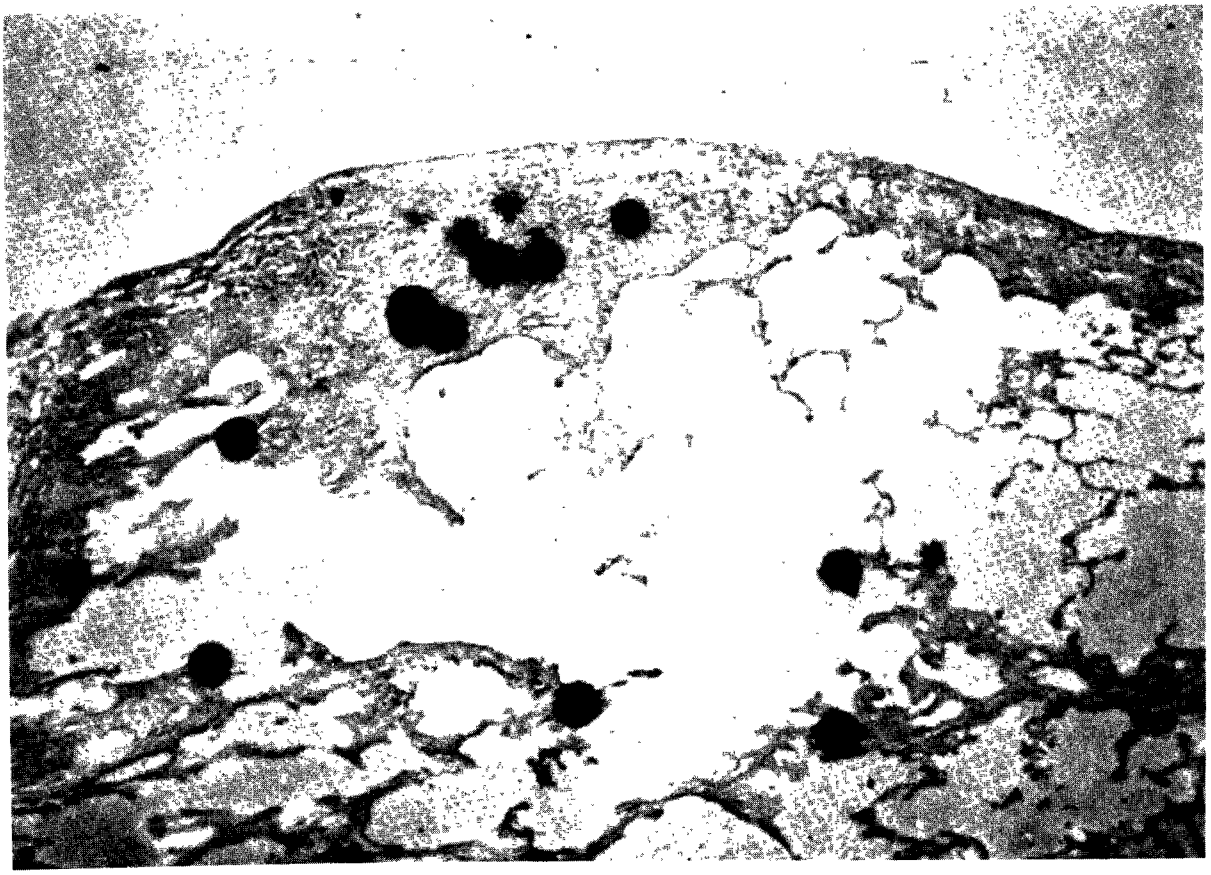

Figure 9

Autoradiograph showing $^{239}PuO_2$ particles in a subpleural area of lung from a dog. (Provided by G. E. Dagle, PNL)
PNL747349-2

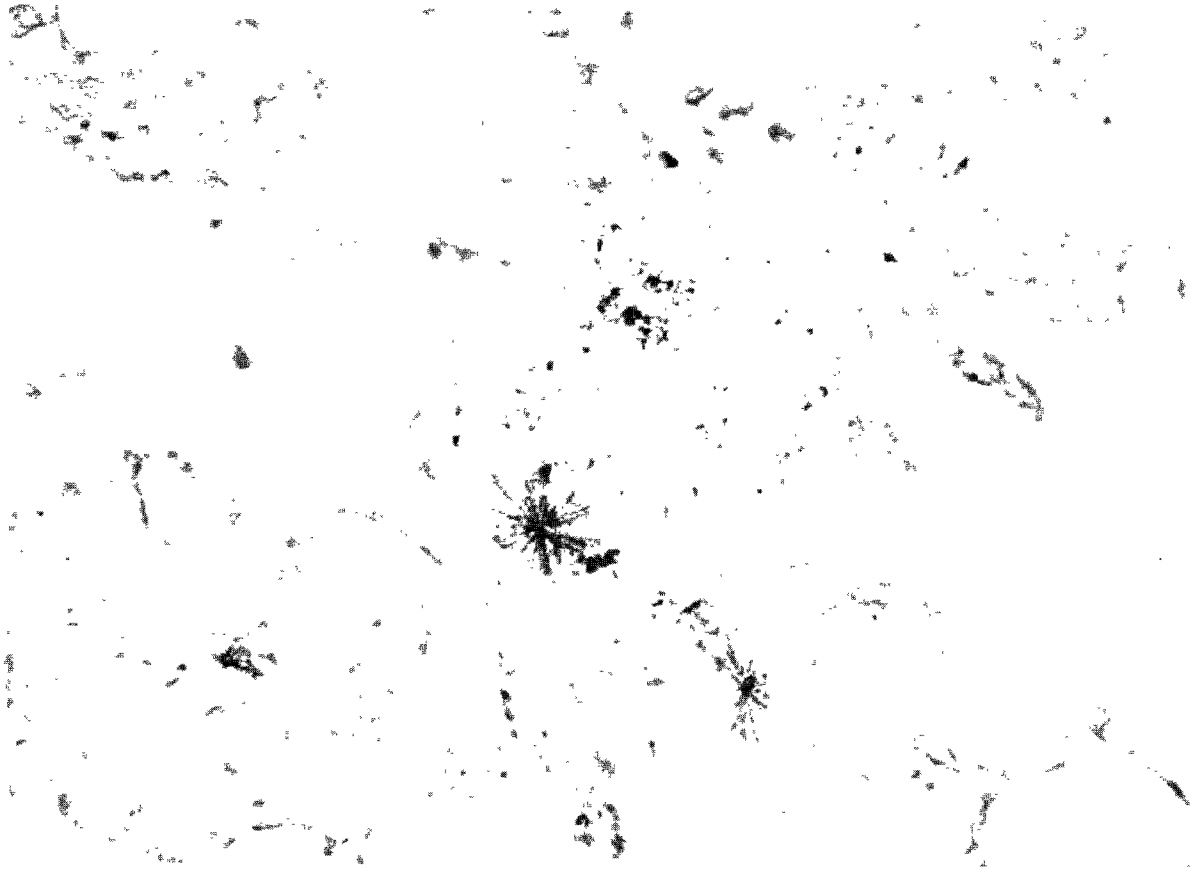

Figure 10

Autoradiograph showing ^{238}Pu particles in scar tissue in a lung of a dog 5 years after inhalation of $^{238}PuO_2$.
(Provided by J. E. Lund) PNL747349-6

DISTRIBUTION OF PLUTONIUM IN DOGS AFTER INHALATION OF $^{239}Pu(NO_3)_4$

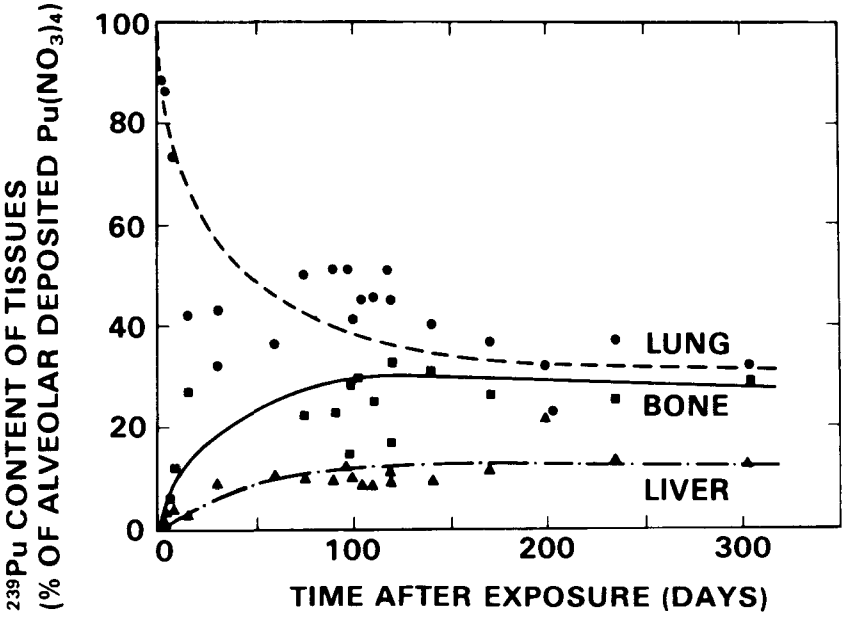

Figure 11

DISTRIBUTION OF PLUTONIUM IN DOGS AFTER INHALATION OF $^{239}PuO_2$

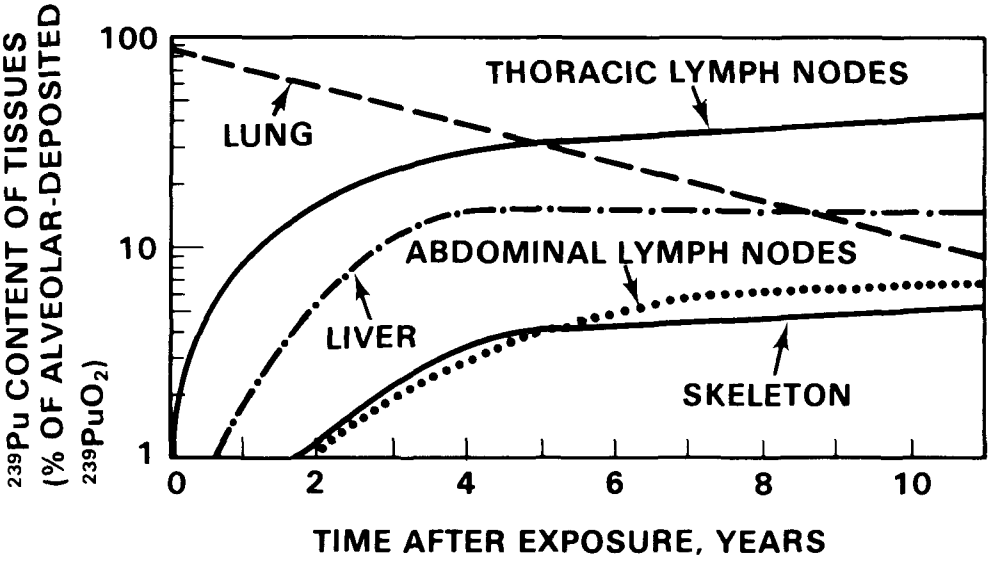

Figure 12

DISTRIBUTION OF PLUTONIUM IN TISSUES OF DOGS 5 YEARS AFTER INHALING $^{238}PuO_2$ OR $^{239}PuO_2$

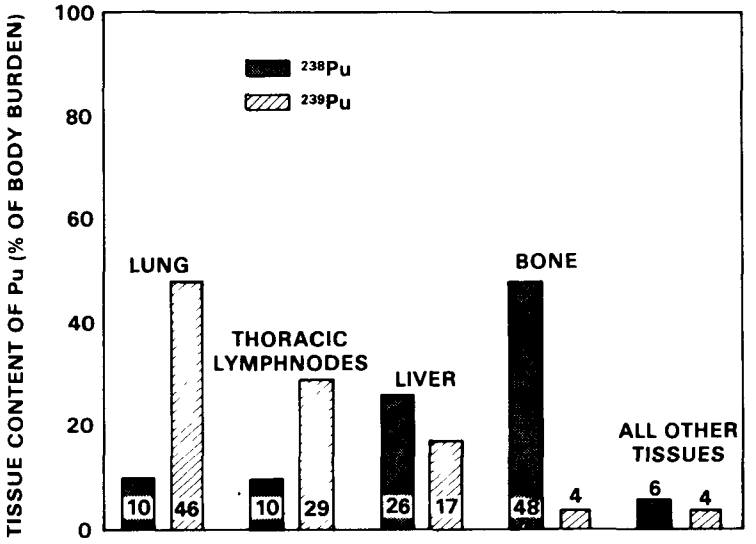

Figure 13

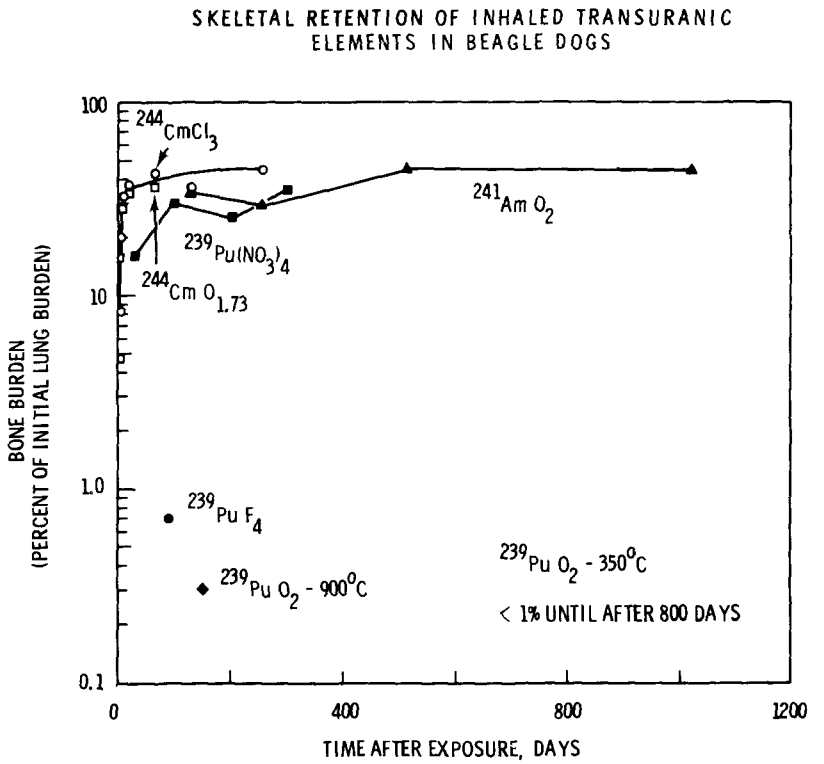

Figure 14

(Redrawn from R. O. McClellan, 1972)

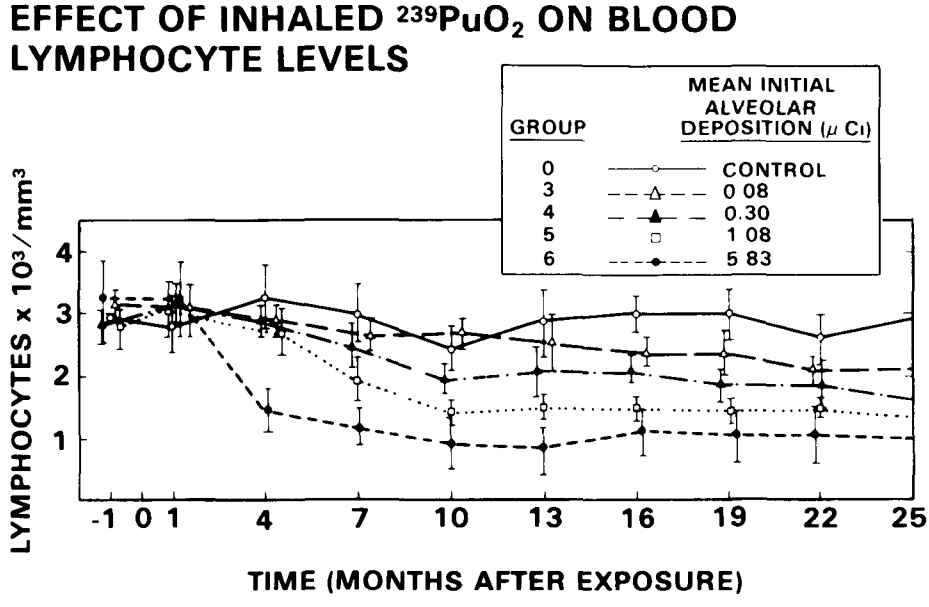
EFFECT OF INHALED $^{239}PuO_2$ ON BLOOD LYMPHOCYTE LEVELS
MEAN INITIAL ALVEOLAR DEPOSITION (μ Ci)
GROUP
0 CONTROL
3 0 08
4 0.30
5 1 08
6 5 83
LYMPHOCYTES x 10^3/mm^3
4
3
2
1
-1 0 1 4 7 10 13 16 19 22 25
TIME (MONTHS AFTER EXPOSURE)

Figure 15

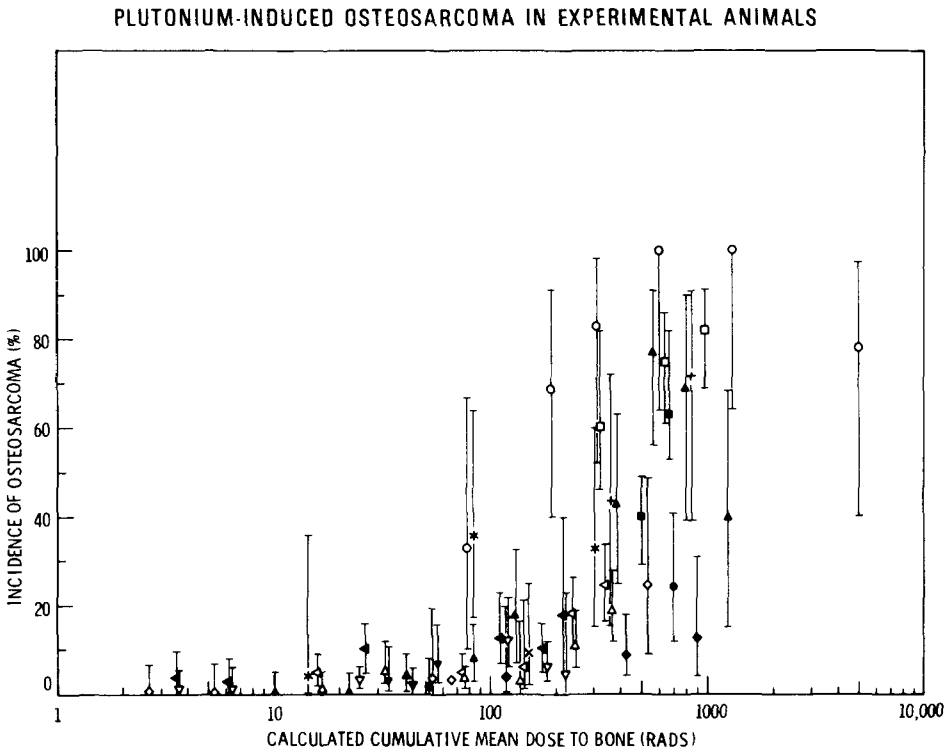

Figure 16

Plutonium-induced Osteosarcoma in Experimental Animals.
Mean incidence and radiation dose values are those reported in the literature. Binomial confidence limits were calculated from data included in the referenced literature.

o ^{239}Pu Citrate, Monomeric - IV - Dogs (from Jee, 1972)

Δ ^{239}Pu Citrate - Inhaled - Rats (from Buldakov and Lyubchansky, 1970)

▽ ^{239}Pu Plutonylpentacarbonate - Inhaled - Rats (from Buldakov and Lyubchansky, 1970)

◇ ^{239}Pu Nitrate - Sub- and Intracutaneous - Rats (from Buldakov, et al., 1971)

▼ ^{239}Pu Citrate - Oral (Daily) - Rats (from Buldakov et al., 1969)

● ^{239}Pu Plutonyltriacetate - I.T. - Rats (from Erokhin et al., 1971)

▲ ^{239}Pu Citrate - IV - Mice (from Finkel and Biskis, 1962)

□ ^{239}Pu Citrate, Monomeric - IV - Mice (from Rosenthal and Lindenbaum, 1967)

■ ^{239}Pu Citrate, Polymeric - IV - Mice (from Rosenthal and Lindenbaum, 1967)

X $^{238}PuO_2$ - Inhaled - Rats (from C. L. Sanders, 1973)

◆ ^{239}Pu Nitrate - I.T. - Rats (from Erokhin et al., 1971)

\+ ^{239}Pu Nitrate - I.T. - Rabbits)from Koshnurnikova et al., 1971)

* ^{239}Pu (Pentacarbonate) - Inhaled - Rabbits (from Koshnurnikova et al., 1971)

◁ ^{239}Pu Citrate - Inhaled - Rats (from Koshnurnikova et al., 1971)

◀ ^{239}Pu Pentacarbonate - Inhaled - Rats (from Koshnurnikova et al., 1971)

(See Bair, 1974 for complete references)

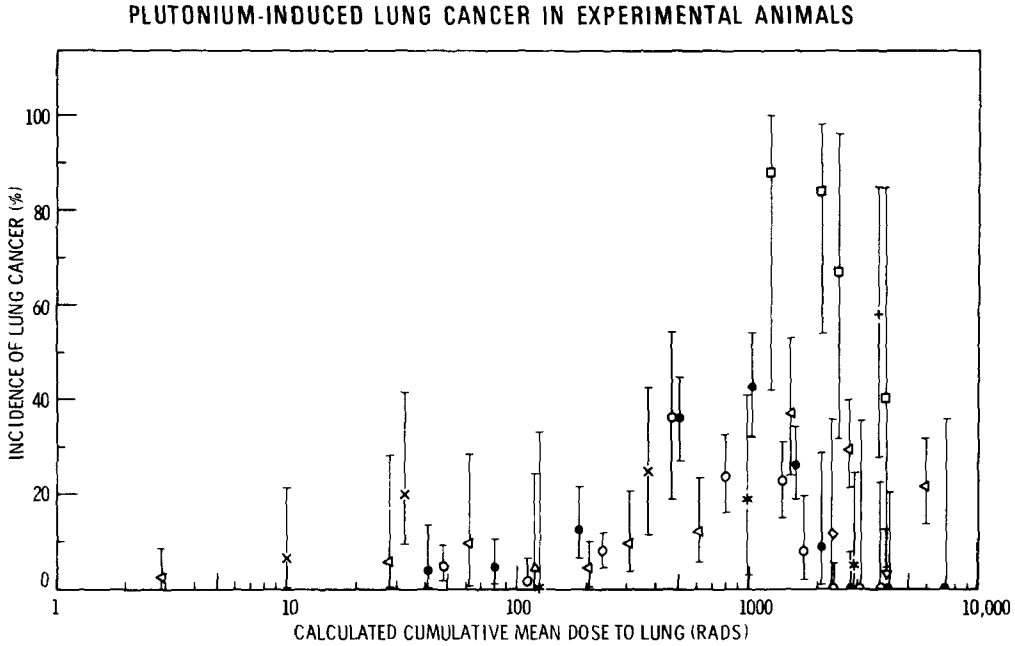

Figure 17

Plutonium-induced Lung Cancer in Experimental Animals
Mean incidence and radiation dose values are those reported in the literature. Binomial confidence limits were calculated from data included in the referenced literature.

■ $^{239}PuO_2$ - Dogs (from Park and Bair, 1972)

▽ $^{239}PuO_2$ - Mice (from Temple et al., 1959)

△ $^{239}PuO_2$ - Mice (from Temple et al., 1959)

◆ $^{239}PuO_2$ - Mice (from Wager et al., 1956)

o ^{239}Pu Citrate - Rats (from Buldakov and Lyubchansky, 1970)

● ^{239}Pu - Plutonylpentacarbonate - Rats (from Buldakov and Lyubchansky, 1970)

x ^{238}Pu - Rats (from C. L. Sanders, 1973)

◁ ^{239}Pu - Rats - $Pu(NO_3)_4$ (from Erokhin et al., 1971)

\+ ^{239}Pu - Rabbits - $Pu(NO_3)_4$ (from Koshnurnikova et al., 1971)

* ^{239}Pu - Rabbits - NH_4 Pu Pentacarbonate (from Koshnurnikova et al., 1971)

(See Bair, 1974 for complete references)

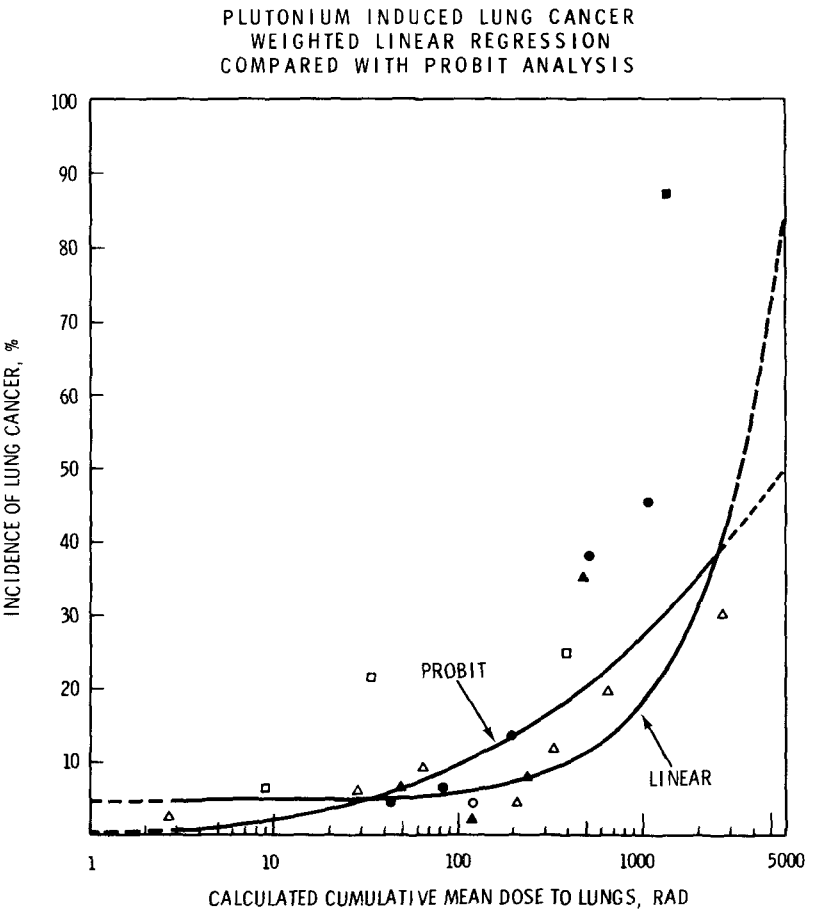

Figure 18

(J. M. Thomas and W. J. Bair, to be published)
PNL66233-1

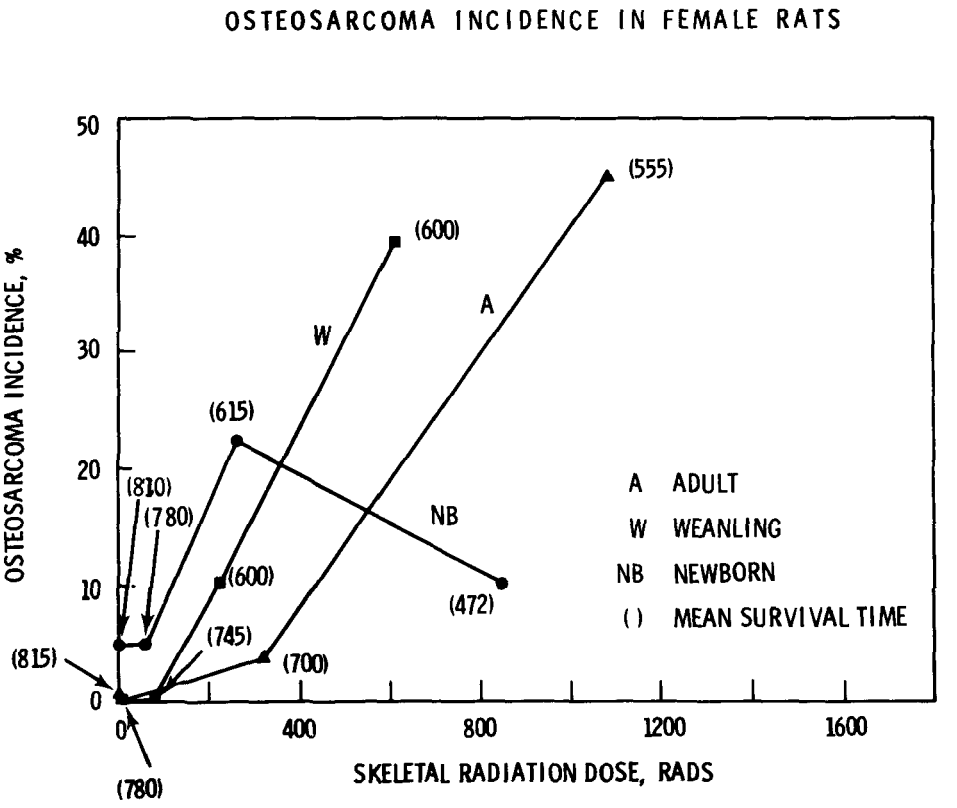

Figure 19

(D. D. Mahlum and M. R. Sikov, PNL, to be published in Pacific Northwest Laboratory Annual Report for 1974) PNL747510-13

Figure 20

Autoradiograph of a histologic section from a lung of a rat after inhalation of $^{244}Cm(NO_3)_3$. (Provided by J. LaFuma, Commissariat a l' Energie Atomique, Association Euratom. C.E.A. CEN. FAR. France.) PNL747596-4

532

Figure 21

Autoradiograph of a histologic section from a lung of a rat after inhalation of $^{239}Pu(NO_3)_4$. (Provided by J. Lafuma, Commissariat a l' Energie Atomique, Association Euratom. C.E.A. CEN. FAR. France.)PNL747596-1

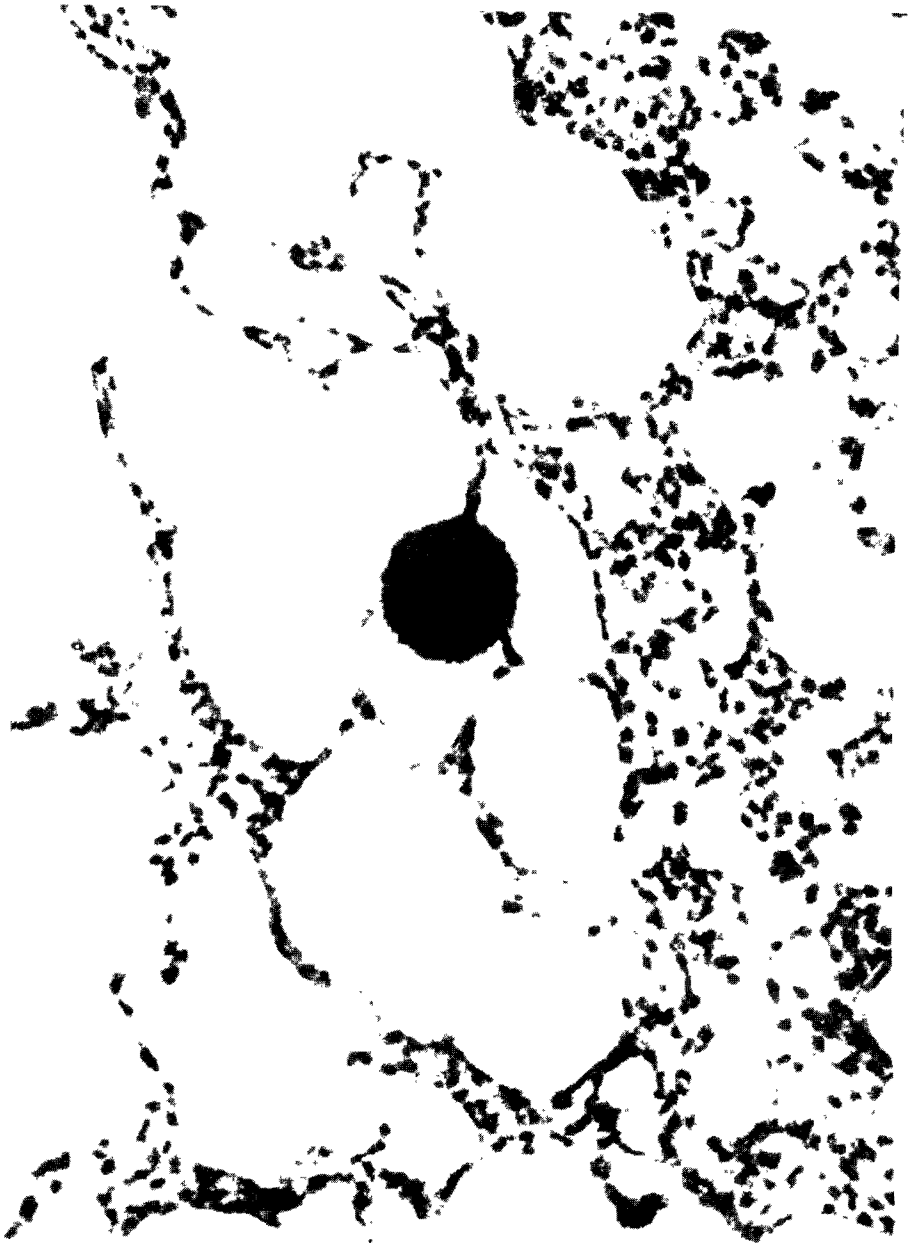

Figure 22

Autoradiograph of a histologic section from a lung of a rat 356 days after intraperitoneal injection of $^{239}PuO_2$ particles. (Provided by C. L. Sanders, PNL) PNL747358-1

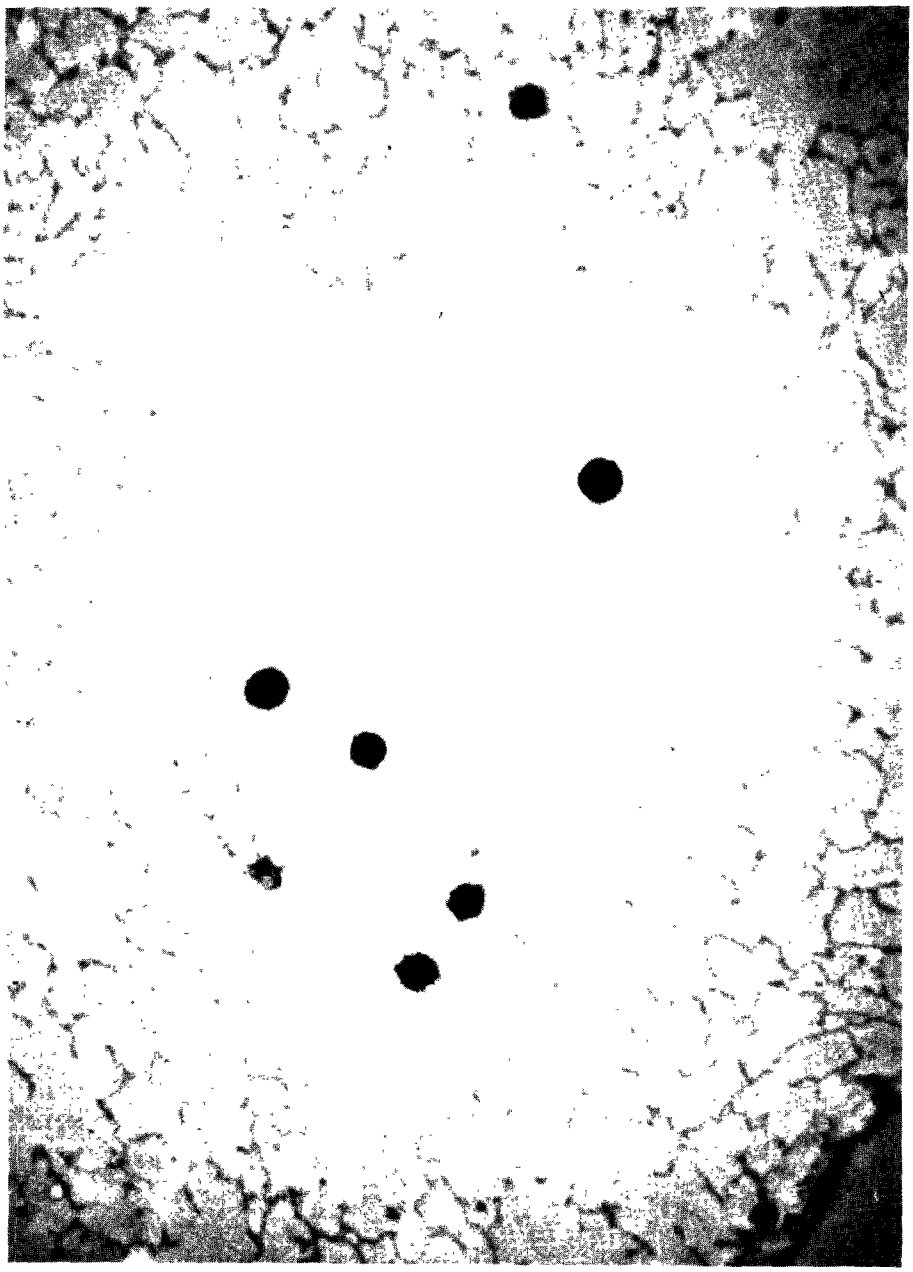

Figure 23

Autoradiogram of a histologic section from a lung of a dog 2 years after inhalation of $^{239}PuO_2$. (Provided by G. E. Dagle, PNL) PNL66199-1

OBSERVED BIOLOGICAL EFFECTS OF INHALED PLUTONIUM

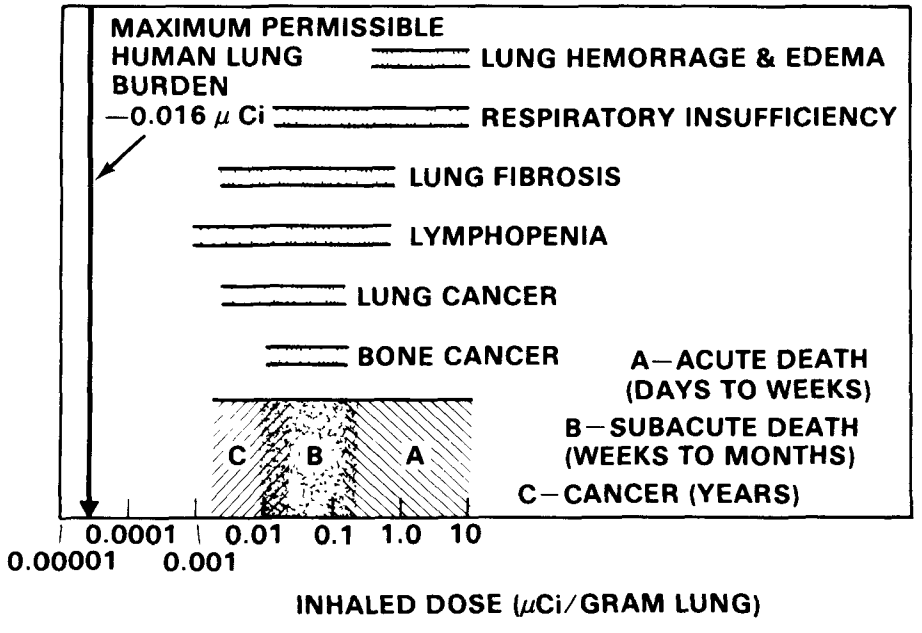

Figure 24

Thank you.

Dr. Mills: The next speaker is Dr. Burr.

Biomedical Effects of Plutonium on Humans

by William W. Burr, Jr., M.D.
Deputy Director, Division of Biomedical
and Environmental Research
U. S. Atomic Energy Commission
Washington, D. C. 20545

part of the AEC presentation at
EPA Plutonium Standards Hearings
Washington, D.C., December 10-11, 1974

Although considerable data exists concerning the biological effects of plutonium on experimental animals, comparatively little information is available regarding the effects of plutonium and other actinide elements on man. However, despite its limited availability, we regard the human data as highly relevant.

The human data serves at least two purposes. First, it provides a check on the metabolic behavior of the actinide elements in man as compared to experimental animals. Secondly, the human observations will, in the course of time, provide an improved basis for the guidelines and standards under which the industry operates. The available data make us confident that present exposure standards are not grossly inadequate and that the experimental animal work can be accepted as relevant to the human situation. However, the human data are far too limited at this time to permit more specific conclusions to be drawn from them with respect to exposure limits.

Those individuals who have been exposed to and/or retained plutonium for the longest periods of time are of particular interest. There are three such groups. The first of these consists of those persons who have

been occupationally exposed to plutonium at some time during their working life. While some of these exposures occurred 30 years ago, others have occurred more recently; it will be some time before these more recent exposures will contribute to our store of knowledge in a meaningful way. Industrial accidents during the Manhattan Project resulted in inhalation exposures of a number of individuals to plutonium. Some of these persons have maintained multiples of the maximum permissible body burden for nearly three decades.

In addition to the depositions that date from the mid-forties, we know of over 200 industrial exposures between 1953 and 1970 that resulted in burdens of plutonium exceeding 25% of the maximum permissible body burden. Other exposures have occurred before and since the period covered by these statistics. Although the exact levels of internal contamination are uncertain in most such cases, it is evident that these exposures constitute a valuable resource for current and future study. Some information has been obtained already from particular groups of industrially exposed persons; other studies are now being formulated and expanded to collect data from additional members of that population.

A second source of valuable information is a group of 18 people, thought to be hopelessly ill, who were injected with plutonium during and immediately after the days of the Manhattan Project to study excretion and distribution patterns in man. Data from these persons provided the basis for the excretion equations developed by Dr. Wright Langham that have been used in modified form to estimate plutonium body burdens in workers ever since then.

A third population of interest is that of the world at large. The general population has accumulated minute quantities of plutonium from the fallout debris that resulted from nuclear testing in the atmosphere and from the atmospheric burn-up of a thermoelectric generator. Study of this population will give insight into the extent to which man takes up plutonium from the biosphere.

Programs for the analysis of human tissues obtained at autopsy from exposed workers and from non-occupationally exposed persons will in time furnish much information regarding the efficiency with which man incorporates plutonium into his body and will provide data regarding the distribution of plutonium among the various body tissues. In the case of occupational exposures these studies permit us to compare estimates of body burdens based on analysis of urine specimens or external lung counting with estimates based on actual analysis of tissues obtained from the same individuals. These programs have been expanded in recent years.

In view of the fact that thousands of persons have been exposed or potentially exposed to plutonium during the course of their work, it is inevitable that some of those people who may have some lung or body burden of plutonium will die of cancer, including lung cancer. When this occurs it must be recognized that the appearance of common forms of cancer in persons with plutonium burdens does not constitute proof that the deposition is causally related to the disease. In order to establish whether or not the number of such deaths exceeds our expectation for a comparable unexposed population, our scientific resources will be taxed to the utmost. We are now entering a period when the working population that was young during the 1940's may be expected to develop a meaningful incidence of disease of all kinds. Follow-up studies attempting to establish whether any detectable

increase in relevant disease may be seen in the exposed populations will become increasingly important.

Although the clinical follow-up of persons with burdens has been reassuring, any conclusions with respect to late effects of plutonium in man must remain tentative for some time. We can, however, state with confidence that available data does not support the viewpoint that the current radiation protection standards and guidelines which have been followed for many years underestimate by many orders of magnitude the risk due to plutonium deposition in man.

Dr. Richmond, Associate Director for Biomedical and Environmental Sciences at the Oak Ridge National Laboratory, will summarize the data obtained from the various populations that I have mentioned.

Biomedical Effects of Plutonium on Humans

by C. R. Richmond
Oak Ridge National Laboratory
Oak Ridge, TN 37830

part of the AEC presentation at
EPA Plutonium Standards Hearings
Washington, D.C., December 10-11, 1974

INTRODUCTION

My name is Chester R. Richmond. I am the Associate Director for Biomedical and Environmental Sciences at the Oak Ridge National Laboratory. However, the views I express here are my own.

Plutonium was recognized as a potentially hazardous material soon after its discovery in early 1941. The urgency to conduct biological studies with plutonium was appreciated by several people, notably Dr. Seaborg, with the hope that the unfortunate problems experienced with radium earlier in the century would not be repeated. Within three years of the discovery of plutonium (^{238}Pu) in February, 1941, 0.5 g ^{239}Pu had been separated from the material produced by the Clinton pile and on 8 February 1944, Dr. J. G. Hamilton and coworkers at Berkeley received about 10 mg to begin experimental studies in rodents.

During late 1943 and early 1944, plutonium operations at Los Alamos consisted of research activities involving milligram quantities of material. During late 1944, gram quantities were processed in research activities directed mainly toward the production of pure plutonium metal and investigation of its physical and chemical properties. By mid-1945, kilogram quantities were processed as part of the effort to produce the nuclear components for the Alamagordo and Nagasaki weapons. Some of our most

relevant data as regards exposure of humans to plutonium comes from the medical follow-up of the military personnel who worked with plutonium at Los Alamos in 1944 and 1945.

Although we have accumulated a considerable amount of information on the biological effects of plutonium on experimental animals, there is little to be said of the data on effects in humans. Obviously, we should be encouraged because of the lack of data on biological effects of plutonium in man.

DEVELOPMENT OF MAXIMUM PERMISSIBLE BODY BURDEN (MPBB) FOR Pu

Throughout 1943 and the first nine months of 1944, a maximum permissible body burden of 4-5 μg was assumed to be an acceptable guide even though no reliable method of estimating personnel exposure to plutonium had been developed. The value was derived by using bone as the critical organ and making a direct comparison with the energy deposited from 0.1 μg of ^{226}Ra fixed in the body (assuming 50% radon exhalation). Later, because of apparent differences in bone deposition patterns between Pu and Ra in rodents, a safety factor of about 5 was introduced, and the maximum permissible body burden became 1 μg. This value was used until the Tripartite Permissible Dose Conference at Chalk River, Canada, in late September 1949, at which time Dr. A. Brues presented experimental chronic toxicity data from rodents that suggested ^{239}Pu was 15 times more damaging than ^{226}Ra when both were injected in equivalent microcurie quantities. The conference recommended that the MPBB be reduced to 0.1 μg.

Subsequent reexaminations of the experimental data led to a recommendation of 0.6 μg as the MPBB for ^{239}Pu. This decision was based upon the following observations related to the assumption that 0.1 μCi of fixed ^{239}Pu was

equivalent to 0.1 μCi of fixed ^{226}Ra.

(1) The Pu:Ra toxicity ratio of 15:1 was based on the injection of known amounts into rodents. Since ~75% of the injected Pu was retained in rodents while only ~25% of the Ra was retained, the ratio on the basis of retained dose could be lowered by a factor of about 3.

(2) Because radon was about 50% retained in man and only about 15-20% retained in rodents, the toxicity ratio could be lowered by another factor of at least 2 on the basis of relative energy deposited.

Thus, strictly on the basis of biological data, the MPBB for man was calculated to be:

$$(MPBB)_{Pu} = 0.1 \times \frac{24,000}{1,600} \times \frac{1}{15} \times \frac{3}{1} \times \frac{2}{1} = 0.6 \text{ μg } (0.04 \text{ μCi})$$

As a result of this information, the AEC authorized 0.5 μg (0.033 μCi) ^{239}Pu as the MPBB. In 1951, the International Commission on Radiological Protection (ICRP) at a meeting in London recommended a value of 0.04 μCi which was later endorsed at the Tripartite Conference on Permissible Dose at Harriman, New York in March 1953. In the fall of 1953, both the National Committee on Radiation Protection and Measurements (now the National Council) and the ICRP recommended a MPBB of 0.04 μCi for ^{239}Pu in their official publications; the value has remained unchanged to date although the MPBB has been discussed in more recent publications of both organizations.

MANHATTAN PROJECT EXPOSURES

Since the discovery of plutonium over three decades ago,[1] personnel exposures have been studied and reported on in varying degree, both during life and after death.[2-9] One of the most interesting groups, because of

both the length of the period since exposure and the levels of exposure, is that of the Manhattan Project plutonium workers.[10]

Twenty-five male subjects, who worked with plutonium during World War II under very crude working conditions by today's standards, have been followed medically during the intervening period. Within the past several years, 21 of these men have been examined at the Los Alamos Scientific Laboratory. In addition to physical examinations and laboratory studies (complete blood count, blood chemistry profiles and urinalysis), roentgenograms were taken of the chest, pelvis, knees and teeth. Chromosomes of lymphocytes cultured from peripheral blood and pulmonary cytology were also studied. Urine specimens assayed for plutonium yielded calculated body burdens which ranged from 0.005 to 0.42 μCi. These estimates of body burden are generally higher than earlier estimates based on radioassay of urine samples collected in the past, perhaps reflecting uncertainties in the models used to estimate body burden from excretion data. Table 1 indicates the kinds of information obtained from the Manhattan Project plutonium workers. Most, but not all, of these examinations have been conducted every four to five years since the group has been studied.

This group of men in their early to mid-fifties had only the usual diseases encountered in this age zone. One man had a coronary occlusion but had recovered and was well compensated. Another of the original group died in 1959 of a coronary occlusion at age 38. Another had a hamartoma of the lung surgically removed without complication in 1971. A third had a melanoma of the chest wall (regional lymph nodes were negative).

A fourth had a partial gastrectomy for bleeding ulcer. Several had mild hypertension and moderate obesity, and one had gout. All were working actively. More detailed information on this particular group of workers has been published.[11-12]

Blood samples were obtained from the group during the most recent medical checkups for chromosome studies using standardized established techniques. No abnormalities were found in these subjects. Except for one special case reported by Schofield and Dolphin[13] chromosome aberration studies carried out on plutonium workers in the United Kingdom showed no significant increase in aberration yield.[14]

Because lung cancer has been observed experimentally in animals exposed to plutonium aerosols, cytological examinations of bronchial cells in sputum samples have been added to these studies. In a few subjects, moderate to severe dysplastic changes have been observed. The significance of these changes is not clear except in one man who was a heavy cigarette smoker (3 packages per day).

It is important to realize that these men worked under very crude working conditions as judged by today's standards. At times, the activity to which some of these personnel were exposed was orders of magnitude over the presently accepted maximum permissible air concentrations. Most of the exposures were believed to have occurred via inhalation as evidenced by a strong correlation with frequent contamination of the nasal vestibule and highly contaminating operations. The nasal swabs on one occasion yielded over 1 μg Pu from each nostril. Figure 1 shows the building in which these men worked in the early years.

Attempts have been made to estimate the number of particles inhaled by the Manhattan Project plutonium workers. By making certain assumptions with respect to the mass median diameter, geometric standard deviation of the distribution and the particle density, one can calculate the mass fraction for plutonium dioxide particles larger than any stated size. For example, the mass fraction for plutonium particles larger than 0.6 micron diameter is approximately 15%. Further calculations indicate that approximately 10^7 particles larger than 0.6 micron diameter could have been retained by the 25 subjects during their exposures in 1944 and 1945.[15] The observed lung cancer incidence is zero almost 30 years since exposure.

Table II shows the current status of several LASL plutonium study groups. Group 1 was discussed in the preceding paragraphs. Group 2, which is now in the early stages of study, will expand the size of the original cohort by perhaps 40 people. Twenty-eight of the 40 men who have been identified have been located and have responded to questionnaires. Once again, these are extremely important subjects to study intensively as approximately three decades have elapsed since their exposures. Group 3 will comprise a broader spectrum of exposures, including more recent accidents and some exposures to ^{238}Pu. All are estimated to have systemic plutonium burdens of 4 or more nanocuries. Table III shows the

estimates of plutonium systemic body burdens on certain workers in Group 1, all of whom had estimated burdens greater than 120 nCi (3 maximum permissible body burdens) in 1972. The table also contains the 1953 and 1962 estimates for these individuals. The increase in the values for each individual with time is at least partly attributed to modifications in the method of estimation that have generally resulted in higher estimates in more recent years. The model for estimation of body burdens from urine assay values involves uncertainties that limit the accuracy of estimation.[16] It is also true that some of the body burden estimates are based on relatively few data points. Again, the original exposures were in the early 1940's so that Case 3, who now has approximately 10 times the allowable occupational bone burden, has carried this estimated 410 nCi of plutonium for approximately three decades. The selected cases shown in Table III represent systemic plutonium burdens ranging from 0.13 to 0.42 μCi, which correspond to annual bone doses of approximately 2 to 6 rad.

Table IV contains information which is detailed in an earlier publication.[10] The data are for the $^{239,240}Pu$ content for some tissues that were removed from Case 2 of Group 1, who developed a non-malignant growth (hamartoma) in the lung. Surgical removal of the hamartoma, which was found during a medical follow-up study, afforded an opportunity to obtain tissue from the hamartoma, lymph nodes, rib and normal lung for radiochemical analysis. The concentration of $^{239,240}Pu$ was approximately the same in both the tumor and normal lung tissue. The lowest plutonium concentration was found in a rib sample and the highest in the lymph node. This distribution is consistent with experimental findings in dogs exposed to plutonium dioxide by inhalation. If one assumes a total lung weight of 1000 grams, tracheo-

bronchial lymph node weight of 20 grams and a homogeneous distribution of plutonium throughout these tissues, the total plutonium burden is estimated to be 8 nCi, roughly equally divided between the lung and lymph nodes. This estimate of the burden of plutonium in the thorax based on extrapolation from the analysis of lung and lymph node tissue is in reasonable agreement (within a factor of 2) with the estimate based on chest counting procedures.

Figure 2 is a photomicrograph of an autoradiograph of a plutonium particle in a lymph node section removed from Case 2. Additional observations on histologic sections of lymph node tissue suggested a non-uniform radiation dose distribution from the plutonium particles.

PLUTONIUM ADMINISTRATION STUDIES IN HUMAN SUBJECTS

In an attempt to determine relationships between urinary excretion, total excretion and body content of plutonium, 18 persons received plutonium parenterally during 1945-1947[17-18] as shown in Table V. Fifteen of the 18 were older than age 45, and all but two of the 18 were given ^{239}Pu only (one received both ^{238}Pu and ^{239}Pu and another received only ^{238}Pu). The amounts of plutonium administered ranged from about 0.1 to about 6 μCi. For comparison, the current occupational maximum permissible body burden for ^{239}Pu is 0.04 μCi.

Although these subjects were thought to be hopelessly ill, four of the group were alive in November 1973, almost three decades after receiving the plutonium. Excretion data for some of the survivors have been reported recently.[19] These data provide a unique opportunity to verify the excretion equations that are used currently by radiation protection personnel to estimate body burdens. It is of considerable interest that much of the data used to establish the excretion equations was obtained from this group

of 18 subjects during the relatively short period (several months in most cases) during which they were studied. In addition to the data obtained from those individuals, Langham used data obtained from several Los Alamos occupational exposure cases for about 300 days and one for about 1700 days in formulating his excretion curves. These equations have been very useful although they have proven to be somewhat conservative when estimated body burdens based on urine assay are checked against estimates based on post-mortem analyses.

One of the original 18 plutonium recipients is of particular interest. He was a white 58 year old male who was believed to have a gastric carcinoma with hemorrhage when he received 5.19 μCi of ^{238}Pu and 0.12 μCi of ^{239}Pu as $PuO_2(NO_3)_2$ by intravenous injection. Gastrectomy disclosed a gastric ulcer from which the patient recovered. He did not die until some 21 years later; the cause of death was cardiovascular disease. We can obtain a very rough estimate of the bone dose by assuming 40% deposition in the skeletal tissues with no subsequent loss. Under these circumstances, the skeletal dose over the 21-year period would be approximately 900 rad. The annual dose rate to the skeletal tissues would be approximately 40 rad, a factor of approximately 70 higher than the annual skeletal dose rate of 0.6 rad delivered by the maximum occupational bone burden of 40 nCi of ^{239}Pu.

Some information can be obtained on the amount of plutonium in the gonads of some of these subjects. The fraction of administered plutonium found in the gonads at autopsy was 9×10^{-5} for one female and about 3×10^{-4} for three male subjects. These numbers agree quite well with data obtained from several species of experimental animals.[20]

U. S. TRANSURANIUM REGISTRY

During the summer of 1968, the United States Atomic Energy Commission authorized the establishment of the National Plutonium Registry which was later renamed the United States Transuranium Registry (USTR). The registry is operated by the Hanford Environmental Health Foundation in Richland, Washington, and collects information from AEC contractors and licensees regarding employees potentially exposed to transuranium elements.[21-23] Cooperation with the USTR is completely voluntary on an individual basis and includes release of medical and health physics data. Permission is also obtained on a voluntary basis for postmortem analyses of tissues of interest. Major AEC contractors and certain licensees handling plutonium and other transuranium elements have agreed to endorse the program and have recommended to their employees that they participate in this program.

The principal criterion used by the USTR to determine inclusion of an individual in the Registry is that the employer provide a routine surveillance program because of a reasonable likelihood that an exposure could occur. This rather broad criterion allows for the different methods used to estimate the extent of contamination, e.g., urine analysis, chest counting, or air concentration data, and for uncertainties in estimating burdens under certain conditions, e.g., chronic inhalation of insoluble plutonium. It also avoids the exclusive consideration of cases involving heavy exposures.

At autopsy, comparisons can be made between estimates of the body burden based upon tissue analyses and estimates made previously on the basis of health physics and operational data. In addition to a medical history, information may be obtained on an employee's work history, smoking habits, exposure to toxic materials, and other pertinent data.

Preliminary findings for the first fourteen autopsy cases reported by the USTR appeared in the proceedings of the 12th Hanford Biology Symposium held in 1972.[24] To date, information obtained by the USTR indicates that estimates of the plutonium systemic burden based on urine analysis have been on the conservative side, that is, they are higher than estimates based on analysis of tissues obtained at autopsy.[24] Workers in the United Kingdom have also found this to be true.[13]

Table VI indicates the status of the USTR as of June 1974. To date, most of the USTR activities have been confined to Hanford, Los Alamos, and Rocky Flats. The interested reader is directed to a recent USTR report for details of the level of cooperation between the USTR and the other AEC contractors shown in Table VI.[25]

ACCIDENT CASES

A considerable amount of information has been obtained from accidental occupational exposures to plutonium. However, the total number of accident cases has been relatively small. Information obtained from the AEC's Division of Operational Safety as shown in Table VII indicates that during the period 1957 to 1970 about 200 contractor personnel had depositions greater than 25% of the occupational maximum permissible body burden (MPBB) or lung burden for plutonium. These data also indicate that inhalation is the major portal of entry and that more than half the exposure cases represent plutonium burdens less than 50% of the maximum permissible burden. Eighteen percent of the total exposures resulted in plutonium burdens greater than one MPBB. Table VII also shows that about 18% of the cases were treated by chelation therapy. Fifty-four percent resulted from production activities.

Operational experience at Windscale in the United Kingdom shows that 15 men have exceeded the maximum permissible body burden of 40 nCi during a time covering about 7000 man-years of plutonium production and handling. It is also possible that about half these men have considerably less plutonium in their bodies than the calculations based upon urine radiochemistry currently indicate.[13] Because of the importance of human data it is important that studies of personnel involved in accidents be continued and perhaps expanded.

A case of contamination resulting from a puncture wound is extremely interesting as it has been interpreted by some as an example of cancer in man resulting from plutonium deposition. The lesion was first described in the literature more than ten years ago[26] and was included along with other information on plutonium wounds at a later time.[4] The 5 nCi particle of plutonium was surgically excised from the individual's palm approximately four years after the accident. The radiation dose around the plutonium implanted in the palmar skin was estimated to be about 75 million rads. However, this kind of dose estimate is probably meaningless as we do not know which cells were exposed or for what time periods. The entire lesion was very small (estimated to be about $3 \times 10^{-5} cm^3$). Figure 3 shows a histologic section of the lesion. The pathologist involved in the study described the cellular pattern in the lesion as having "a similarity to known precancerous epidermal cytologic changes."[26] This particular lesion appears to be the most severe demonstrable effect having a direct relationship to plutonium deposition in man.

TISSUE ANALYSIS PROGRAMS

For many years the Los Alamos Scientific Laboratory[27] and other AEC contractor laboratories[28-31] have conducted tissue analysis programs to

determine plutonium levels in tissues obtained at autopsy from both exposed occupational personnel and members of the general population who are not engaged in work with plutonium. These programs were started in the 1940's in the Hanford plant and at the Los Alamos Scientific Laboratory. A report from one program contains information on approximately 350 autopsies.[28] Additional reports from this and the other groups are available.[32-34] Table VIII shows plutonium concentrations as determined for lung, liver, lymph nodes, kidney, and bone for the period 1959-1971 for non-occupationally exposed persons from several parts of the United States and for occupationally exposed persons.[35] Data for plutonium concentrations in gonadal tissue, which appeared in the original publication, are not included in Table VIII because errors associated with a change in analytical procedures were detected by the authors subsequent to the original publication. Similar data shown in Table IX have been obtained for non-occupationally exposed persons and represent analyses made during the period 1972-1973.[35] The average concentration in the lungs for the data shown in Table IX is about 0.3 pCi for a 1000 gram lung, and the lymph node concentration is about 11 pCi/g. No unusually high concentrations of plutonium in gonadal tissue have been observed in this particular study. Recent analysis of the gonadal data suggest that the concentrations of plutonium are about 0.18 pCi/kg for non-occupationally exposed persons.

The higher plutonium concentrations in lymph node tissue of non-occupationally exposed individuals in Table IX as compared with those in Table VIII are not thought to represent real increases but rather to reflect an improvement in the technique for dissecting the lymph nodes from the lungs.

The AEC's Health and Safety Laboratory (HASL) recently has used information obtained from the International Commission on Radiological Protection to model the intake and body burden resulting from plutonium in fallout and to estimate the radiation dose to man from this source.[36] The cumulative lung and bone doses for the period 1954-2000 are estimated to be 16 and 34 mrem respectively. The HASL group has also compared body burdens based on their model with values obtained from the tissue sampling programs. The agreement is quite good between the Colorado-New Mexico tissue data and the model predictions as shown in Table X for 1970-1971. The comparison based on the New York tissue sampling data is not as good and may reflect the small sample of 25 autopsies that were included in the analysis.

Results of the tissue sampling programs for occupationally exposed plutonium workers has also given us the opportunity to compare the body burden at autopsy with that estimated during life on the basis of bioassay data. Almost without exception, workers in the USA[25,29,35] and United Kingdom[13] have found less plutonium by significant factors at autopsy as compared with the amount predicted during life. For example, the United Kingdom workers found that for 9 plutonium workers studied at autopsy, the body burden estimates based upon tissue analysis were lower by factors of 1.2 to 8.3 than those estimates made during life on the basis of urinary excretion analyses. Thus it would appear that estimates of the body burden made during life are conservative in that they predict more plutonium than is actually present in the body. Because a considerable amount of relevant data is now available, it may be appropriate for scientists in the field of radiation protection to explore this observation in more detail as regards current radiation protection practices and the guidelines followed in the nuclear energy industry.

Recently several investigators have examined the United Kingdom medical experience for workers handling plutonium. They have concluded that the information to date cannot conclusively validate or repudiate the presently accepted working levels for plutonium, but the information does allow for a certain amount of cautious optimism. They also state, "it is true to say that after 30 years' experience in the USA and 22 years' in this country, no disease attributable to plutonium toxicity has been diagnosed in any worker concerned in the production or manipulation of plutonium."[13]

PLUTONIUM IN MAN FROM FALLOUT

Plutonium is present in extremely small quantities in various organs of man today. Although most of the plutonium in fallout resulted from atmospheric testing of nuclear weapons by several countries prior to the 1963 limited test treaty ban, some material from contemporary atmospheric weapons testing by France and the People's Republic of China adds to the total human burden. The current lung burden as estimated for persons in the United States is about 0.3 pCi of $^{239,240}Pu$, and a very rough estimate of the total amount in the body is perhaps 3.5 pCi as shown in Table XI. Estimates of the total amount of plutonium produced in the course of nuclear weapons testing vary, but a value of about 0.4 megacurie is a reasonable estimate. Of this amount, if 0.3 megacurie has returned to the biosphere, very little (about 10^{-8}) has found its way into the earth's population (3×10^{9} people). Another approach to this matter is to divide the estimated average human burden (3.5×10^{-12} curies) by the estimated amount in the biosphere (0.3×10^{6} curie); the average accumulation is about 10^{-17} per person.

CONCLUSION

Control of industrial hazards of ^{239}Pu processing is based upon the premise that personnel exposure should be as low as practicable not because the maximum permissible body burden is a level which would do harm but because it is sound industrial medical and health protection practice.

The lack of demonstrable biological effects of plutonium in man is reassuring and represents presumptive evidence that the standards are not grossly inadequate. My personal opinion is that those standards are adequate and that there is no compelling reason at this time to initiate changes, either upward or downward.

I would like to now quote a portion of the Rulison decision as given by Judge Arraj as I believe it is appropriate.

> "The field of radiation protection is constantly changing with the appearance of new scientific knowledge on the biological effects of ionizing radiation. Careful decisions must be made in the context of contemporaneous knowledge. Such decisions cannot be indefinitely postponed if the potentials of atomic energy are to be fully realized. All that is required to establish reasonableness of the decision setting a standard under the statutory directive to protect the public health and safety is that it be made carefully in light of the best available scientific knowledge. Absolute certainty is neither required nor possible."

REFERENCES

1. G. T. Seaborg, Plutonium revisited. In Radiobiology of Plutonium, (B. J. Stover, and W.S.S. Jee, Eds.), pp. 1-21. The J. W. Press, University of Utah, Salt Lake City, 1972.

2. H. F. Anderson, W. E. Sheehan, J. R. Mann and R. W. Bistline, Evaluation of accidental personnel exposure to plutonium-238: Whole body counting and bioassay results. Health Physics 18, 631-639 (1970).

3. J. R. Mann and R. A. Kirchner, Evaluation of lung burden following acute inhalation exposures to highly insoluble PuO_2. Health Physics 13, 877-882 (1967).

4. C. C. Lushbaugh, R. J. Cloutier, G. Humason, J. Langham and S. Guzak, Histopathologic study of intradermal plutonium metal deposits: Their conjectured fate. Ann. N. Y. Acad. Sci. 145, 791-797 (1967).

5. W. D. Norwood, J. A. Norcross, C. E. Newton, Jr., D. B. Hylton and C. Lagerquist, Preliminary autopsy findings in U. S. Transuranium Registry cases. In Radionuclide Carcinogenesis (C. L. Sanders, R. H. Busch, J. E. Ballow, and D. D. Mahlum, Eds.), pp. 465-474, AEC Symposium Series #29, USAEC Office of Information Services, June 1973.

6. C. R. Lagerquist, S. E. Hammond and D. B. Hylton, Distribution of plutonium and americium in the body 5 years after an exposure via contaminated puncture wound. Health Physics 22, 921-924 (1972).

7. W. H. Langham, J.N.P. Lawrence, Jean McClelland and L. H. Hempelmann, The Los Alamos Scientific Laboratory's experience with plutonium in man. Health Physics 8, 753-760 (1962).

8. C. E. Newton, Jr., M. V. Larson, K. R. Heid, I. C. Nelson, P. A. Fuqua, W. D. Norwood, S. Marks and T. D. Mahoney, Tissue analysis for plutonium at autopsy. In Diagnosis and Treatment of Deposited Radionuclides.

(H. A. Kornberg and W. D. Norwood, Eds.), pp. 460-468. Excerpta Medica Foundation, N.Y., N.Y. (1968).

9. H. Foreman, W. Moss and W. Langham, Plutonium accumulation from long-term occupational exposure. Health Physics 2, 326-333 (1960).

10. L. H. Hempelmann, W. H. Langham, C. R. Richmond, and G. L. Voelz, Manhattan Project plutonium workers: A twenty-seven year follow-up study of selected cases, Health Physics 25, 461-479 (1973).

11. L. H. Hempelmann, C. R. Richmond, and G. L. Voelz, A twenty-seven year study of selected Los Alamos plutonium workers, Los Alamos Scientific Laboratory report LA-5148-MS, 31 pp. (1973b).

12. L. H. Hempelmann, W. H. Langham, G. L. Voelz, and C. R. Richmond, Biomedical follow-up of the Manhattan Project plutonium workers, In Proc. Third Congress of the Int. Radiation Protection Assoc., Washington, D. C. 1974 pp. (Sept. 9-14, 1973).

13. G. B. Schofield and G. W. Dolphin, U. K. experience on the medical aspects of radiological protection of workers handling plutonium, Annals of Occupational Hygiene (In press).

14. G. W. Dolphin, D. C. Lloyd and R. J. Purrott, Chromosome aberration analysis as a dosimetric technique in radiological protection, Health Physics 25, 7-15 (1973).

15. W. J. Bair, C. R. Richmond and B. W. Wachholz, A radiological assessment of the spatial distribution of radiation dose, USAEC WASH-1320, 47 pp., (Sept. 1974).

16. James N. P. Lawrence, "PUQFUA: An IBM-704 code for computing plutonium body burdens, Health Physics 8, 61-66 (1962). See also, Los Alamos Scientific Laboratory Report LA-2329 (April 1960).

17. W. H. Langham, S. H. Bassett, P. S. Harris, and R. E. Carter, Distribution and excretion of plutonium administered intravenously to man, Los Alamos Scientific Laboratory report LA-1151, p. 16 (Sept. 1950).

18. P. W. Durbin, Plutonium in man: A new look at the old data, (B. J. Stover and W.S.S. Jee, Eds.), pp. 469-530. The J. W. Press, University of Utah, Salt Lake City (1972).

19. J. Rundo, P. M. Starzyk and J. Sedlet, The excretion rate of plutonium 10,000 days after acquisition, Abstract of paper presented at Radiation Res. Congr. Seattle, Washington. Radiation Res. 59, pp. 86-87, (July, 1974).

20. C. R. Richmond and R. L. Thomas, Plutonium and other actinide elements in gonadal tissue of man and animals, Health Physics, In press.

21. H. D. Bruner, A plutonium registry, In Diagnosis and Treatment of Deposited Radionuclides, (H. A. Kornberg and W. D. Norwood, Eds.), pp. 661-665, Excerpta Medica Foundation, (1968).

22. W. D. Norwood, U. S. Transuranium Registry: progress and expectations, In Radiobiology of Plutonium, (B. J. Stover and W.S.S. Jee, Eds.), pp. 531-537, The J. W. Press, University of Utah, Salt Lake City, (1972).

23. J. A. Norcross and C. E. Newton, Jr., U. S. Transuranium Registry: A Progress Report, Health Physics 22, 887-890 (1972).

24. W. D. Norwood, J. A. Norcross, C. E. Newton, Jr., D. B. Hylton and C. Lagerquist, Preliminary autopsy findings in U. S. Transuranium cas In Radionuclide Carcinogenesis, (C. L. Sanders, et al., Eds.), AEC Symposium Series 29, pp. 465-474 (1973).

25. W. D. Norwood and C. E. Newton, Jr., United States Transuranium Registry Summary to June 30, 1974 to USAEC Division of Biomedical and Environmental Research Hanford Environmental Health Foundation Report HEHF #22 28 pp., (1974).

26. C. C. Lushbaugh and J. Langham, A dermal lesion from implanted plutonium, Arch. Dermatol. 86, 461-464 (1962).

27. E. E. Campbell, M. F. Milligan, W. D. Moss and H. F. Schulte, History of the Plutonium Bioassay Program at the Los Alamos Scientific Laboratory, 1944-1972, USAEC Document LA-5008, 7 pp., (1972).

28. I. C. Nelson, K. R. Heid, P. A. Fuqua, and T. D. Mahony, Plutonium in autopsy tissue samples, Health Physics 22, 925-930 (1972).

29. C. R. Lagerquist, S. E. Hammond, D. L. Bokowski and D. B. Hylton, Distribution of plutonium and americium in occupationally exposed humans as found from autopsy samples, Health Physics 25, 581-584, (1973).

30. C. R. Lagerquist, D. L. Bokowski, S. E. Hammond and D. B. Hylton, Plutonium content of several internal organs following occupational exposure, Am. Ind. Hyg. Assoc. J. 30, 417-421 (1969).

31. E. E. Campbell, B. C. Eutsler, J. McClelland, and H. M. Ide, Plutonium in man, Health Physics 22, 931 (1972).

32. C. E. Newton, Jr., I. C. Nelson, K. R. Heird and H. V. Larson, Transuranium elements and thorium in man, assessment, applicability, of biologic models and needed research, BNWL-SA-279, (August 1965).

33. C. E. Newton, Jr., K. R. Heid, H. V. Larson and I. C. Nelson, Tissue sampling for plutonium through an autopsy program, BNWL-SA-918 (Sept. 1966).

34. E. E. Campbell, M. F. Milligan, W. D. Moss, H. F. Schulte, and J. F. McInroy, Plutonium in autopsy tissue, Los Alamos Scientific Laboratory report LA-4875, 47 pp., (January 1973).

35. Annual Report of the Biomedical and Environmental Research Program of the LASL Health Division for 1973 to the USAEC, Division of Biomedical and Environmental Research, Los Alamos Scientific Laboratory Report LA-5633-PR, (C. R. Richmond and E. M. Sullivan, Eds.), (1974).

36. B. G. Bennett, Fallout ^{239}Pu dose to man, In Fallout Program, Quarterly Summary Report, Health and Safety Laboratory report HASL-278 (January 1, 1974).

Figure 1

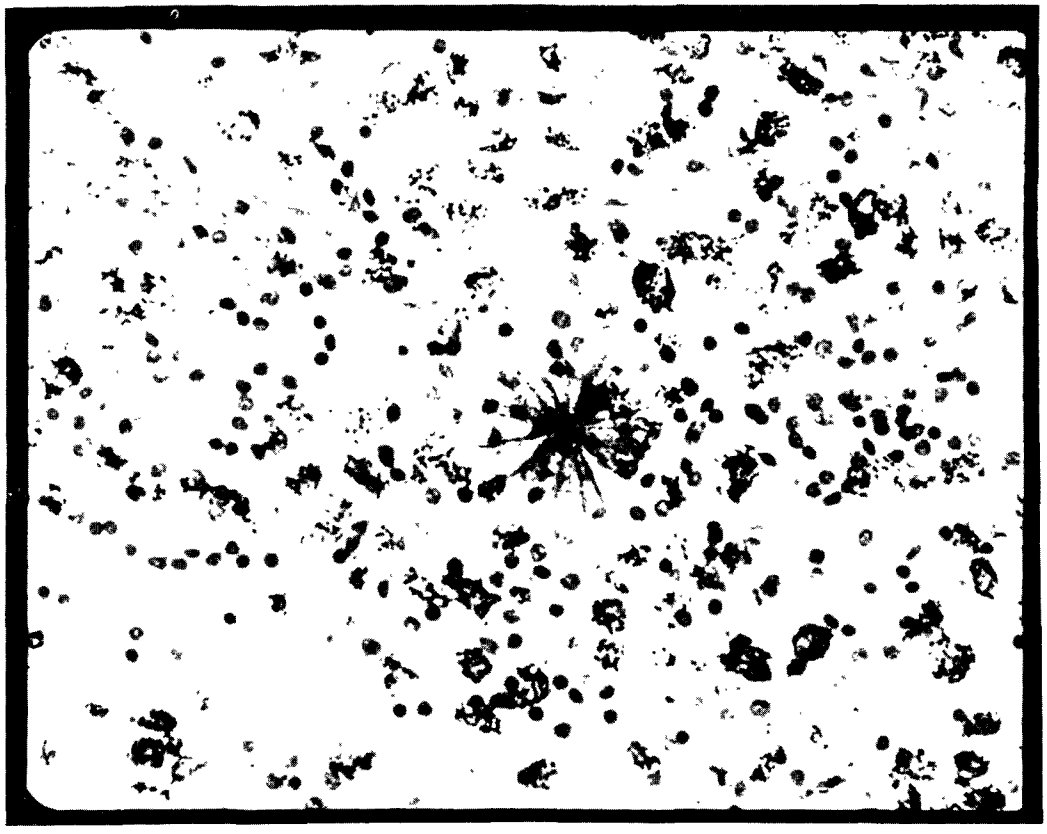

Figure 2

564

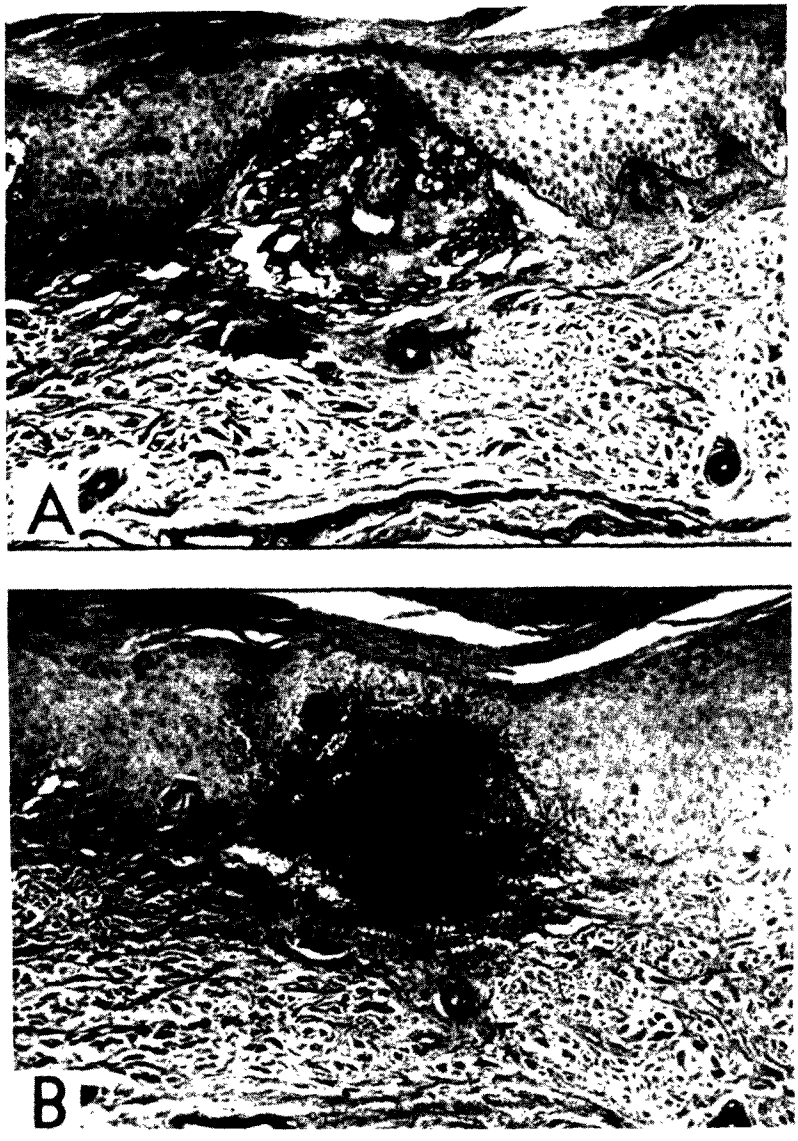

Figure 3

TABLE I

BIOMEDICAL WORK RELATED TO MANHATTAN PROJECT PLUTONIUM WORKERS

MEDICAL HISTORY AND EXAMINATION
RADIOLOGY
KARYOLOGY
PULMONARY CYTOLOGY
URINE RADIOCHEMISTRY
CHEST COUNTING (URANIUM L X-RAYS)
BLOOD CHEMISTRY PROFILES
HEMATOLOGY

TABLE II

LOS ALAMOS SCIENTIFIC LABORATORY PLUTONIUM STUDY GROUPS

GROUP 1[a]

25 MEN EXPOSED DURING 1944-1945
PERIODIC BIOMEDICAL FOLLOW-UP FOR THREE DECADES
REPORTS AVAILABLE IN LITERATURE

GROUP 2

42 MEN ALSO EXPOSED DURING MANHATTAN PROJECT
28 LOCATED AND RESPONDED TO QUESTIONNAIRES

GROUP 3

190 EARLY AND CURRENT PLUTONIUM WORKERS
175 IDENTIFIED BY SOCIAL SECURITY NUMBER
2 IDENTIFIED BY MILITARY SERVICE NUMBER
29 RESPONSES

[a]MANHATTAN PROJECT PLUTONIUM WORKERS

TABLE III

PLUTONIUM SYSTEMIC BODY BURDEN ESTIMATES FOR SELECTED MANHATTAN PROJECT PLUTONIUM WORKERS AT THREE DIFFERENT TIMES [a]

CASE CODE	$^{239-240}Pu$ (nCi) 1953	1962	1972
1	30-60	10	210
3	80	130	420
4	80	140	260
5	80	140	180
6	60	70	140
7	60	80	150
17	40	90	130

[a]PERSONS WITH MORE THAN 120 nCi $^{239-240}Pu$ SYSTEMIC BURDEN IN 1972.

TABLE IV

$^{239-240}$ PLUTONIUM CONTENT OF TISSUES REMOVED FROM CASE NO. 2 IN MAY 1971

TISSUE	WET WEIGHT (g)	$^{239-240}$PLUTONIUM	
		dpm/g	pCi/g
LUNG	70.85	8.48	3.85[a]
LYMPH NODE	1.25	451.00	205.00
HAMARTOMA	0.77	7.47	3.40
RIB	20.00	3.55	1.61

[a]CONTEMPORARY LEVEL FROM WEAPONS DETONATIONS IS ABOUT 0.004 pCi/g.

TABLE V

PLUTONIUM RECIPIENTS

- EIGHTEEN PERSONS RECEIVED PLUTONIUM IN 1945 AND 1946.
- FIFTEEN OF THE 18 WERE OLDER THAN AGE 45.
- ALL BUT 2 GIVEN ^{239}Pu; ONE RECEIVED ^{238}Pu ONLY AND ONE RECEIVED ^{238}Pu AND ^{239}Pu.
- AMOUNTS RANGED FROM $\sim$0.3 TO $\sim$6 μCi (CURRENT MAXIMUM PERMISSIBLE OCCUPATIONAL BODY BURDEN IS 0.04 μCi).
- DATA FROM GROUP PROVIDED BASIS FOR PLUTONIUM EXCRETION FUNCTIONS.
- ONE MALE RECEIVED 5.2 μCi ^{238}Pu AND 0.12 μCi ^{239}Pu AND PuO_2 $(NO_3)_2$. LATER HAD TOTAL GASTRECTOMY AND SPLENECTOMY. DIED 21 YEARS LATER OF CARDIOVASCULAR DISEASE.
- SOME OF ORIGINAL GROUP STILL ALIVE THREE DECADES LATER.

TABLE VI

CURRENT STATUS OF
UNITED STATES TRANSURANIUM REGISTRY

AEC CONTRACTOR	WORKERS IDENTIFIED	RECORD RELEASES[a]	AUTOPSY AGREEMENTS	AUTOPSIES PERFORMED	AUTOPSY REPORTS COMPLETED
HANFORD	2199	2132	525	12	8
LOS ALAMOS	259	259	127	1	0
ROCKY FLATS	1504	1489	167	30	21
SAVANNAH RIVER	1559	0	0	0	0
MOUND LABORATORY	322	0	0	1	1
OAK RIDGE	0	0	0	1	1

[a]HEALTH PHYSICS AND MEDICAL RECORDS

TABLE VII

INTERNAL PLUTONIUM DEPOSITIONS EXCEEDING 25% OF THE OCCUPATIONAL MAXIMUM PERMISSIBLE BODY BURDEN AMONG AEC CONTRACTOR PERSONNEL DURING THE PERIOD 1957-1970

BY YEAR		BY ACTIVITY		BY % OF PERMISSIBLE BODY BURDEN	
1957	12	RESEARCH	25	25 TO 50%	118
1958	6	PRODUCTION	109	50 TO 75%	35
1959	10	MAINTENANCE	17	75 TO 100%	13
1960	10	DEVELOPMENT	4	100 TO 200%	15
1961	16	HEALTH PHYSICS	18	200 TO 500%	15
1962	20	CONSTRUCTION	2	500 TO 1000%	7
1963	9	ANALYTICAL	1		
1964	29	RECOVERY	5		
1965	22	UNKNOWN	22		
1966	27				
1967	10				
1968	8	BY ROUTE OF ENTRY		BY THERAPY EMPLOYED	
1969	6	INHALATION	131	CHELATE	37
1970	3	WOUND	48	EXCISION	21
???	15	BOTH	8	BOTH	10
TOTAL	203	UNKNOWN	16	NONE	135

TABLE VIII

50TH PERCENTILE DISTRIBUTION OF PLUTONIUM IN HUMAN TISSUE (1959-1971)

	PLUTONIUM DISINTEGRATIONS PER MINUTE PER KILOGRAM									
	LUNG		LIVER		LYMPH NODE		KIDNEY		BONE	
NONOCCUPATIONALLY EXPOSED:										
LOS ALAMOS	1.3	(57)[a]	1.1	(58)	5.0	(52)	0.1	(54)	0.4	(35)
NEW MEXICO AND U. S.	1.0	(76)	0.9	(73)	4.0	(66)	0.2	(66)	0.5	(41)
COLORADO	0.5	(66)	1.7	(60)	2.0	(46)	1.4	(45)	0.9	(65)
NEW YORK	0.4	(26)	1.7	(26)	[b]		[b]		2.0	(25)
ALL POPULATIONS	0.8	(217)	1.4	(217)	3.0	(164)	0.6	(163)	0.6	(166)
OCCUPATIONALLY EXPOSED:[c]										
LOW POTENTIAL	4.0	(44)	1.0	(41)	15.0	(42)	0.1	(42)	0.3	(25)
HIGH POTENTIAL	100.0	(15)	100.0	(15)	700.0	(14)	10.0	(13)	50.0	(11)

[a] NUMBER OF SAMPLES (IN PARENTHESES)

[b] SAMPLES NOT REQUESTED

[c] DATA CANNOT BE COMPARED AS A GROUP BECAUSE OF DIFFERENCES IN TYPE AND DURATION OF EXPOSURE

TABLE IX

50TH PERCENTILE DISTRIBUTION OF PLUTONIUM IN HUMAN TISSUE (1972-1973)

	PLUTONIUM DISINTEGRATIONS PER MINUTE PER KILOGRAM									
NONOCCUPATIONALLY EXPOSED:	LUNG		LIVER		LYMPH NODE		KIDNEY		VERTEBRAE	
LOS ALAMOS	0.8	(8)[a]	1.6	(5)	35	(4)	0.2	(5)	1.6	(5)
NEW MEXICO AND U. S.	0.4	(17)	0.7	(10)	20	(15)	1.2	(10)	0.4	(16)
COLORADO	0.7	(29)	1.8	(25)	15	(22)	3.0	(25)	1.1	(25)
NEW YORK[b]	0.3	(34)	1.4	(31)	[c]		[c]		0.7	(32)
SAVANNAH RIVER	0.4	(20)	1.2	(14)	40	(6)	2.2	(11)	0.7	(12)
ALL POPULATIONS[d]	0.6	(74)	1.5	(54)	25	(47)	1.5	(51)	0.7	(58)

[a] (n) NUMBER OF SAMPLES (IN PARENTHESES)

[b] NEW YORK DATA FOR 1972 INCLUDE ALL DATA ANALYZED

[c] SAMPLES NOT REQUESTED

[d] ALL POPULATION DATA FOR 1972 DO NOT INCLUDE THE NEW YORK DATA ANALYZED DURING 1972

TABLE X

PLUTONIUM-239 IN MAN

COLORADO-NEW MEXICO (1970-1971)

	CONCENTRATION (dpm/kg)	BURDEN (pCi)	COMPUTED BURDEN (pCi)
LUNG (1.0 kg)	0.6 (96)	0.30	0.3
LYMPH (0.015 kg)	5.0 (73)	0.03	0.6
LIVER (1.7 kg)	1.8 (88)	1.40	0.8
KIDNEY (0.3 kg)	1.1 (73)	0.10	–
BONE (5.0 kg)	0.6 (96)	1.40	0.9
		3.20	2.6

NEW YORK (1968)

LUNG (1.0 kg)	0.4 (25)[a]	0.20	0.6
LIVER (1.7 kg)	1.7 (25)	1.30	0.7
BONE (5.0 kg)	2.0 (25)	4.50	0.8
LYMPH (0.015 kg)	–	–	0.7
		6.00	2.8

[a]NUMBER OF SAMPLES (IN PARENTHESES)

TABLE XI

PLUTONIUM IN MAN FROM ATMOSPHERIC NUCLEAR WEAPONS TESTS

A. PLUTONIUM PRODUCED FROM ATMOSPHERIC WEAPONS TESTS ~0.4 MCi

B. PLUTONIUM NOW ON EARTH'S SURFACE ~0.3 MCi

C. PLUTONIUM IN CONTEMPORARY MAN

	$dpm \cdot kg^{-1}$	$pCi \cdot kg^{-1}$	kg	pCi·ORGAN
LUNG	0.8	0.4	1.0	0.4
LIVER	1.4	0.6	1.7	1.0
BONE	0.6	0.3	5.0	1.5
OTHER	–	–	–	0.6
			TOTAL	~3.5pCi

D. EACH PERSON ON EARTH ACCUMULATED ABOUT 10^{-17} OF B

$$\frac{3.5 \times 10^{-12} \text{Ci} \cdot \text{PERSON}^{-1}}{0.3 \times 10^{6} \text{ Ci}}$$

E. ABOUT 10^{-8} OF THE EARTH'S INVENTORY FOUND ITS WAY INTO THE 3×10^{9} PERSONS ON EARTH

$$\frac{(3 \times 10^{9} \text{ PERSONS})\ (3.5 \times 10^{-12} \text{ Ci} \cdot \text{PERSON}^{-1})}{0.3 \times 10^{6} \text{ Ci}}$$

Thank you.

Dr. Mills: Our next speaker is Dr. Thompson.

Implications with Respect to Protection Criteria

by R. C. Thompson
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part of the AEC presentation at
EPA Plutonium Standards Hearings
Washington, D.C., December 10-11, 1974

My name is Roy Thompson. I am a staff scientist in the Biology Department of Battelle Pacific Northwest Laboratory.

Introductory Description of Problem

Those preceding me in this presentation have tried to summarize the facts that define the problem--present and projected--of plutonium and other transuranic elements in our environment. It is my task to suggest to you how these facts might be utilized in arriving at appropriate standards for control of these transuranic elements, for the protection of the general populace. This is a presumptuous undertaking, considering the collective wisdom represented on the Hearing Board. I do not expect to tell these gentlemen something they do not already know about the philosophy or practice of radiation protection.

I've therefore chosen the opposite approach. If I cannot propose a new concept to solve our problem, I will try, instead, to review the problem, in its most basic aspects and hope that from this "return to fundamentals" we may achieve some clarification of what it is we need to do. If you feel at times that your intelligence is insulted by my

simplistic approach, I can only ask that you bear with me--I won't take very long.

In the first figure, I present what seems to me the most basic formulation of our problem. An exposure to some noxious substance results in an undesirable effect. We wish to prevent or minimize this effect. So, from our knowledge of this exposure-effect relationship, we establish a standard, which in some manner acts to control the exposure at a level that does not produce an unacceptable effect.

For the case of plutonium, we can elaborate this a bit, as shown in Figure 2. Exposure is often translated into terms of a radiation dose that is thought of as producing the effect. We know that exposure must occur via some kind of environmental pathway, and that the plutonium in the environment has its origin in some "source term." It also seems obvious that the best place for the standard to be applied for control of exposure is at the level of the source term.

Note that "dose" is enclosed in brackets, to indicate that it is really not an essential step in the process. Dose, as employed in radiation protection, is a concept in the mind of the scientist, which may or may not be useful in relating exposure to effect. Exposures, on the other hand, are real occurrences that happen to people. Effects happen to people. If a relationship between exposure and effect is known, a standard may be set to control that exposure and eliminate that effect--in total ignorance of the dose or any other knowledge of the mechanism

by which the effect is thought to be produced. I stress this point because, as will be noted later, much of the confusion in this field is due, in my opinion, to a misplaced emphasis on, and confidence in, dose. I might add that this problem does not trouble most other areas of industrial toxicology where we are too ignorant of mechanisms to be concerned with such sophistication.

Exposure

I would like to consider the individual elements of our basic problem--first exposure. I think it will help us to think in terms of three kinds, or levels, of exposure. First, there are the levels that we know can produce effects in animals. Roughly speaking, these are exposures that result in lifetime doses to bone or lung in excess of about 30 rad (1). Now, I'm speaking of dose, because it's a convenient way to lump a lot of exposure data; but, you know from Dr. Bair's presentation, that I'm lumping rats and mice and dogs and baboons--so you won't place too much confidence in my numbers. I must also specify that I am talking about average organ dose. And I must remind you that in terms of dose equivalent, as currently defined, we are talking about 300 rems to lung or 1500 rems to bone (2). These exposures, we know, have resulted in a low, but significant incidence of malignant tumors in animals.

Second, there are the exposure levels that have occurred in man. Some occupational exposures approach, or perhaps even exceed, the minimum levels that have produced effects in animals (3,4). But most occupational exposures are much lower, and the exposures from fallout plutonium, very much lower (5).

Finally, there are the exposure levels about which we should be concerned if we are to protect the general populace from plutonium effects. We don't know exactly what these levels are--or we wouldn't be here. But, I think everyone would agree that these levels must certainly be much lower than those we have considered acceptable for occupational exposure.

Effect

Now, let's try to relate these exposure categories to the effects side of our relationship. For the exposure levels studied in animals, this is relatively easy--easy because of 30 years, and many millions of dollars worth of research. We know more about the effects of plutonium in animals, I would guess, than about any other industrial pollutant.

For the human exposures, one is tempted to say that we know nothing about effects, but this is not strictly true. Effects clearly attributable to plutonium have been observed at the cellular level--histological changes (6), perhaps chromosome abberations (7). Of course we knew before we looked that each alpha disintegration would probably kill cells. But we cannot, even qualitatively, relate these kinds of effects to health consequences. So, effectively, we know nothing about effects in humans.

But this absence of information is itself informative. It sets some upper limit to our problem. We don't quite know how to evaluate this limit, because we don't know as much about our population of plutonium-

exposed humans as we should, and because we may yet see effects, although it may be difficult to identify these effects as due to plutonium. However, we can at least qualitatively contrast the problem with that of exposures to radium, or exposures in uranium mines, where, within much less than 25 years after these exposures commenced, lethal effects were all too obviously evident. This kind of experience we have thankfully not had with plutonium.

If we have no useful human data on plutonium effects, can we perhaps utilize other radiation effects data that are available for humans? We can certainly make such an attempt--the UNSCEAR (8) and BEIR (9) committees, among others, have done so--but we must be aware of the uncertainties involved in such an approach. In fact, we must be aware that whatever route we take to the estimation of the health consequences of plutonium in humans, we are necessarily involved in some uncertain extrapolations. We must either extrapolate from observed plutonium effects in animals to predicted effects in humans, or we must extrapolate from observed non-plutonium radiation effects in humans to predicted plutonium effects in humans. Whichever of these routes we take, we must further extrapolate from exposure levels where we have data, to the much lower exposure levels that are of primary concern in the protection of large populations.

Extrapolations

Let us look at some of the problems involved in these extrapolations. The human radiation effects data, as recently summarized in the BEIR Report, derive largely from whole-body, external exposure to penetrating

radiation, at high dose rates and high dose levels (9). We must extrapolate to a condition of very non-uniform, internal exposure of a few organs to alpha radiation, at very much lower average dose rates, but perhaps very much higher local dose rates. Such extrapolation can only be made through the medium of simplifying assumptions regarding dose and dose equivalent. These assumptions are familiar to you--I will mention only a few of the more critical ones. One must assume a relative biological effectiveness for alpha particles--a number derived from non-human studies (2). One must correct for non-uniformity of distribution--a correction presently based on animal data in the case of bone, and assumed to be insignificant in the case of lung (2) [though this latter assumption is challenged by some as grossly in error, on dosimetric grounds (10)].

For my money the extrapolation of the animal data is subject to fewer uncertainties. The whole quagmire of dose can be sidestepped. Animals can be exposed to the actual materials of concern, whether they be "hot particles" or solutions, ingested, injected, or inhaled, chronically or in a single exposure. And, effects are directly observed. They are, of course, effects in a rat or a dog--not in man. But bone and lungs of different animals are not that different, as can be demonstrated by comparative toxicity studies in several animal species. Such differences as are observed can often be explained in terms of anatomical or physiological factors and corrections can be applied for the predicted influence of these factors in man.

But one needn't choose between these two approaches. Both animal and human data should be utilized as best one can, and the encouraging fact is that the two approaches lead to similar predictions. Figure 3 shows some of these predictions as prepared for inclusion in the LMFBR Environmental Impact Statement. These cancer risk predictions are stated in terms of cancers produced per million person-rems. The range of numbers estimated from the BEIR Report data are not maximum and minimum estimates, but the range of "best" estimates derived by different procedures--all involving an assumed linear response to dose (9). The numbers derived from animal data also assume linearity of response, and are of varying quality (1). Much better animal data should be available within a few years.

The point of this comparison is not to establish a particular number, but to indicate the kind of agreement that is seen. As an indication of the agreement seen in a related area, Figure 4 shows similar numbers for radium, where we have direct data for humans to compare with experimental animal data (11). The animal data show a generally higher incidence, but there is certainly "ballpark" agreement. Recalling the numbers on Figure 3, let me say that I would have considerable confidence in that "ballpark" of plutonium numbers, if applied to individual "person" exposures in the range of a few hundred to a few thousand rem. Whether any of these numbers have any significance when applied to exposures in the range of a rem or less is far less certain, and is the major extrapolation uncertainty that we face.

Figure 5 attempts to graphically portray this problem. We are plotting average organ dose equivalent, to bone or lung, in rem, against effect in unspecified units. The heavy line at doses in excess of 100 rem represents the hard data from animal studies. The vertical lines are meant to indicate the considerable statistical uncertainty in that data. Actually, the hard data now stops at about 300 rem for lung and 1500 rem for bone, but I think that experiments currently in progress may well extend the range of observed significant effects to something approaching this level of 100 rem. Below 100 rem we have no data on plutonium toxicity nor can we expect to obtain any. We can, with confidence, assume zero effect at zero dose; and the simplest interpolation over the unknown interval is a straight line between the last data and the zero-zero point. I won't try to review the theoretical arguments that have been presented to justify such a linear interpolation, nor will I present the theoretical arguments for some kind of enhanced effectiveness at lower dose levels, or the arguments for a threshold dose below which there will be no effect. Because they are based on unsupported theory, none of these arguments are totally convincing, though some I must admit are more convincing than others.

What I do find convincing is this zero point. And, I feel quite confident that the approach to this zero point is much more likely to be asymtotic to the dose axis than to the effect axis. I said a moment ago that we can expect to obtain no experimental data in this region below a lifetime dose of about 100 rem, but we do have data of a sort in this

region that I have cross-hatched, below about 10 rem. An experiment in this dose region has been in progress for quite a few millions of years, during which time the human race has received lifetime doses averaging about 3 or 4 alpha rem per person to bone and lung, and approaching 10 rem total lifetime radiation dose (18, 20). The numbers on the viewgraph represent 70-year cumulative background doses. Though we know something about the dose, we can't evaluate the effect side of this experiment, except to say that we <u>are</u> the effect. What we might have become if not subjected to this radiation is a fascinating, but academic question. It is quite apparent, however, that we have not evolved in a manner to spare us from this radiation. We have not developed external shielding nor have we rejected potassium as a metabolically critical element, because of its ^{40}K content. These facts argue strongly, I think, that any precipitous change in the dose-effect relationship does not occur within the range of natural background. If there is an enhanced effect of radiation at low dose levels as represented by the upper range of curves on the viewgraph, this effect certainly cannot continue to zero dose, and I think cannot reasonably be thought to persist within the region of background dose.

<u>Conclusions</u>

Now, may I express just a few general conclusions. Most importantly, I would say that "As Low As Practicable" is still a very good idea--particularly for plutonium, in view of the uncertainties we've discussed;

and particularly for population exposure standards where it may be often difficult to identify an individual benefit to balance an appreciable risk.

Exposure of total populations should be controlled at some fraction of natural background levels, because it is only in this range of exposure that I feel we have assurance of insignificant effect--an assurance based upon the survival, over past eons, of the human race.

Because the dispersal of plutonium amongst the general populace will, for many centuries at least, be quite non-uniform, I think we cannot accept limitations on person-rems as a totally adequate basis of control. While it may be expedient, and even conservative, to assume dose-effect linearity for the evaluation of risk to populations, we cannot use such an assumption as an argument for permitting individual overexposure. If 1000 person-rems are distributed evenly among 1000 persons, the probability of an eventual effect may be less than, equal to, or greater than the probability associated with the same 1000 person rems delivered to a single individual--we cannot be sure. And in no way should that uncertainty be used to justify the high individual exposure. We don't need to choose between these alternatives. We should protect the "critical individual" as well as the total population, although not necessarily to the same per-capita limits.

It seems inevitable that control must be based on environmental monitoring, since the appropriate "people-limits" will be certainly unmeasurable. This places a burden of great significance on our knowledge of food chain and inhalation pathways, which is required for translating

a people-limit to an environment-limit. Of critical importance is the assumption to be made with regard to an ultimate environmental sink for plutonium. Certainly, the longer-lived plutonium isotopes need not be assumed to remain optimally available to man for the hundreds of thousands of years before they undergo complete radioactive decay.

It may be expedient to express exposure limits for the individual in the population as some appropriate fraction of an occupational exposure limit, because the derived occupational limits will incorporate considerations of exposure pathways and the summation of dose commitments to critical organs. This "appropriate" fraction, however, cannot be an arbitrary number applicable to all radionuclides under all circumstances. It should be set primarily in relation to considerations of natural background and "practicability." Thus, the absolute value of occupational exposure limits is of little relevance to population exposure--a different set of criteria are involved on the benefit side of the risk-benefit equation.

Finally, I would just like to address, very briefly, a few specific, critical questions that have been raised with regard to the adequacy of plutonium toxicity information. Enough has probably already been said about the "hot particle" problem. This is a theoretical argument, centering around totally inadequate knowledge of the microdose-macroeffect relationship (10). Fortunately, there are experimental animal data and human experience, not dependent upon theoretical interpretation of dose, that denies the existence of any major enhanced effectiveness of such particulate exposure (13).

Concern has been expressed that the potential for genetic effects from plutonium deposited in gonads may not be adequately evaluated. Although animal experiments to prove this point have not been done, and would be very difficult, there is evidence from both animal and human data that plutonium is not concentrated in gonads, and that the dose from gonadal plutonium is therefore small--much smaller, and therefore of less concern, than the dose to lung, bone, or liver (14). Some early analyses, which seemed to indicate high levels of fallout plutonium in human gonads, have been shown to be in error (14, 15).

Lymph nodes draining the lung will probably receive the highest radiation dose from inhaled plutonium but this dose has not been considered in setting occupational exposure standards. This seems justified in light of the overwhelmingly greater incidence of cancer in bone and lung of animals that have inhaled plutonium (1).

One must be particularly concerned for the exposure of the very young members of a population, since they are usually considered to exhibit an enhanced radiosensitivity. The fact that the radiation exposure from each increment of internally deposited plutonium is spread over the whole subsequent lifetime of the exposed person, provides an automatic safety factor for the young child. Assuming uniform continuous exposure, dose rate will increase throughout the life span, and will be at its lowest value in the newborn. While gastrointestinal absorption of plutonium may be markedly increased in the infant, this condition is probably limited to a very short period following birth, a period during which the infant is relatively protected against most forms of exposure (16).

REFERENCES

1. W. J. Bair, "Toxicology of Plutonium," in Advances in Radiation Biology, Vol. 4, Academic Press, New York, pp. 255-315, 1974.

2. International Commission on Radiological Protection, "Report of Committee II on Permissible Dose for Internal Radiation," ICRP Publication 2, Pergamon Press, 1959.

3. D. M. Ross, "A Statistical Summary of United States Atomic Energy Commission Contractors' Internal Exposure Experience," in Diagnosis and Treatment of Deposited Radionuclides, Excerpta Medica Foundation, Amsterdam, pp. 427-434, 1968.

4. L. H. Hemplemann, W. H. Langham, C. R. Richmond, and G. L. Voelz, "A Twenty-seven Year Study of Selected Los Alamos Plutonium Workers," Health Physics 24, pp, 461-479, 1973.

5. B. G. Bennett, "Fallout ^{239}Pu Dose to Man," Fallout Program Quarterly Summary Report, HASL-278, 1974.

6. C. C. Lushbaugh and J. Langham, "A Dermal Lesion from Implanted Plutonium" Arch. Dermatol. 86, pp. 461-464, 1962.

7. W. F. Brandom, R. W. Bistline, A. D. Bloom, and P. G. Archer, "Somatic Cell Chromosome Changes in Humans Exposed to ^{239}Plutonium," Radiation Research 59, p. 206, 1974.

8. U. N. Scientific Committee on the Effects of Atomic Radiation, Ionizing Radiation; Levels and Effects, Vol. I and II, United Nations, NY, 1972.

9. U. S. National Academy of Sciences - National Research Council, The Effects on Populations of Exposure to Low Levels of Ionizing Radiation," Report of the Advisory Committee on the Biological Effects of Ionizing Radiations, Washington, DC, 1972.

10. A. R. Tamplin and T. B. Cochran, "Radiation Standards for Hot Particles," Natural Resources Defense Council, Washington, DC, 1974.

11. C. W. Mays and R. D. Lloyd, "Bone Sarcoma Incidence vs. Alpha Particle Dose," in Radiobiology of Plutonium (B. J. Stover and W. S. S. Jee, eds.) J. W. Press, Salt Lake City, pp. 409-430, 1972.

12. W. M. Lowder, J. H. Harley, and J. E. McLaughlin, "Data Needs for the Assessment of Population Dose from Background Radiation," Population Exposures (J. C. Hart, R. H. Ritchie, and B. S. Varnadore, eds.) USAEC Doc. CONF-741018, pp. 23-28 (1974).

13. W. J. Bair, C. R. Richmond, and B. W. Wachholz, "A Radiobiological Assessment of the Spatial Distribution and Radiation Dose from Inhaled Plutonium," WASH-1320, 1974.

14. C. R. Richmond and R. L. Thomas, "Plutonium and Other Actinide Elements in Gonadal Tissue of Man and Animals," Health Physics, Manuscript Submitted, 1974.

15. E. E. Campbell, M. G. Milligan, W. D. Moss, H. F. Schulte, and J. F. McInroy, "Plutonium in Autopsy Tissue," Los Alamos Scientific Lab. Doc. LA-4875, 1973.

16. M. R. Sikov and D. D. Mahlum, "Plutonium in the Developing Animals," Health Physics 22, 707-712, 1972.

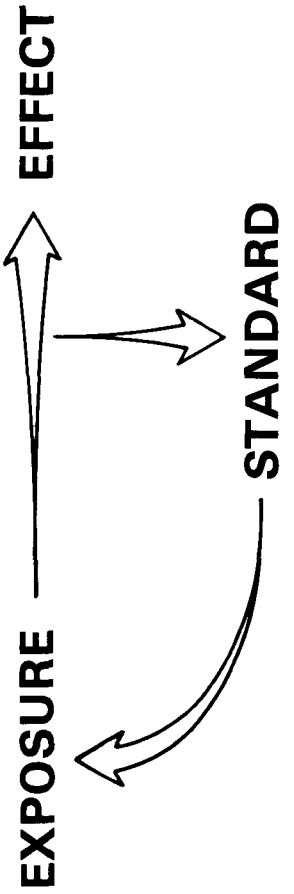

FIGURE 1

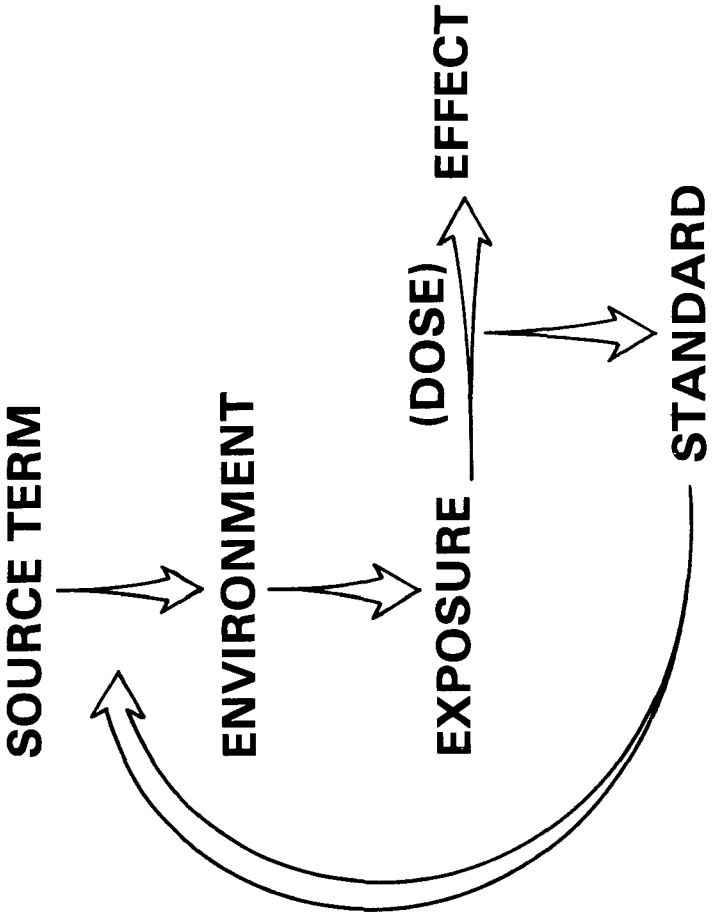

FIGURE 2

PLUTONIUM-INDUCED CANCER PREDICTIONS

(cancers per million person-rems)

PREDICTION BASED ON DATA FROM:	CANCER TYPE		
	LUNG	BONE	LIVER
MAN (BEIR REPORT)	16-110	2-17	1-7
DOG	70	70	
RAT	60 (700)*	10	
MOUSE		20	

* ^{238}Pu

FIGURE 3

RADIUM-INDUCED BONE CANCER EXPERIENCE
(cancers per million person-rems)

	DATA FROM:	
MAN	$^{226,228}Ra$	5
	^{224}Ra (ADULT)	9
	^{224}Ra (JUVENILE)	15
DOG	^{226}Ra	43
	^{228}Ra	130
MICE	^{226}Ra (FEMALE)	43
	^{224}Ra (FEMALE)	120
	^{224}Ra (MALE)	7

FIGURE 4

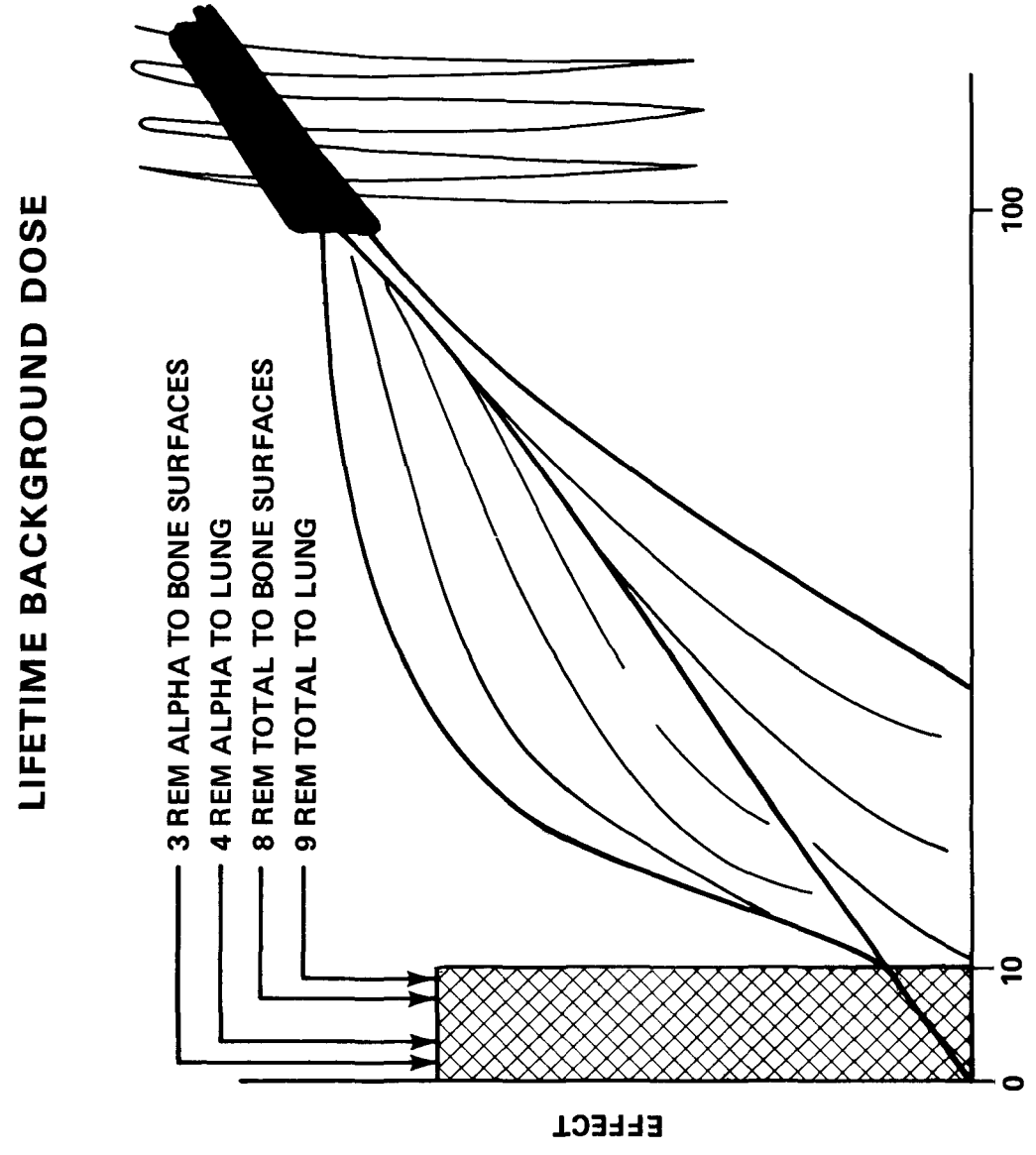
LIFETIME BACKGROUND DOSE
3 REM ALPHA TO BONE SURFACES
4 REM ALPHA TO LUNG
8 REM TOTAL TO BONE SURFACES
9 REM TOTAL TO LUNG
EFFECT
0
10
100
REM

FIGURE 5

Standards for the Transuranic Elements

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part of the AEC presentation at
EPA Plutonium Standards Hearings
Washington, D.C., December 10-11, 1974

The following remarks are in lieu of personal appearance for testimony which I regret previous commitments precludes. It is not heavily documented or intended to be in any way a complete summary of the many important considerations which have had or will have a significant bearing on both these important standards and their implementation. Reference will be made, however, to especially pertinent documents and summaries where needed.

While I take responsibility for this statement entirely as an individual scientist, it cannot help but be influenced by my current interests and activities for the National Council on Radiation Protection and Measurements whose Scientific Committee-34 I happen to Chair, and by interaction among its members and others in the field. Committee-34 has as its charge the recommendation to the Council of radionuclide concentration standards for both occupational and population exposure in the United States. It is actively engaged in consideration of aspects of this urgent subject but has not yet reached any conclusions on matters as detailed as standards for the transuranics.

My personal view is that some of the current recommendations regarding exposure to transuranics, now many years old, will be changed by the responsible

national and international bodies such as ICRP and NCRP and will, quickly, or even before, be modified somewhat in the Federal and probably the State codes. It is also my view that the modification will be in the direction of a reduction in derived limits, perhaps also in the primary dose standards, although the change in the latter might be relatively smaller. Decisions regarding the magnitude of any future reductions and to which nuclides they might be applied is now the prime source of debate and delay. Fortunately the extant philosophy of operating on the "as low as practicable" basis makes such delays in decision-making of less importance than they might otherwise be. However, none of the above remarks should be interpreted as implying that we have reliable scientific evidence showing significant biological damage in either workers or populations who have never been exposed above the current standards. But the future increases in numbers of potential exposees and in the quantities of transuranium nuclides potentially available makes the current emphasis on reexamination of standards a very legitimate enterprise even though the organizations concerned have and continue to maintain constant vigilance over the validity of the basic recommendations.

Basis for Present Standards

The biological basis for ICRP, NCRP and various governmental standards has been reviewed and scrutinized in depth by many, probably also at these hearings. In addition to basic documents, I especially commend the excellent historical review of maximum permissible body burdens and concentrations of plutonium by Langham and Healy[1], and of concentration and body burdens of the transplutonic elements by Dolphin.[2]

Yet a few points need reiteration even here. Firstly is the fact that the body burden standard for plutonium is based on a large volume of excellent

biological work first in rodents and then in the dog, and to a lesser extent primates. In addition there is a respectable amount of information on the behavior of plutonium in man which suggests no major differences in its metabolism in the human as compared to the animal species used.

It was the empirical ratio of the toxicity of plutonium relative to radium found in animal experiments which led to a reversal of proposed early standards based on energy considerations alone and to our present standards with bone as critical organ. But we have no storehouse of information on effects of plutonium in man as we do for radium (both -226 and -224). Indeed fortunately we have nothing but one or two isolated instances of effects which may be attributable to plutonium exposure. But it is frequently forgotten that we do have a storehouse of metabolic information both in man and animals and of effects in animals upon which to base a standard for plutonium.

Because of its similarities to radium the standard for plutonium in bone was therefore based on the biological information alluded to above, including the experience with radium in man. By contrast both body burden and derived standards for plutonium when organs other than bone are critical were derived quite differently viz: by calculation of that amount in the organ which will yield no more than the maximum allowable dose or dose rate to that organ. This maximum allowable dose or dose rate was derived not from experience with radium but largely from experience with external radiation sources. For most soft tissues in which the transuranics deposit (lung, liver, kidney, GI tract, et cetera) this rate is 15 rem per year for occupational exposure. Since the calculated dose to bone using the radium experience is

at least double this quantity, a factor of at least two enters into the prime standards between bone and other likely critical organs. A difference of this magnitude is well within the limits of our present knowledge.

More recently the ICRP has essentially abandoned the system of direct comparison to radium and substituted calculation of the dose to endosteal cells as the basic procedure for bone. Since this would allow a dose rate of only 15 rem per year for occupational exposure situations, the prime standard might be expected to be reduced by a factor of at least two by this change. But, as of the present writing, the complexities of calculating dose to endosteal cells from alpha emitters have made the ICRP decide to keep the old approach for alpha-emitting bone seekers.

The transplutonic elements such as Am, Cm, Cf, Es, Fm, et cetera, seemed by and large to behave enough like plutonium to be handled in much the same way, i.e., bone as critical organ and the comparison to radium retained. Or so it would seem from the official ICRP and NCRP publications on internal emitters. But Dolphin makes no mention of direct comparison to radium in deriving body burden figures for the trans-plutonics in his recent survey.[2] Instead he cites the basic dose standards of 5, 15, and 30 rem/year, the latter presumably applying to bone and calculates therefrom. The NCRP in its most recent report on basic radiation standards[3] does not make specific mention of any dose rate for bone, although it might be presumed to be included in "other organs...." at 15 rems per year. In fact, the NCRP Report specifically defers judgment (paragraph 202, page 77, reference 3) on bone doses to await recommendations from its committees on internal emitters; which committees have yet to issue judgements beyond the one contained in the referenced paragraph above.

Thus the official primary standards for the transuranium elements remain, despite much ferment, pretty much as they were in 1959 except for certain additions and modifications of derived figures. But let it not be forgotten that changes would have been made quickly and certainly if the growing storehouse of biological information had begun to indicate any serious flaws in the basic information used originally. The situation would not have remained static very long.

The Current Reexamination

A. Changes in Models and Metabolic Parameters

Over the years since 1959 much new biological information has been gathered and formulated. In addition to different values for some of the metabolic parameters, we have a new and more versatile lung model, a new GI tract model, much more about standard man, et cetera. Only a small fraction of this has found its way into official use, although it has been generally drawn upon for almost every other purpose. In my paper at Los Alamos[4] I presented "old" and potential "new" figures for Maximum Permissible Annual Intake by ingestion or inhalation of plutonium-238 and 239 and the derived values for air concentrations. For the "new" figures I selected likely - but totally unofficial - metabolic values and models. The changes in derived values were almost all within a factor of ten, some increasing and some decreasing. While it must be admitted that other choices - especially of aerosol characteristics might have made larger differences, the prediction that the newer models and metabolic data would lead to drastic reduction in standards, has not been realized for plutonium.

The accumulated information on toxicity ratios between transuranics and radium in the monumental dog experiment at the University of Utah indicates rather remarkable similarities to the ratios derived from shorter-lived rodents. However, the current ratio of five (expressed as the "N" factor in ICRP and NCRP formulations) is certainly none too high. Some of the dog experiments indicate factors more like eight or ten. This combined with Marshall's indication that slower movement of the nuclides in bone structure of man might lead to a higher toxicity in man indicates a potential for some reduction in basic derived standards on this basis when the responsible bodies complete their sifting of the newer (and still accumulating) data. Newer work with the transplutonics has been ably summarized by Durbin.[5] Her survey plus currently appearing papers suggest larger accumulations of some of these nuclides in soft-tissues and correspondingly less in bone than in earlier work. If the critical organ dose calculation mode is used, these changes would seem unlikely to lower standards. If the risk estimate approach is employed the situation might be different. Results so far suggest that the transplutonics may be about equally effective with plutonium (on activity basis) in inducing bone tumors. Although the experiments are far from complete, especially those with ^{249}Cf and ^{252}Cf, if this is indeed true then these nuclides by their greater mobility compared to plutonium may present greater risks to soft tissue. The net result might well be a reduction of derived standards. But current data do not suggest a large reduction on this basis if it does occur.

B. Cancer Incidence Relationship

In an important paper at the Fifth International Congress of Radiation Research, Dr. Roy C. Thompson presented two summary graphs which put together in one place most of the animal data on bone and lung cancer incidence from long-term exposure to plutonium. These present the incidence rates as a function of calculated radiation dose and are fraught with all of the pitfalls and difficulties of determining the true radiation dose which caused the cancer. These are especially serious difficulties for an internal emitter like plutonium. Also, the combining of data from many experiments employing many species into a single summary graph is a very gross way to express relationships. Yet, the broad outlines of cancer incidence rates are discernable since the data are reasonably coherent.

As Dr. Thompson will no doubt point out in his own testimony at these hearings, the composite figures for lung cancer show a small but apparently significant increase at a cumulative mean dose as low as 30 rads. The composite portrayed for plutonium-induced osteosarcoma shows several points above the abscissa (i.e., above zero increase in incidence) below 10 rads, although the mean figures are not above zero until a cumulative rad dose of slightly over 20 rads. If one considers that at 15 rem per year and 50 years of exposure, the total allowable cumulative occupational dose to the lung could be 750 rem while 30 rad is only 300 rem, one wonders if the safety factor in this standard is as large as desirable.

Fortunately the occupational limits for air concentration have been arranged so that the limiting dosage rate of 15 rem per year is reached only in the 50th year of exposure. Thus 750 rem would never be reached under this regimen. But if this annual rate were to be applied to single or a series of short exposures, the total doses might come uncomfortably close to those associated with detectable increase in cancer incidence.

A similar argument might be made for bone, although the practice of tying its limits directly to radium exposures in humans and the even greater difficulties of calculating radiation dose to bone for alpha emitters make it more likely to be specious.

Application of the dose commitment concept for single or short bursts of exposure has probably helped to prevent unacceptably large accumulations in man. But it seems reasonable to expect that the presence of finite cancer incidence at calculated doses as low as 10 rads or 100 rems will exert pressure toward lowering of the present official ICRP, NCRP, and other permissible exposures and intakes.

C. Non-uniform Distribution

It is amply clear that the transuranic nuclides show a marked tendency to form aggregates in vitro and in vivo, especially in the chemical and physical states of most likely exposure. Thus, the maximal radiation doses in some areas may far exceed the average dose to the organ conventionally calculated. A special case of this well-known non-uniform distribution phenomenon is the "hot particle"

problem emphasized in extenso by Tamplin and Cochran[6] and the Natural Resources Defense Council, Inc.

While the bulk of current biological information does not support the notion of any special carcinogenic effectiveness of "hot particles" in the lung, there are many critical pieces of information which are not available. Nor can they be expected to appear until more is known of the mechanisms of carcinogenesis itself. While I disagree with the 115,000 factor by which Tamplin and Cochran suggest the standards should be lowered, I do believe the "hot particle" discussion will tend, along with other factors noted in the testimony, to drive standards down, even if the scientific basis is not clearly evident from experimental work.

There is one aspect of the "hot particle" problem, however, which I feel needs special emphasis. As discussed earlier, we are dealing with actual incidence data for plutonium, and to a lesser extent for the transplutonics. The animal exposures undoubtedly involved non-uniform distributions, even "hot particles." The tissue responses measured have thus largely resulted from non-uniform sources. If maximal doses are utilized for the incidence curves which take into account the non-uniformity of distribution, instead of the average dose to the whole tissue, then the apparent radiosensitivity, i.e., the dose to produce the effect, would be correspondingly lowered. The "effective dose" would be much higher by this convention. Then standards should be keyed to those doses

rather than to the calculated average dose. Thus, in a sense the dosage calculations have led us astray. We should be sure we do not forget that direct biological information should always take priority. The great strength of the data for radium in man and of the derivations of many of the standards for internal emitters therefrom, lies in the fact that activity and effect can be correlated without obligatorily going through the step of calculating a radiation dose. This is also true in our extensive animal data with transuranics. Thus, I personally will await a clear demonstration of a special effectiveness of hot particles in the lung before accepting a drastic reduction based on dosage calculations alone.

D. Population Exposures

The enormous impetus of the "fall-out controversy" and the subsequent UNSCEAR and BEAR committee deliberations led first the Federal Radiation Council[7] then the ICRP[8] and NCRP[3] to set down specific limits for radiation exposure of the general population both on the average and to an individual. These were applied to radioisotope releases in the Federal Code of Regulations essentially by scaling down the occupational figure by factors of 1/10 or 1/30 (the iodines and particulates have received separate and much more stringent treatment). Such a scaling down process introduces many dilemmas for the transuranics as described in a paper I gave at the Los Alamos Plutonium Symposium[4] so long as one continues to use the calculation of dose and critical organ convention. An alternative, taken up at length in the report of the BEIR

Committee[9] and in the 1972 UNSCEAR report[10] is to attempt to assay total or specific health effects. Estimates of risk and decisions regarding acceptable risk take the place of comparing a given exposure with a maximum allowable dose or dose rate. This approach has its attractions, but it must lean heavily on estimates of risk derived from a few special human populations.

While there are an increasing number of papers appearing in which the direct estimation of total or some specific health effect is employed in connection with aspects of the nuclear fuel cycle (e.g., Barr[11]), neither ICRP or NCRP has yet officially embraced this alternative. What effect if any such a change if it does occur will have on basic and derived standards is difficult to predict, particularly since opinions are still widely divergent on details of risk assessment. Nonetheless, it seems unlikely that the figures for total health effects or even the most likely specific effects from the presently accepted dose rates or total doses will be accepted if the technology will permit lower risks without undue loss of benefits. In any event, the use of a population exposure figure for the transuranic group of nuclides based on a simple scaling factor from occupational levels is probably untenable. Thus change in these, not necessarily drastic, but definite seems very likely, and it will probably be downward.

E. The Lymph Node Problem

A final example of how dosage calculations, unmodified by biomedical information, can lead to dilemmas and claims of overexposure is seen in the deposition of inhaled nuclides in pulmonary, particularly bronchiopulmonary, lymph nodes. This was discussed at some

length in my paper at Los Alamos in May 1974.[4] Every toxicologist knows that insoluble materials leaving the lung deposit, sometimes in very high concentrations, in the lymph nodes along the channels of lymphatic drainage of the lung. This is fully true for the transuranic elements and very high radiation doses can be calculated as resulting from the amounts deposited. But there has yet to be found a primary cancer associated with or resulting from these deposits. The nodes may be completely fibrosed and essentially non-functional, but no cancer. Lung and bone cancers appear in the same animals and at much lower calculated doses.

Because of the strong concentration of nuclide in lymph nodes, dosage rate alone would make them critical organ after inhalation exposure in nearly all cases of inhalation of insoluble compounds and derived standards would be automatically reduced. But this has <u>not</u> been done because of the apparent radioresistance of this tissue in terms of local cancer induction. Perhaps this should be recognized and the dilemma of not allowing an "overdose" solved for the health physicist by providing a more realistic maximum permissible annual dose rate for this tissue. But I would not personally wish to see such a move allow doses which would produce significant fibrosis or other definite damage, and these would probably not be so far above current dose levels that the dilemma would cease to exist. On this basis, I feel that a proper accounting should be made of the lymph node activities and biological changes associated therewith rather than simply pass the problem by as too difficult to

handle. I can envision such a move as resulting in some lowering of current standards under certain conditions.

Conclusions

This statement is much more speculative in some respects than I usually allow myself to engage in. But since my subject concerns the probable future trends of standards for the transuranic elements, I feel it necessary to indulge in many personal prognostications. These in summary predict downward alterations of present primary and derived standards but of magnitudes which would probably not strain current technology unduly. But on the other hand, it must be stressed that we still need some very important biomedical information which only time, patience, and careful scientific work can supply and standards will probably continue for some time to involve many assumptions which must rest on incomplete information.

REFERENCES

(1) Langham, W. H. and J. Healy, Chapter 12 in Vol. 36 of the Handbook of Experimental Pharmacology series, entitled "Uranium, Plutonium, and the Transplutonic Elements." H. C. Hodge, J. N. Stannard and J. B. Hursh, Ed., Springer-Verlag, New York, Heidelberg, Berlin, 1973.

(2) Dolphin, G. W., Ibid. Chapter 19.

(3) National Council on Radiation Protection and Measurements, Report No. 39, "Basic Radiation Protection Criteria." NCRP Publications, Washington, D.C., 1971.

(4) Stannard, J.N., "The Concepts of Critical Organ and Radiation Dose as Applied to Plutonium," presented at Los Alamos Biology Symposium, May 1974. To be published in Health Physics.

(5) Durbin, P.W., Chapter 18 in Vol. 36 of the Handbook of Experiment Pharmacology series, entitled "Uranium, Plutonium, and the Transplutonic Elements." H. C. Hodge, J. N. Stannard and J. B. Hursh, Ed., Springer-Verlag, New York, Heidelberg, Berlin, 1973.

(6) Tamplin, A. R. and Cochran, T. B., "Radiation Standards for Hot Particles, A Report on the Inadequacy of Existing Radiation Protection Standards Related to Internal Exposure of Man to Insoluble Particles of Plutonium and Other Alpha-Emitting Hot Particles," Natural Resources Defense Council, Washington, D.C., February 14, 1974.

(7) Federal Radiation Council (FRC), Report No. 1, 1960, (U.S. Department of Commerce).

(8) International Commission on Radiological Protection (ICRP), 1966, Publication No. 9 (Pergamon Press, Oxford).

(9) National Academy of Sciences-National Research Council (NAS-NRC), Division of Medical Sciences, 1972, Report on "The Effects on Populations of Exposure to Low Levels of Ionizing Radiation," (NAS-NRC, Washington, D.C.).

(10) United Nations Scientific Committee on "The Effects of Atomic Radiation (UNSCEAR), 1972, Vol. II: Effects, (United Nations, N.Y.).

(11) Barr, N. F., "Quantitative Health Estimates of Transuranic Releases," Division of Biomedical and Environmental Research, paper presented at American Nuclear Society meeting, Washington, D.C., October 1974.

Dr. Mills: Before we turn to the comments and questions, could we take about a five minute break.

(Brief recess.)

Dr. Mills: I would like at this time to introduce Dr. Karl Z. Morgan of the Institute of Technology, a member of the panel.

We are happy that Dr. Morgan has recovered partially and is able to sit with us today.

We will have some scheduling problem. What I have suggested is that we limit our comments and questions of this particular group to about 15 or 20 minutes or so, but ask if they would, if they would stick around for this afternoon, so if we have any additional questions -

I do not know how much difficulty that will give you people. Those who can. If they are not around, we may submit some written questions.

Dr. Radford: Will they be able to stay around?

Dr. Liverman: They each have individual travel plans.

Dr. Burr: Some have problems after four.

Dr. Mills: Hopefully we will get through before that.

Dr. Liverman: What about the group from yesterday? Those, too, or just this group?

Dr. Mills: Does anyone have any questions of the group from yesterday?

I think it is primarily this group.

Yesterday, I started off with the questions. Today, I would like to turn it around a little bit: I would like to start with Dr. Taylor.

Dr. Taylor: I would like to make a comment first.

This group of papers this morning was really one of the nicest collection of information on the status of this situation that I have listened to in many a day.

I was going to ask a question, but the question was very nicely answered for me in the last statement of Dr. Richmond.

I wanted to draw from these people some feeling on their part, at least their personal feeling, as to whether we were moderately within base, as it were, with our present plutonium standards for occupational exposure as well as for population exposure.

I think both of these questions have been adequately answered. Two things have really come out of discussion: One, that we do not seem to be, in their opinion, really off base much; and secondly, there is no great likelihood of there being any vast reservoir of new information developing as a result of our experience which is likely to change the situation with regard to our present day standards.

I would just like to ask one general question.

Is that conclusion that I am drawing the same as the conclusion you people were trying to present? Does anybody want to argue about it?

Dr. Thompson: I think I am on record-if I was not already, Herb Parker put me on record yesterday-as feeling that the present occupational standard for plutonium is less conservative than the radium standard by something like a factor of ten.

I feel that a factor of ten in such a standard is sort of a marginal change, that you cannot be certain about such things by less than a factor of ten.

So I do not consider this to be a serious problem or a major change. Compared to the standard for radium I think the standard for plutonium is not quite as safe.

Dr. Taylor: I regard a factor of ten as having one foot on the base still.

Dr. Thompson: Right.

Dr. Richmond: I would like to add that the usual practice and procedures followed operationally within the industry is to remove people when they show a fraction of the maximum permissible occupational burden.

I think it is very interesting that the autopsy data that is now being accrued from various laboratories and from the United Kingdom suggests quite strongly that there is a conservative factor built into the bioassey procedures that are used to estimate the body burden.

So I point out that almost without exception, the amount in the body at autopsy is less than that predicted.

The reason I make a point of this is that when people are removed from the particular job, they are put into another. Very often, people make the assumption that there is no risk with any other operation in the industry.

We all know this is not true, so I think it is a very important consideration, the fact that there is apparently this conservation built in.

Dr. Mills: Dr. First?

Dr. First: I have just one general question. This relates to the details of the human exposure data; the data base, as many of you have

mentioned is quite small. This did not come up in your discussions. I wonder if there has been a consideration of what the confidence limit would be in drawing conclusions from this small number of cases that you reviewed?

Dr. Richmond: Yes. We have addressed that question in the references that accompany my information and that was submitted for the record.

There is a reference to a publication which is now available, part of the Third International Congress on International Radiation Protection, which was held here in Washington in September, 1973.

It is a very good question you bring up. I think that is primarily the reason that some of the information I showed this morning reflects the concern in terms of building up that data base.

Group II is an attempt to increase those individuals that were exposed back in 1940's. Since we have a three decade period of potential change.

In the paper I mentioned specifically, we did look at vital statistics data. You would expect more, perhaps five or six, I believe, as the number of cancer deaths in a group of say 25 people, let us say, normal individuals from a population. However, there are only certain kinds of effects one would expect to see on the basis of the animal data: cancer, notably cancer of the lung, bone and perhaps liver. So one can make estimates of the numbers of those kinds of effects one would see, even with a population that small.

The number happens to be about one for lung cancer, and a very small fraction, for example, for bone cancer. So I think it would be disastrous

not to study a small group on the basis of statistics alone.

It is reassuring because if we saw three or five bone cancers in this group where we would expect a smaller fraction, perhaps .04, as I remember, this is very telling.

So, I guess my point is there are only certain kinds of effects that screens down the statistical problem, in a sense.

Dr. First: This is referenced in your paper? I could find its reference?

Dr. Richmond: Yes. I could make it available to the Chairman, if you would like the entire publication.

Dr. First: No. That will be all right. Thank you.

Dr. Mills: Dr. Radford?

Dr. Radford: I have a great many questions, and I may be asking some of you to come back. I do not want to usurp all of the time this morning from my colleagues.

It seems to me we are really getting to grips with the issue that is before this panel predominantly.

Anyway, may I add to what Dr. Taylor had said and congratulate especially Dr. Bair, but also Dr. Richmond in their presentations, and to congratulate Dr. Bair especially for the work that has been done at the Hanford Laboratory on these problems over many years, which obviously goes back a long time before 1970.

It is regrettable that the operational division of the Agency had not seen fit to be, perhaps, as vigilant in looking at this problem from the environmental point of view.

Now, I would like to address a number of questions and I will try to keep them down so that I wiil give my colleagues on the left a chance.

First, with regard to the current plutonium standard or other transuranic standards, they have been based on bone effects. The .04 occupational body burden is based on bone end point. Is that correct?

I believe in reading through that section that Dr. Richmond skipped over, that is the thrust of the statement. Is that correct?

It is a comparison between the radium 226 results and the plutonium results?

Dr. Richmond: Yes.

Dr. Radford: So that if there were problems in connection with certain of the transuranic mix that did not have bone as the primary site of ash, then that approach would not be applicable?

Dr. Richmond: Correct. There are other considerations. For example, I think you are alluding probably to effects that might occur in a lung.

In that case, there is another primary radiation standard which, I am sure you know, is 15 rem per year for occupational workers. This standard is based on other data.

So that it depends on the specific organ which one is concerned with as to what standard one uses and how it is developed.

Dr. Radford: The version of the body burden standard that I am familiar with, and I may not have the latest one, does not give a lung burden as the standard for plutonium 239. Correct?

Dr. Richmond: That is correct in a sense. I think that should be explained. You will not normally find calculated values in tables for any

regulation applied to the lung.

Specifically for plutonium 239, let us consider the lung; the derived standard is a quantity (0.016 microcuries) of plutonium which will deliver the annual dose rate equivalent which was 15 rem per year.

This is the procedural mechanism that is involved for calculating the derived standard from the primary standard, which is the dose rate for various radionuclides.

Dr. Radford: Dr. Richmond, since you are answering, you mentioned in answer to Dr. First's question, I think, that the data comparing the models of exposure, say, of lung tissue or other tissue to excretion data or other criteria by which you calculate body burden, contain an element of conservatism because in Britain and the United States finding that perhaps the model was a little over-estimating the body burdens.

Yet, you state there was good agreement between the calculated and the observed data by organ tissue in the human samples that you showed in one of your charts.

To my eyes, that agreement is not really terribly spectacular when you looked at the particular ones; the big deviation seemed to be the lymph nodes calculated to be substantially higher than they were since the lymph nodes, apparently have a fairly large fraction of the total body burden.

That would give the appearance that the body burdens were conservative. What I just said, is that in accord with your understanding of the facts.

Dr. Richmond: I am not sure I understand, but let me try to answer, I think there are two issues. Basically, you are right in both.

One comparison I made was with the amount found at autopsy in the body

as compared with the amount predicted from bioassey data.

There was another comparison made; that is, the amount found in non-occupationally exposed personnel or people with the amount predicted from models that Burt Bennett talked about yesterday which incorporated the ICRP parameters that determine lung deposition and translocation to different organs and tissues.

So there are really two comparisons that I made.

Dr. Radford: Which ones do you think are the most important and relevant?

Dr. Richmond: I have already addressed my responses about how I view the importance of the finding. Apparently there is a conservatism built into the bioassey models that are used to estimate the amount of plutonium in a worker during life.

I think the other comparison is important in that it tells us that we are not way off base in using the metabolic parameters that have been developed by ICRP in getting the material from the air through the lung, for example, to a given organ.

Dr. Radford: I am referring to Table X in your paper, "Plutonium 239 in Man." You have Colorado-New Mexico and New York. That is the table I am referring to.

Those are occupational exposures?

Dr. Richmond: These are non-occupational exposures.

Dr. Radford: Do you consider the agreement good there?

Dr. Richmond: Yes, I see your question now. You are concerned about the fact that the lymph burden as measured is .03; whereas computed, it

is .6.

Dr. Radford: Right.

Dr. Richmond: That is the one tissue that does not agree well. I think my interpretation is that the particle size -

Dr. Radford: All the other organs show higher values when you calculated, so to that extent, if you are talking about other tissues than lymph nodes, the exposure would be underestimated.

Dr. Richmond: I think there are a lot of uncertainties in these values. When you are talking about measuring small quantities. You have .3 piocuries for an entire lung. There is a notable difference in the lymph tissue.

My own feelings there are, this case represents plutonium from fallout. It is relatively small particles, and the quantity is small so you do not have a physical entrapment, for example, in a lymph node, because of radiation dose considerations.

You have transit through the lymph tissue. These are reflections on the kind and size of plutonium during fallout.

Dr. Radford: I think it was brought out yesterday that the fallout distribution of both isotopes and particle size may be quite different from the kind of thing you have observed occupationally or in the environment around a nuclear facility.

That is correct, isn't it?

Dr. Richmond: Yes. I think basically one would expect these to be different, but I think you have to actually have a set of data to compare one to the other.

Dr. Radford: I would like to ask the question, when you do these lung measurements, how do you actually measure the plutonium in the lung that you report on these tables, lung tissue. How is it actually done?

Dr. Richmond: You are referring to the analytical procedure?

Dr. Radford: I do not care about the radionanalytical part. I mean you have a cadaver lying there. What happens? How do you sample?

Dr. Richmond: The samples are taken by pathologists who are involved in these studies in a cooperative basis. They are sent to the laboratory involved.

Dr. Radford: OK. What does the pathologist give you?

Dr. Richmond: The samples that are asked for.

Dr. Radford: What you ask for?

Dr. Richmond: Lung, lymph nodes, bone. The ones that were indicated. There are established procedures in terms of quantities requested; if possible, entire half lung, or one lung.

Dr. Radford: Do you get whole lungs?

Dr. Richmond: In some cases, yes.

Dr. Radford: When you get a whole lung, you put it in a blender and measure the whole lung?

Dr. Richmond: The samples are processed by both wet and dry procedures, put in ovens and reduced. Ultimately, one does a chemical separation and then does spectroscopy, identifying the alpha emitters, following electrodeposition, by measurement of the actual energy of the alphas involved, 238, 239 or whatever.

Dr. Radford: Would it be fair to say most of the lung samples you

mentioned up to now have been pices of lung obtained by the pathologists rather than whole lungs?

Dr. Richmond: It is very difficult. I think what one would have to do is sit down and look at the data base.

For example, many of the individual autopsies that date back into the 1940's, say, in Hanford and Los Alamos, were done in small communities with local people. It was not uncommon to be able to obtain entire lungs.

I think more recent in history, it is progessively difficult to get entire organs.

Dr. Radford: Those measurements, to summarize then, are basically lung paretum measurements?

Dr. Richmond: I think again -- I hate to make broad statements. I think one would have to go back and look at the actual information. There are very detailed studies looking at, for example, the periphory of the lung just under the outer covering, looking at different portions of the lung.

So it depends. In addition to looking at the entire amount within an organ, there have been other attempts to see if the concentrations vary.

I think in most cases, the primary piece of information one gets is the total amount of plutonium in the tissue sample that is submitted.

Dr. Radford: I have a lot of other questions, both for you and for Dr. Bair, but I would like to ask just one final question so we can move on to the next questioner.

Did I read your statement correctly, that in the one case of hematoma

that occurred in an early exposed group, that the total burden as measured was largely the lymph nodes and it was eight nanocuries?

Is that a correct statement?

Dr. Richmond: I believe that is correct. It is estimated to be eight nanocuries, roughly, evenly distributed between the lung and lymph tissue.

Dr. Radford: So in that one istance, a rather rare tumor, which may be of low malignancy, but nevertheless would be life threatening if it were not operated on, was obtained with the body burden well below the current value of 40 in lung tissue?

Dr. Richmond: Would you repeat the question, please?

Dr. Radford: The question is, there is one tumor of the thorax which has been observed in this group of 21 that have been followed. That tumor arose, a rare tumor, unusal; you would not expect to find it in 21 people or even maybe 21,000.

Yet, that occurred in a person with eight nanocuries body burden, most of which is in lung tissue.

Dr. Richmond: I think what I would like for you to do is to refer to Appendix I in the Health Physics paper which we wrote on this, which is Volume 25, 1973.

There is an appendix referring to the medical follow up on patient #2. I do not presume to be a physician. I think it would be unfair for me to try to answer that kind of question.

Dr. Radford: OK. I would like to indicate that I would like to ask many more questions, since these are very important presentations.

Dr. Mills: Dr. Garner?

Dr. Garner: I would like just to refer back to the dialogue between Dr. Radford and Dr. Richmond.

There are two models: One is an excretion model used for predicting body burdens from urinary excretions data. The other model he was referring to was a model based on the ICRP model, two entirely different things.

I would like to come back to Dr. Thompson, who seems to extrapolate from animal data. Once you choose to extrapolate from animal data, you open up an enormous can of worms.

I would like to ask a couple of questions bearing on this.

One is, all the data so far, at least the data you referred to, was obtained on a homogeneous group of healthy animals, I would presume. I would like to ask if any data exists on modification and response; for example, intercurrent bacterial infection?

Dr. Bair: To my knowledge, no plutonium experiments are in progress with animals that have been subjected to bacterial infection.

There is an experiment in progress where animals are being exposed to plutonium plus benzo(a)pyrene. Also, an experiment with asbestos plus plutonium has been done.

Dr. Garner: Isn't there some work of the Lovelace Foundation on this problem?

Dr. Bair: I believe it is a pulmonary clearance.

Dr. Garner: I thought it had something to do with mataplastic and neoplastic tissue.

Dr. Bair: It may be, but I am not aware of it.

Dr. Liverman: We do have a man here from Lovelace.

Dr. Hobbs: I am Chuck Hobbs of the Lovelace Foundation. We do have some work which has not been published on the combined effects of plutonium inhalation and influenza infection, both in mice and in hamsters.

It is in the earlier stages.

Dr. Garner: So something is going on anyway. That is what I wanted to establish.

The second thing is, I would like to ask Bill Bair if, in fact, the spectrum of tumors that was seen in animals produced by plutonium and other transuranium elements can be expected in humans?

Isn't there a difference in the type of tumors? Isn't this a big problem, the extrapolation from animals to man?

Dr. Bair: The question of extrapolating from animal experiments to man is important. In animals which have inhaled plutonium the site of origin of the tumors appears to be primarily in the lung periphery. I would expect the same thing in man.

In the event of a human exposure, I would expect the plutonium to be deposited and accumulated in essentially the same areas of the lung that accumulate plutonium in experimental animals.

Consequently, if a tumor develops, I would expect it to originate in the lung periphery.

In experiments being performed in laboratories in the United States and France, the types of tumors observed are similar to the types of tumors that occur in man.

In France, they are seeing an equal number of squamous cell carcinomas and bronchiola alveolar carcinomas in rats after inhalation of plutonium and other transuranics.

One difficulty in extrapolating to man from experimental animals is man himself. As you have already brought out, man is exposed to many toxic agents. Smoking, certainly contributes to the pathology of the human lung and we do not know how this might influence the response to inhaled plutonium. The fact that pathologists often disagree in classifying tumors and identifying the origin of tumors in human lung creates a further problem.

In summary, I believe the origin of tumors and the types of tumors which occur after inhalation of plutonium are reasonably well identified in experimental animals. I would expect a similar response in human beings, unless complications were brought about by the exposure of human beings to other agents.

Dr. Garner: Just one final comment, for Dr. Thompson. I appreciated his presentation very much, but I thought he started off on the wrong foot because he skipped the real big problem.

He mentioned unacceptable risk because the problem is what is an acceptable risk.

Dr. Mills: Dr. Morgan?

Dr. Morgan: I would like to ask Bill Bair how he would interpret today the early experiments of Finkle et al where small amounts of plutonium, as small as one microgram of plutonium 239, were injected in the animals and got about a 40 percent to 50 percent incidence of tumors.

Yet, the tissue involved, the tissue at risk is essentially the same type of tissue that is involved in parts of the lung.

Have you any interpretation of the reason that we have these differences?

Dr. Bair: No. I am not prepared to answer that question. I would have to look at the experimental data.

Dr. Morgan: There are several other data that suggests that wounds are particularly vulnerable at the site, and yet as I say, it is some of the same type of tissue that behaves differently, apparently, in the lung.

First of all, I should commend each of you for the very fine and scholarly presentations that you have made.

Dr. Burr, you mentioned the fact that common forms of cancer that will undoubtedly occur in former employees in the National Laboratory's production facilities and so on, that these should not be taken as evidence that they resulted from the exposures to plutonium.

Perhaps you did not intend to underline the words "common forms of cancer," but my question is, what types of cancer are you thinking about that we should focus on?

Certainly, you would be concerned about increased instances of these common forms, but did you mean to imply that there are other types we should be looking for?

Dr. Burr: Your interpretation is right: I should not have put the emphasis on "common." In other words, what I was trying to point out is the fact that if one sees cancer; that does not show a causal relationship because in a population like this, one anticipates that there will be

cancers and cancer deaths.

What I was trying to emphasize is that we are going to be taxed to considerable extent with the sizes of population to try to decide if there is indeed an increase in the number of incidents.

You are quite right. That is what we are looking for, an increase in incidents of any tumors as an indication of the effect.

There was one other point I wanted to make that Dr. Richmond made earlier - but it slipped my mind now - in one of his earlier answers, which I thought in part answered that.

Dr. Morgan: Dr. Richmond, you recall some of the earlier exposure data on humans where presumably we have good information on the quantities that were administered to these humans and yet give data on the total body content.

Is their information on the distribution of the body organs -- It seems to me that to know the distribution in the human body from a known intake, and of course, we would like a known intake primarily from insoluble plutonium oxide forms, what would the distribution be in the lung, the liver, the bone and osteotissue of the bone, as a function of time and age of the individual, having taken in the known burden of plutonium oxide by inhalation?

It seems to me maybe this is the $64 question, because you may have some evidence that turns the heat off the hot particle problem, at least in my eyes it does, or at least may shelve that problem until we get more information.

But I do not think we have any cause to relax our concern for the

Certainly, it is evidence, I believe, that it is not the lymph nodes that presumably receive the largest dose, so the tissue of highest dose is not the accurate or necessarily sufficient criterion of the critical organ.

Dr. Richmond: Let me say I agree very wholeheartedly with your last comment. The particular case that Dr. Radford was referring to earlier is pointed out in the appendix to our 1973 paper in Health Physics. It is of interest and is consistent with much information obtained from other experimental data.

We sometimes see changes, high concentrations or relatively high concentrations and yet, essentially, no biological effects relative to effects you see in the lung, for example.

Dr. Morgan: Dr. Thompson, you referred to the BEIR Report and the extrapolation from external exposure primarily. The, going to the use of the alpha emitters, the use of the RBE and the end factor of the non-uniform distribution.

But it seems to me that there are a number of other factors that he might have focussed on. One that was brought out in the meeting at Alta, Utah this past summer and was emphasized is the fact that with human exposure to radium 224, which like plutonium 239 deposits on the surface tissue of the tibecular bone, because it does not have time, having a short half-life, to be buried as does radium 226, so this radium 224 deposits, then, on the surface and behaves very much than like plutonium 239.

This is human data. It was emphasized at this meeting that protraction of the dose enhances the hazard rather than diminishes the

hazard, as is the case with external exposure.

Of course, this might be something that would be great concern or great interest, let us say, for chronic long time exposure to humans because that certainly is protracted exposure.

Would you care to comment on this?

Dr. Thompson: I think that is a very significant observation and one which certainly is applicable to this problem.

One can speculate that this observation might be explained in terms of a more uniform distribution of the dose. Just as is seen in other experiments on a spatial basis, here we have a more uniform distribution on a time basis and we are exposing more cells by fractionating the dose in time.

I did not mention the radium 224 data specifically, although it was included on the one viewgraph. But this is an important source of information on human effects which, though it is not plutonium data as Dr. Morgan has explained, its distribition in bone is perhaps very similar to plutonium because of its short half-life.

Dr. Morgan: Also, you had a graph that gave, I believe, the effects axis of the dose -- you indicated it was more likely to be asymptotic to the dose axis than to the effects axis.

This would seem to be contrary to the paper given by Dr. Bonn at the annual meeting of the Health Physics Society in Houston this year in which he plotted his data on bi-rythmic curve, and it's the best fit of the data for alpha emitters in humans.

For the function, say, of effect E equal to some constant times dose to the nth power, the best fit was to take n equal to one half rather than one, or something greater.

This would mean it would likely become asymptotic to the effects axis rather than the dose axis.

Do you have any comment on this, or any criticism you would like to make of Dr. Bonn's report?

Dr. Thompson: I did not hear the report and I have not got a clear picture of it. From this brief discussion, I would say, in the first place, my figure was not semi-logarithmic. It was meant to be linear. I do not know how that would affect your question.

It does seem to me, though, on almost intuitive grounds, that when you get down into the range of background exposure, you can not have a steeply rising curve relating effect to dose.

Otherwise, there would be such a tremendous advantage to living in a low background area that our higher elevation areas would be unpopulated.

Dr. Morgan: We could discuss this later.

One final question, to the panel. I do not address it to anyone in particular, but following up on Dr. Taylor's question, it may be as I said before, we cannot resolve to our liking the question of the hot particle problem.

It has been with us, or at least with me, for over 30 years. It is recognized for that long. But the question of the incidents of tumor in bone, if we look at that and take the excellent data at Utah it would

seem to me that the end factor could be increased somewhere between, somewhere in the neighborhood of 10 to 15.

So we might have justification of increasing the end factor of the present guideline. We now use for Q the body burden based on bone by a factor of three.

Dr. Thompson and Dr. Bair pointed out, I believe it was in the paper in Science in February of the past year or this year, that the surface to volume ratio where you have the deposition on the skeleton of the actinide elements is roughly twice that in a dog to that in a human.

So that would have a factor two. Then, Bill, both you and Roy pointed out that the burial effectiveness of the actinides, presumably ten times greater in a dog than it is for man.

The rate of burial, so there we have a factor of ten.

Then there is the French paper which shows that in the case of primates such as the baboon, that they are four times more radiosensitive in terms of survival following exposure to plutonium oxide than is man.

That would be a factor of four.

So it would seem to me, if you would multiply all of these together, you end up with something of a hundred or more rather than your factor of ten.

It seems to me, then, setting the exposure value based on bone's critical tissue, that maybe our present value should be lower by a factor of 100.

I believe you said maybe by a factor of ten.

Dr. Bair: I might comment about the appropriateness of multiplying factors and identify at least one that perhaps should not be multiplied by the factors for bone that you mention.

That is, the factor you mentioned with regard to the baboon studies in France. I believe the life shortening in these baboons was due to plutonium dioxide in lungs and not to radiation exposure of bone.

I am not sure you would want to multiply a factor obtained for lung by other factors that pertain to bone, without at least some modification to reflect the distribution of plutonium between these two tissues.

Dr. Thompson: I think Dr. Morgan and I agree that there is some reason to perhaps lower the standard. Whether it is by a factor of ten or a hundred, I do not think this is probably the place to try to settle that issue.

I do think that there is a question about the multiplicability of all these various factors.

Dr. Richmond: I would like to add to that, if I may. I think it is important to realize that these are studies that are underway.

We are now trying to find out more about the relative deposition, bone surface to volume ratio in dog, man and other animals, and make refinements.

I guess my personal feelings are I think we had better get more

of this information and try to understand it a little better before we do calculations and get too carried away with them.

To me, that is a very important thing. We are recognizing some of these factors, but they have not been quantitated yet. Personnally, I think a lot needs to be learned yet.

Dr. Mills: Dr. Radford has one more question.

Dr. Radford: I would like to ask this of the whole panel because it is germane to some of the discussion we have been having on the effects of dose.

I think you gentlemen are all familiar with the ICRP publication on the relative biological effectiveness concept and the conclusions that the ICRP committee drew on that.

It is presented in the form of a graph which shows, for example, that if you plot the effect as a function of dose for low radiation, the power may be greater than one which is consistent with an exponent of less than one, meaning that the curve effect is a curve linear downward to the axis.

The point I want to ask, do you not infer from this, as indeed the ICRP committee inferred from this, that the relative effectiveness of high L.E.T. radiation is greater at lower doses than at higher doses?

Dr. Thompson: I will tackle at least one aspect of that question.

The question in my mind is when does this curve -- if there is an enhanced effect of dose -- when does that curve come down? It curves

down some time before it gets to zero. It's got to reach zero at zero dose.

I do not think there is any evidence I am aware of to indicate where in this area that curve comes down.

My feeling is it comes down before you get to the background region -- it does not just come down asymptotic to the effect axis. But we do not have experimental data in this area. I revert to my basic conviction that the important point here is not dose, but the effects, as seen in experimental animals.

Dr. Radford: As you know, in the uranium miners, there have been considerable discussions on just this point. I heard some data presented at the Seattle meeting this year, showing that more recent uranium mine data does support the concept of the relative effectiveness per rad dose does go up at the lower dose.

This has been the orthodoxy.

Dr. Thompson: But these lower doses are still far higher than natural background.

Dr. Radford: Sure, I am not talking anything about natural background.

Dr. Thompson: This (natural background) is the area of concern as far as general populations are concerned.

Dr. Radford: But the point is that a group of people from the ICRP who are very knowledgeable about the whole theoretical and experimental basis did conclude that one would expect the R. B. E. would

increase at lower doses; that is, low L.E.T. radiation becomes less effective in low doses where high L.E.T. radiation would stay about the same.

I am not saying it is getting more so.

Dr. Mills: I hate to cut this discussion off, but I would like to add to the panel opinion here, that the material you have submitted is well documented.

Thank you very much.

SUPPLEMENTAL ADDITIONS TO THE AEC TESTIMONY

UNITED STATES
ATOMIC ENERGY COMMISSION
WASHINGTON, D.C. 20545

AUG 16 1974

Clarence C. Lushbaugh, M.D.
109 Darwin Lane
Oak Ridge, Tennessee 37830

Dear Dr. Lushbaugh:

The Atomic Energy Commission has received from the Natural Resources Defense Council a petition to establish special standards for alpha-emitting radionuclides in insoluble, particulate form. A copy of this petition, and a supporting statement submitted with the petition, are enclosed. On pages 26 through 29 of the supporting statement a quotation from an article by C. C. Lushbaugh and J. Langham, published in the Archives of Dermatology in 1962, is used as the basis for the following conclusions:

(1) A single Pu-239 particle is capable of inducing cancer;
(2) The risk of cancer may be greater than 1/1000 per particle.

The Commission's standards for exposure to insoluble, airborne plutonium and other alpha-emitters are based on a permissible lung burden of 16 nCi, which could consist of many thousands of particles deposited in the lung, the actual number depending upon the size of the particle. For example, 16 nCi is equivalent to 2×10^6 particles of 0.3-micron diameter. The risk associated with such a large number of particles would obviously be unacceptable if the risk per particle is as great as concluded in the supporting statement.

The Commission is currently conducting an evaluation of its standards for airborne, alpha-emitting radionuclides in insoluble form, and great importance is attached to the risk which may be associated with relatively small numbers of alpha-emitting particles in the lung. In this connection we would appreciate receiving from you a statement as to whether your findings in the case reported in the Archives of Dermatology do in fact support the two conclusions drawn in the supporting statement, as listed above.

Sincerely yours,

Lester Rogers
Director of Regulatory Standards

September 10, 1974

Mr. Lester Rogers
Director of Regulatory
Standards
U.S. Atomic Energy Commission
Washington, D.C. 20545

Dear Mr. Rogers:

In reference to your letter of August 16, 1974, I should point out that earlier this year I worked with Dr. Bruce Wachholz of Bio-medical Programs, DBER, Germantown Headquarters, on the initial stages of a document recently numbered WASH-1320; entitled, *A Radiobiological Assessment of the Spatial Distribution of Radiation Dose from Inhaled Plutonium Particles;* and authored by W. Bair, C. Richmond, and B. Wachholz. Although I have not seen this paper in its final form as it is at this moment still being printed, I am certain that it contains an attempt to answer the question of whether or not Mrs. Langham's and my article in Archives of Dermatology (1962) supports the contention of Dr. Tamplin and Mr. Cochran that a single particle of Pu-239 is capable of inducing cancer and that the risk of cancer from such a particle is 1 per 1000. We believe that these conclusions cannot be derived from the histopathologic observations we reported in this case report nor in the other cases we subsequently published along with it in the Annals of the New York Academy of Science.

In the petition from the Natural Resources Defense Council to which you refer, one can see that the authors apparently do not know the difference between a precancerous cellular change and a cancer. While it is true that the term "precancerous change" contains the implication that a cancer follows it, this is not always the case because precancerous changes are reversible and reparable. In fact when a lesion showing precancerous changes is removed surgically, the surgeon knows from this diagnostic impression given him by the pathologist that the lesion he removed is not a cancer and that he does not have to worry about it further. My object in using

the term "precancerous" to describe the cytologic appearance of some of the epithelial cell nuclei around the plutonium particles in the skin of the case in Arch. Dermatol. was to point out that in spite of the amazingly huge dose of alpha radiation over a period longer than 4 years a cancer had not developed and that one could at most only call the changes pre-cancerous. In reviewing this case in the Annals of the New York Academy article, we attempted to show that the strictly localized injury caused by the plutonium particles was developing in such a fashion (like a pimple) that the particles would have been shed in time along with a small amount of pus-like material as the pimple "ripened" and drained spontaneously. Dr. Tamplin in his arguments assumes that fibrosarcomas in rat skin are equateable with the minimal changes we described in the skin of this man. Of course, they are not. The statement that it is "clear" on the basis of this one human case that plutonium can cause skin cancer in man is false. If this case and others like it show something of radiobiologic importance, they show only that the development of cancer from plutonium exposures of human tissues must be much more difficult to obtain than cancers in rodent tissues, since no human cancers have ever been seen or reported following plutonium exposure of human beings. Logically, if there is no observed plutonium-induced human cancer case, the one per thousand per particle level of cancer risk for plutonium exposure has no basis in fact and amounts to only a conjecture on the part of the authors of the NRDC petition.

C. C. Lushbaugh, M.D., Ph.D

A Critique of the Tamplin-Cochran Proposal for Revision of the Current Plutonium Exposure Standards

Roy E. Albert, M.D.
Professor and Vice Chairman
Institute of Environmental Medicine
New York University Medical Center

March 25, 1974

Summary

Largely on the basis of rat skin tumor experiments, Tamplin and Cochran propose that a single radioactive particle in the lung which delivers a local dose of more than 1000 rem per year will produce focal tissue damage and that this focal damage per se confers a risk of lung cancer of one in two thousand.

A review of current knowledge about the relationship of tissue damage to the induction of cancer does not support the contention that tissue damage is a proximate cause of cancer; rather that tissue damage represents a parallel toxic action of carcinogens which, to some extent, may enhance the development of tumors produced by carcinogens. Since the Tamplin-Cochran proposal is based almost wholly on radiation tumor studies of the rat skin hair follicles, the decisive argument against this proposal is the evidence that focal alpha irradiation of localized regions on the hair follicle, in a pattern similar to that from a plutonium particle, is non-tumorigenic.

The Tamplin-Cochran Proposal (1)

The authors point out that the current ICRP occupational exposure standard for insoluble plutonium in the air is

4×10^{-11} uCi/ml. This is the calculated level of atmospheric contamination that would lead to a maximum permissible lung burden (MPLB) of 0.016 uCi and would be associated with a maximum permissible lung dose of 15 rem/yr when the radiation dose is averaged over the entire lung.

They point out that the dose is not delivered uniformly to the entire lung:

"It would take 53,000 particles...(1 u in diameter, 0.28 pCi)...to reach the MPLB of 0.016 uCi which results in 15 rem/yr to the entire (1000 g) lung. However...these particles would irradiate only 3.4 g of this 1000 g to the lung, but at a dose rate of 4000 rem/yr...these particles result in an intense but highly localized irradiation. A fundamental question is, then: is this intense but localized irradiation more or less carcinogenic than uniform irradition?" (ref. 1, pg. 17).

The Tamplin-Cochran approach to the risk assessment from hot particles is based on the Geesaman Hypothesis (2, 3) which in turn is based almost wholly on the radiation skin experiments of Albert and co-workers. The interpretation placed on these experiments by Tamplin and Cochran and the rationale for their proposed standard is described by the following excerpts from their report (1).

"A high incidence of cancer was observed after intense local doses of radiation, and the carcinogenesis was proportional to the damage or disordering of a critical architectural unit of the tissue, the hair follicles." (ref. 1, pg. 23).

"Certainly a reasonable interpretation of these experimental results is: when a critical architectural unit of a tissue (e.g., a hair follicle) is irradiated at a sufficiently high dosage, the chance of it becoming cancerous is approximately

10^{-3} to 10^{-4}. This has become known as the Geesaman hypothesis." (ref. 1, pg. 26).

"Geesaman indicates that the tissue repair time in the lung is of the order of one year. It therefore seems appropriate, but not necessarily conservative, to accept as guidance that this enhanced cancer risk occurs when particles irradiate the surrounding lung tissue at a dose rate of 1000 rem/yr or more." (ref. 1, pg. 33).

"As seen from Table IV, using Geesaman's lung model, a particle with an alpha activity between 0.02 pCi and 0.14 pCi is required to give a dose of 1000 rem/yr to irradiated lung tissue. For purposes of establishing a maximum permissible lung particle burden we will use 0.07 pCi from long half-lived (greater than one year) isotopes as the limiting alpha activity to qualify as a hot particle." (ref. 1, pg. 34).

"The existing standards for uniform radiation exposure of the whole body or lung can be used as the basis for establishing particle exposure standards by equating the risk of cancer induction between the two types of exposure (uniform vs. grossly non-uniform). The most recent assessment of the risk associated with uniform irradiation of man was performed by the NAS-NRC Advisory Committee on the Biological Effects of Radiation. Their report, published in 1972, is referred to as the BEIR Report.

The existing occupational exposure standard for uniform whole body irradiation is 5 rem/yr and for the lung, 15 rem/yr. The BEIR Report estimates that exposure of the whole body of an individual to 5 rem/yr would lead to a cancer risk between 4.5×10^{-4} and 2.3×10^{-3}/yr. Their best estimate is 10^{-3}/yr." (ref. 1, pgs. 41-42).

"It is recommended here that the best estimate of the effects of uniform exposure by the BEIR Committee be used together with a risk of cancer induction of 1/2000 per hot particle in determining the MPLPB for insoluble alpha-emitting radionuclides in hot particles. This is a somewhat arbitrary compromise and is not the most conservative value that could be recommended. Thus, the recommended MPLPB for occupational exposure from hot particles of alpha-emitting radionuclides in the deep respiratory zone is 2 particles. This corresponds to a MPLB of 0.14 pCi and represents a reduction of 115,000 in the existing MPLB." (ref. 1, pgs. 43-44).

Differences Between the Tamplin-Cochran Proposal and the Geesaman Hypothesis

Whether intentional or not there is a subtle but important difference between Geesaman's hypothesis and the Tamplin-Cochran proposal. The pertinent portion of Geesaman's conclusion is the following:

"Tissue injury and disturbance are a primary consequence of intense radiation insult, and are observed in association with carcinogenesis. Albert has exhibited a simple proportionality between skin carcinomas and atrophied hair follicles. No general description of precarcinogenic injury exists, but in a crude sense the available observations are compatible with the idea of an injury-mediated carcinogenesis. Cancer is a frequent instability of tissue. Since tissue is more than an aggregate of cells, and has a structural and functional unity of its own, it would not be surprising if some disrupted local integrity, a disturbed ordering, comprises a primary pathway of carcinogenesis. The induction of sarcomas with inert discs of Mylar, cellophane, Teflon and Millipore (Brues et al.) is indicative that such a mechanism exists." (ref. 3, pgs. 6-7).

Geesaman is saying that "...some disrupted local integrity, a disturbed ordering, comprises a primary pathway of carcinogenesis." This means that it is not the radiation but rather the tissue damage which is the proximate cause of cancer.

Tamplin and Cochran blur the issue by saying: "Certainly a reasonable interpretation of these experimental results is: when a critical architectural unit of a tissue (e.g., a hair follicle) is irradiated at a sufficiently high dosage, the chance of it becoming cancerous is approximately 10^{-3} to 10^{-4}. This has become known as the Geesaman hypothesis." Taken literally, Tamplin and Cochran do not require that tissue damage be produced, only that the "...critical architectural unit is irradiated at a sufficiently high dosage..."

The Tamplin-Cochran proposal is evaluated here from two standpoints: (1) the Geesaman hypothesis, i.e., does tissue

damage, per se cause cancer? (2) The Tamplin-Cochran interpretation of the Geesaman hypothesis, i.e., would intense irradiation of a "critical architectural unit" cause tumors, regardless of whether damage was produced?

The Theory that Tissue Damage Causes Cancer

The Geesaman hypothesis, on which the Tamplin-Cochran proposal is based, revives one of the oldest theories of cancer, namely that the cause of cancer is chronic tissue damage. This is the chronic irritation theory propounded by Virchow in 1863. As reviewed by Oberling (4), the theory was in vogue for about 50 years. It stemmed from the early clinical observations that cancer rarely appears in healthy tissue and is almost always preceded by chronic inflammatory conditions such as scars, ulcerations or fistulas. Post-mortem observations in this era suggested that the same association applies to internal organs.

Virchow pointed out that every injury of tissues is followed by a state of irritation in which the cells are stimulated to multiply in order that the damage may be repaired. If the noxious influence persists, the irritation persists with it and the proliferation grows more and more excessive and irregular. Virchow argued that if such a condition persists year after year, cancer will occur.

The Virchow theory claimed that chronic irritation was the

sole and non-specific cause of cancer, i.e., cancer was the secondary outcome of a whole series of conditions widely differing from one another and possessing no features in common except chronic damage.

As pointed out in a review by Berenblum (5), Virchow's theory was demolished by experiments beginning in 1918 which showed that cancer can be produced by very potent substances that vary widely in their capacity to cause damage whereas many agents which cause damage do not cause cancer. Furthermore, there are many conditions in humans in which tissue disorganization and damage is a characteristic feature where no association with cancer has been demonstrated, e.g., tuberculosis and silicosis of the lung and traumatic injuries associated with war wounds that have occurred by the millions during this century. The focus of cancer research long ago shifted away from tissue damage as a cause of cancer. Nevertheless, the frequent association between tissue damage and cancer remains valid for many types of human and experimental cancer but there are other types of cancer where no association exists.

The most probable reason for the association is that virtually all carcinogens are highly toxic agents. The only outstanding exceptions are the oncogenic RNA viruses. There are many examples to show that an appreciable yield of tumors

can be produced only at carcinogen doses which cause a large amount of cell death in the target tissue. This can be seen for example in relating the doses of radiation required to produce tumors in mouse skin (6) to those which cause cell death (7). The action of chemical carcinogens and ionizing radiation in producing the parallel effects of cell death and neoplastic cell transformation is also evident in tissue culture studies (8, 9).

There are various forms of damage produced by carcinogens which depends mainly on the target tissue. For example, application of a chemical carcinogen or ionizing radiation to the surface epidermis of the skin or the bronchial mucosa results in cell loss followed by a hyperplastic response in which the number of epithelial cells is much increased for long period of time. In the bronchial epithelium the hyperplasia is also accompanied by squamous metaplasia of mucosal cells. Another form of tissue damage can be produced by inhaled radioactive particles which deposit in the alveoli; such particles can produce fibrotic damage. Atrophy is still another form of tissue damage as illustrated by the damage to the hair follicles in the irradiated rat skin.

Although tissue damage cannot be assigned a primary causal role in cancer induction, there are various ways in which tissue

damage could contribute to tumor formation. One possibility is that the killing of a portion of cells in the target tissue has the consequence of stimulating the survivors to proliferate in order to restore the cell population. There is evidence that neoplastic transformation does not become fixed unless cell division occurs within a relatively short period after carcinogen exposure. This is true for ionizing radiation (10) and viruses (11). The likelihood of producing transformed cells could thus be increased by provoking cell division particularly in a tissue which normally has a low rate of proliferation.

There is evidence that neoplastically transformed cells in physical contact with normal non-transformed cells are inhibited from proliferating (12). Tissue injury could free transformed cells from this type of growth restraint.

It is possible that an area of tissue, heavily damaged by a carcinogen, particularly with scar formation, would constitute an immunologically privileged site and thus interfere with important defense mechanism against neoplastically transformed cells (13).

There are several other speculative ways in which damage could contribute to tumor formation which can be mentioned: cell damage might interfere with repair of carcinogen-induced DNA damage; dedifferentiation of surviving cells in a heavily damaged organ

could make them more susceptible to infection by oncogenic viruses, as with the irradiated thymus (14); in the case of chronic carcinogen exposure the increased cell proliferation induced by tissue damage could make cells more susceptible to the transforming action of a carcinogen.

Although all of the above mechanisms for the enhancement of carcinogen effects by various forms of tissue damage have some basis in scientific evidence, the degree of importance as contributing factors has not been established.

The Effect of a "Hot Particle" Type of Irradiation Tumor Induction in the Rat Skin

The Tamplin-Cochran proposal uses mainly the results obtained by the Albert-Burns radiation skin experiments to infer alpha-particle risks in the lung. Hence, the critical test of their hypothesis is the question of whether a hot particle pattern of alpha irradiation of the skin could produce tumors.

Two approaches were used in skin experiments. The first approach determined whether isolated areas of irradiated skin gave the same yield of tumors per unit area as large-area skin irradiations. The focal irradiation pattern was produced by use of sieve plates. Low LET radiation, such as electrons (15) and soft X-rays (16) showed pronounced suppression of tumor

formation with sieve irradiation. A higher LET radiation (protons) did not show a protective effect of sieve radiation (17).

The second approach involved the use of irradiations at different depths in skin. The results of electron irradiations with different penetrations on the induction of tumors and atrophic follicles suggests the existence of target cells at a depth of about 0.3 um in the skin corresponding to the lower end of the resting hair follicle (18). This critical depth remains constant even when the skin is irradiated with the hair in the growing phase, i.e., when the follicles extend to a depth of 0.8 mm (19). There is a quantitative association between the incidence of tumors and atrophic follicle for various types of ionizing radiation, various spatial distributions of dose within the skin and for different phases of hair growth (20). In our view, a plausible explanation for the experimental results is that each follicle has a population of stem cells at a depth of 0.3 mm that are concerned with the production of sebaceous cells and hair. These stem cells constitute the most sensitive tumorigenic cell population to ionizing radiation in the rat skin. The tumors are mainly of hair follicle origin (21). Neoplastic transformation of a significant number of these target cells requires large radiation doses which in turn kills most of the

target cells and thus causes follicle atrophy.

Since the radiation from alphas has a range of only about 45 microns from a plutonium particle, the effect of focal irradiation at different levels of the hair follicle is a crucial test of the Tamplin-Cochran proposal. Alpha and proton irradiations that extend from the skin surface to a depth of about 0.15 mm do not produce tumors (22). This result, however, is consistent with the existence of a target cell population at a depth of about 0.3 mm. However, selective irradiation of the lower end of the hair follicle at a depth of 0.3 mm by use of the Bragg peak from an alpha beam did not produce tumors or atrophic follicles unless there was substantial irradiation of the entire follicle (22). This observation suggests that even though the critical cell population is located at 0.3 mm, that there are recovery mechanisms that block tumorigenesis when only part of the "critical architectural unit of tissue" is irradiated. What these recovery processes might be is not understood. Nevertheless, this result does not support the contention that a single plutonium particle positioned next to a "critical architectural unit" such as the hair follicle, will produce a tumorigenic risk of the magnitude assumed by Tamplin and Cochran.

It might be argued that since particles can move about in

the lung, it is appropriate to consider the effects of a single plutonium particle in the skin which moves up and down and irradiates the entire follicle. However, under these circumstances it should be necessary to consider the important factor of temporal recovery from the tumorigenic action of ionizing radiation which has been shown by split dose experiments to be very large for low LET radiation (23); preliminary data from an ongoing split dose experiment suggests that recovery from proton radiation is also very substantial (24). Data applicable to estimation of the recovery rates from exposure to a moving radioactive particle are not available. Geesaman's estimate of a one year recovery time for radiation effects on the lung is mere speculation.

References

1. Tamplin, A. R. and T. B. Cochran. Radiation Standards for Hot Particles. A Report on the Inadequacy of Existing Radiation Protection Standards Related to Internal Exposure of Man to Insoluble Particles of Plutonium and Other Alpha-Emitting Hot Particles. Natural Resources Defense Council, Washington, D.C., 1974.

2. Geesaman, D. P. An Analysis of the Carcinogenic Risk from an Insoluble Alpha-Emitting Aerosol Deposited in Deep Respiratory Tissue. Lawrence Radiation Laboratory, University of California, Livermore, TID-4500, UC-48, Feb. 1968.

3. Geesaman, D. P. An Analysis of Carcinogenic Risk from an Insoluble Alpha-Emitting Aerosol Deposited in Deep Respiratory Tissue: Addendum. Lawrence Radiation Laboratory, University of California, Livermore, TID-4500, UC-48, Oct. 1968.

4. Oberling, C. Riddle of Cancer, Yale University Press, New Haven, 1952.

5. Berenblum, I. Irritation and Carcinogenesis. Arch. Path. 38:233-244, (1944).

6. Albert, R. E., F. J. Burns and P. Bennett. Radiation-Induced Hair-Follicle Damage and Tumor Formation in Mouse and Rat Skin. J. Natl. Cancer Inst. 49:1131-1137, (1972).

7. Withers, H. R. The Dose-survival Relationship for Irradiation of Epithelial Cells of Mouse Skin. Brit. J. Radiol. 40:187-194, (1967).

8. DiPaolo, J. A., K. Takano and N. C. Popescu. Quantitation of Chemically Induced Neoplastic Transformation of BALB/3T3 Cloned Cell Lines. Cancer Res. 32:2686-2695, (1972).

9. Borek, C. In Vitro Cell Transformation by X-Rays. Radiat. Res., (1973). (Abst.)

10. Sachs, L. An Analysis of the Mechanism of Carcinogenesis by Polyoma Virus, Hydrocarbons, and X-Irradiation. In: Moleculare Biologie des Maligner Wachstums, Springer Verlag. New York, 1965.

11. Todaro, G. J. and H. Green. Cell Growth and the Initiation of Transformation by SV40. Proc. Natl. Acad. Sci., U.S. 55:302-308, (1966).

12. Sivak, A. and B. L. Van Duuren. A Cell Culture System for the Assessment of Tumor-Promoting Activity. J. Natl. Cancer Inst. 44:1091-1097, (1970).

13. Bates, R. R. and R. T. Prehn. Role of the Fibrous Capsule in Carcinogenesis by Plastic Film. Nature 205:303-304, (1965).

14. Kaplan, H. S. On the Etiology and Pathogenesis of the Leukemias: A Review. Cancer Res. 14:535-548, (1954).

15. Albert, R. E., F. J. Burns and R. D. Heimbach. Skin Damage and Tumor Formation from Grid and Sieve Patterns of Electron and Beta Radiation in the Rat. Radiat. Res. 30:525-540, (1967).

16. Unpublished data.

17. Burns, F. J., R. E. Albert, P. Bennett and I. P. Sinclair. Tumor Incidence in Rat Skin After Proton Irradiation in a Sieve Pattern. Radiat. Res. 50:181-190, (1972).

18. Albert, R. E., F. J. Burns and R. D. Heimbach. The Effect of Penetration Depth of Electron Radiation on Skin Tumor formation in the Rat. Radiat. Res. 30:515-524, (1967).

19. Unpublished data.

20. Albert, R. E., F. J. Burns and R. D. Heimbach. The Association between Chronic Radiation Damage of the Hair Follicles and Tumor Formation in the Rat. Radiat. Res. 30:590-599, (1967).

21. Albert, R. E., M. E. Phillips, P. Bennett, F. Burns and R. Heimbach. The Morphology and Growth Characteristics of Radiation-Induced Epithelial Skin Tumors in the Rat. Cancer Res. 29:658-668, (1969).

22. Heimbach, R. D., F. J. Burns and R. E. Albert. An Evaluation by Alpha-Particle Bragg Peak Radiation of the Critical Depth in the Rat Skin for Tumor Induction. Radiat. Res. 39:332-344, (1969).

23. Burns, F. J., R. E. Albert, I. P. Sinclair and P. Bennett. The Effect of Fractionation on Tumor Induction and Hair Follicle Damage in Rat Skin. Radiat. Res. 53:235-240, (1973).

24. Unpublished data.

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657

A Radiobiological Assessment of the Spatial Distribution of Radiation Dose from Inhaled Plutonium

by W. J. Bair, C. R. Richmond,
and B. W. Wachholz

United States Atomic Energy Commission

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PREFACE

This report was prepared at the request of the Division of Biomedical and Environmental Research, U.S. Atomic Energy Commission. The authors have attempted to assemble and review the data currently available which bears upon the problem of uniform versus nonuniform dose distribution in the lung. This problem has been termed the "hot particle" question. Because the quantity of material available from laboratories and individuals in the United States and foreign countries far exceeds the space limitations of this document, the more peripheral work, as judged by the authors, was omitted. While a compendium of all information relative to the subject would be useful, the authors elected to prepare a report of less voluminous dimensions, directed specifically to a radiobiological assessment of the spacial distribution of plutonium in the lung.

The authors requested and received assistance from numerous individuals and/or laboratories throughout the country in an effort to include additional general and specific expertise in various disciplines, as well as to consider as broad a sampling of expert opinions as possible.

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It is hoped that the report will serve as an informative scientific document which will provide the reader with an overview of the applicable human, experimental and theoretical evidence to date. For additional information the reader is referred to the specific references provided.

TABLE OF CONTENTS

		Page
Summary and Conclusions		1
I.	Statement of the Problem	3
II.	Background	5
III.	Animal Studies	9
IV.	Human Experience	25
V.	Theoretical Considerations	31
VI.	Bibliography	43

SUMMARY AND CONCLUSIONS

1. Recognition of the importance of spatial distribution of dose to radiation protection practices by national and international standards setting organizations and the scientific community predates the discovery of plutonium. Continued examination of the radiobiological aspects of the spatial distribution of dose, especially as regards alpha-emitting particles, has not led to major changes in radiation protection standards. However, the problem is and should be continually reassessed.

2. Experimental animal studies clearly indicate that inhaled radioactive particles move from the lung to other organs and may be excreted from the body by several mechanisms. The experimental data also show that truly uniform distributions of inhaled radionuclides in lung seldom, if ever, occur. However, because of the mobility of plutonium within lung, there is some biological justification for averaging the radiation dose to the total tissue.

3. Although particles deposited in lung are dynamic and mobile unless trapped, i.e., in scar tissue, experiments have simulated the static plutonium particle to study the biological effects of truly "hot spots" of radioactivity in lung. These and other comparative experiments of uniform and nonuniform distributions of absorbed energy from radioactive particles suggest a biological sparing effect for both acute and late responses to the nonuniform distribution. Available experimental data indicate that averaging the absorbed alpha radiation dose from plutonium particles in lung is radiobiologically sound.

4. Dosimetric models used to predict lung tumor probability in animals and in human beings are biologically deficient, primarily because of the lack of the required biological information. Also, most models are based on studies of tumor induction in irradiated rat skin and on the assumed validity of extrapolating to lung tissue. This practice is questionable for several reasons including the fact that the results of studies with rats, i.e., tumor type, vary with rat strains and that the results of comparable studies of irradiated mouse skin have not given results identical to the rat experiments. Thus, use of these models can lead to erroneous predictions of tumor probabilities.

5. Consideration of mechanisms of radiation carcinogenesis suggests that there has been no change in direction or strength of data which would compel departure from the concept that average lung dose for alpha particles provides a reasonable and conservative base for protection.

6. After thirty years experience with plutonium in laboratory and production facilities, there is no evidence that the mean dose lung model on which occupational radiation protection standards for plutonium are based is grossly in error or leads to hazardous practices. Currently available data from occupationally exposed persons indicate that the nonhomogeneous dose distribution from inhaled plutonium does not result in demonstrably greater risk than that assumed for a uniform dose distribution. Thus, empirical considerations lead to the conclusion that the nonuniform dose distribution of plutonium particles in the lung is not more hazardous and may be less hazardous than if the plutonium were uniformly distributed and that the mean dose lung model is a radiobiologically sound basis for establishment of plutonium standards.

The nonuniform distribution of radionuclides and the attendant biological response of tissues at risk relative to the spatial distribution of the absorbed energy have been of interest for many decades to the scientific community, particularly those individuals and groups charged with the responsibility for derivation of exposure standards. Permissible limits for the respiratory intake of radioactive materials are commonly calculated on the assumption of complete absorption of the radiation energy by the critical organ. Further, it is implicitly assumed that there is a uniform distribution of the energy per gram of tissue throughout the critical organ. This particular situation raises the interesting question as to the probability of a unique hazard to the respiratory tissues for a given amount of inhaled radioactive material distributed in the form of small, discrete, radioactive particles or aggregates as compared with a more homogeneous distribution. Stated in another way: for the same amount of radioactive material, is the biological harm to the lung greater or less when the energy is concentrated into very small tissue volumes than when the energy is absorbed by the entire organ? For alpha and some other radiations, the distribution of energy will be nonuniform and consequently concentrated about the particles, thereby producing intense radiation doses to the nearby cells. For the case of nonuniform distribution of alpha-emitting materials in the lung, the initial biological interaction is that of an extremely large energy deposition in a very small tissue volume. For such situations, the use of the organ-mean dose concept for radiation protection has been seriously questioned.

At present the recommended dose limit (occupational exposure) for lung is 15 rem/year; the quantity of ^{239}Pu required to deliver this dose equivalent rate, if one uses the currently accepted method of assuming homogeneous absorption of energy throughout the entire lung, is 0.016 μCi. However, as shown in Table I, the number of cells which absorb the energy is a function of the size of the particles comprising the 0.016 μCi. As the particle size increases there are fewer particles and, therefore, fewer cells are irradiated but at progressively increasing dose rates.

The theoretical aspects of dosimetry and oncogenesis, results of animal experiments, and 30 years experience with humar beings occupationally exposed to plutonium will be examined to assess the relative hazards of nonuniform and uniform distribution of alpha radiation in lung and other tissue. This assessment will be applied to an evaluation of the currently accepted practice of averaging the radiation dose throughout the lung, or other organs as appropriate, for purposes of quantitating the biological effects of inhaled plutoninum and for establishing radiation protection standards.

Table I

RELATIONSHIP OF PARTICLE SIZE TO NUMBER OF CELLS AT RISK FOR A STATIC LUNG BURDEN OF 0.016 μCi $^{239}PuO_2$*

Particle diameter	Number of particles	Activity per particle	Cells at risk	Fraction of lung
(μm)		(pCi)		(%)
0.1	5.4×10^{7}	3×10^{-4}	3×10^{11}	30
0.3	2.0×10^{6}	0.01	1.3×10^{10}	1
0.7	1.8×10^{5}	0.08	1.2×10^{9}	0.1
1.0	5.4×10^{4}	0.3	3.6×10^{8}	0.03

* Assuming static particles in a structureless human lung of uniform density 0.2 g cm^{-3} with an average cell volume of 10^{3} μm^{3}. Cells at risk are taken to be those in a sphere of radius equal to the alpha range (200 μm at the assumed density)

II. BACKGROUND

The nonuniform distribution of radiation dose within the body and within tissues of the body has been of long standing interest to those concerned with the potential exposure of persons to radiation, especially from radionuclides. Almost every kind of radiation exposure, whether it be for diagnostic or therapeutic purposes, from accidental occupational exposures, from fallout radionuclides, or from natural background radiations, results in nonuniform absorption of energy within the body. In 1969, an International Commission on Radiological Protection Task Group (ICRP, 1969) identified three classes of nonuniformity of dose:

> "(i) Partial irradiation of an organ or tissue, where the part irradiated is representative of the whole organ or tissue, as in external irradiation of skin or bone marrow."
>
> "(ii) Partial irradiation, where the part irradiated is not representative of the whole. This often occurs with internal emitters, such as bone-seeking radioactive materials in bone, where certain locations and cell types are preferentially irradiated. A special case of this class is irradiation by short-range emitters metabolically localized in structures which are biologically very important, for instance, tritiated thymidine in DNA."
>
> "(iii) Irradiation from radioactive materials in particulate form."

This report will deal with the third class, which is the common situation following the deposition of radioactive materials in the respiratory tract.

The decision to use the average dose to the lung* (and other organs) has been consistently maintained over three decades by numerous organizations and individuals. The bodies responsible for such recommendations have not ignored the subject during these decades, but, rather, have periodically reviewed the relevant human and experimental data and have maintained their position that nonhomogeneous dose distribution does not result in a demonstrably greater risk than does uniform dose distribution. Thus, there has been recognition, if not complete resolution, of this problem since the 1940's. In the early days of the Manhattan Project, the concern for the problem of nonuniform dose distribution led to studies of radionuclides inhaled or deposited on skin. In fact, interest in nonuniform dose distribution in animals and man predates the discovery of plutonium in 1941 because of the occupational and medical exposures to ^{226}Ra.

At the Chalk River Tri-Partite Conference attended by scientists from the United States, the United Kingdom, and Canada (McMurtrie, 1950), Dr. Hamilton pointed out, in relation to the possible pathological effects of radioactive particulates in the lungs, that cells in the immediate neighborhood of a dust particle containing 1 or 2 percent of plutonium would be subjected to a dose of about 400 r/day. The general opinion which emerged from the discussion was that the carcinogenic effect per unit volume is probably considerably less for the irradiation of small masses of tissue than for large.

The National Academy of Sciences-National Research Council considered the question of nonuniform dose distribution in Publication 848, Effects of Inhaled Radioactive Particles (NAS-NRC, 1961a). This publication pointed out that lung exposures are often expressed as mean dose to the lung by calculating the dose assuming uniform distribution of radioactive material throughout the lung, although uniform distribution of inhaled particles is not observed in practice. The report also stated that because local concentration of particles results in nonuniform distribution of energy, the dose

* The average radiation dose is calculated by assuming the complete and homogenous absorption of energy throughout the entire organ. An exception to this approach is the calculation of dose resulting from the inhalation of radon daughters.

delivered to small volumes of lung tissue could vary by several orders of magnitude above and below the mean value and, therefore, the calculated mean dose to the lung should be used with caution in estimating biological effects.

Report 848 also contains specific discussions of point sources and tumor production and the then current status of the radioactive particle hazard evaluation. It also recognized as unresolved the effect of the spatial distribution of the radiation on pulmonary tumorigenesis. It was not known whether differences in tumor production were due to the particular tissue in which the deposition occurs or to the localization and resulting strong irradiation of the tissue. The skin experiments, cited in Report 848, using radioactive point sources as compared with flat plates indicated that, in the range where extremely large doses are given, with consequent killing of cells, tumor production was considerably lessened for localized sources. The report, however, states that these experiments shed no light on the localization of smaller quantities of materials where the dose rate is not adequate to definitely kill the cells within a given range of the radioactive material.

The subject of energy distribution also was considered in the National Academy of Sciences-National Research Council Report of the Subcommittee on Internal Emitters of the Committee on Pathological Effects of Atomic Radiation (NAS-NRC, 1961b). In chapter IV, entitled Special Problems, the report states that there are good reasons to believe that, when radiation is uniformly delivered to tissues, the biological effects may differ from those observed when the radiation arises from focal aggregations of radioactive material (point sources) (Marshall and Finkel, 1959, 1960). In the latter case, dose rates close to the point source would be different from those near the end of the range of the particles with an extremely high dose rate found near the origin. The report notes that spatial differences in dose may have considerable importance if the relationship between biological injury and energy absorbed is not linear.

The NAS-NRC report (1961b) pointed out that spatial distribution of dose is of significance when particular tissue elements are selectively irradiated, and insofar as the relation between dose and the degree or probability of any type of injury is not linear. The report states that the available information is not adequate to define differences in hazard between focal and diffuse radiation.

The question of nonuniform dose distribution was addressed also in the BEIR Report (NAS-NRC, 1972). A statement is made that an important issue is whether local or "hot spot" radiation doses are more effective in producing cancer of the respiratory tract as compared with uniform radiation exposure to the entire respiratory epithelium. The report cites the work of Grossman *et al.* (1971), in which ^{210}Po chloride was given intratracheally either alone or with hematite particles, as being pertinent to the issue. Because polonium solution alone was as effective as polonium given with hematite, the authors of the BEIR Report thought that it may be inferred that a higher localized dose from alpha particles was not more carcinogenic than the same mean tissue dose delivered more uniformly to critical cells.

The 1971 report of the National Council on Radiation Protection and Measurements, entitled Basic Radiation Protection Criteria (NCRP, 1971), contains a concept of "significant volume" over which radiation dose should be averaged. The report states:

> "Simplifications in practice hinge largely on reporting a single representative protection dose for a limiting organ system even when the actual irradiation is grossly non-uniform. The representative dose is taken as the highest that can be obtained by averaging over a prescribed significant volume. The implication of this concept, or at least the convention that is followed, is that any redistribution of a given dose within such a volume does not materially alter the radiation response. It is usually assumed that the 'significant volume' should be of the order of one cubic centimeter. This will be grossly conservative under most circumstances, and in special situations use of a larger volume is justified."

As indicated in the NCRP report, there are some cases in which choice of significant volumes or areas are virtually meaningless. For example, the averaging of dose over the entire lung or over one cubic centimeter may have little meaning if a single radioactive particle in the lung or lymph node can be carcinogenic.

The ICRP periodically has addressed this subject of nonuniform dose distribution, usually by special groups commissioned by the ICRP to study the question. In its Publication 9 (ICRP, 1966), the ICRP pointed out that for the case of nonhomogeneous distribution of absorbed dose in the lung, an estimate of the

Dose Equivalent to the whole lung as determined merely by the product of QF and the mean absorbed dose might be greatly in error but full understanding of this problem must await further experimental evidence. The report indicated that there was no clear evidence to show whether, for a given mean absorbed dose, the biological risk associated with a nonhomogeneous distribution is greater or less than the risk resulting from a more diffuse distribution of that dose in the lung.

The authors of the ICRP report point out that the problems of high local concentration of dose are most severe for radioactive particles, especially alpha-emitters, in tissue where the local dose can reach very high levels even though the mean tissue dose may be very low. They state that one cannot assume that linearity of radiation dose and effect will hold at these high doses and dose rates yet there may be a great deal of cell death, particularly for the short well-defined range of alpha particle irradiation, and the number of affected but viable cells may be small as compared with the number of killed cells.

The report (ICRP, 1966) states:

> "On the basis of general considerations and of some experimental data and clinical experience the Task Group were of the opinion that, for late effects, the same radiation energy absorption might well be less effective when distributed as a series of 'hot spots' than when uniformly distributed. Thus, with particulate radioactive sources within a tissue, a mean tissue dose would probably introduce a factor of safety. However, a severe practical problem has now been recognized in connection with the inhalation of plutonium particulates, and is now being considered in detail by a Task Group of Committee 1 of ICRP."

Current radiation protection standards for limiting radiation dose to the lung from internally deposited radioactive materials continue to be based upon our collecting knowledge of the effects of radiation on the lung. Calculations of the average dose to lung tissue as a correlative step between biological effects and a quantity of radionuclides have been based on the assumption that the absorption of energy is uniform throughout the mass of tissue. It is well known that this situation does not exist for "insoluble" radionuclides which can produce focal spots of high levels of radiation close to the particle, with the level decreasing with distance in a pattern depending upon the quality and energy of the radiation. Also well known is the fact that postulated cases of uniform distribution of energy for "soluble" radioactive materials seldom, if ever, occur.

Since the opinions of the standard setting bodies were expressed, additional data have accumulated which bear on the problem and will be discussed in the sections to follow. While the question of nonuniformity of dose cannot be answered unequivocally, these new data tend to support the conclusion expressed by the ICRP Task Group (ICRP, 1969) that for radioactive particles "a mean tissue dose would probably introduce a factor of safety."

Thus, it is clear that nonuniform distribution of radiation dose has been examined continually by national and international standard setting bodies. The fact that these organizations have not changed or recommended changes in the procedures used for calculating dose to the lung as the result of their deliberations is an indication of implicit guidance on this particular problem.

III. ANIMAL STUDIES

The disposition and biological effects of inhaled plutonium and other radionuclides have been reviewed recently (Buldakov *et al.*, 1969; Sanders *et al.*, 1970; Bair *et al.*, 1973; Bair, 1974; Healy, 1974). Therefore, attention will be given only to those experimental data relevant to spatial distribution of radiation dose from inhaled radionuclides.

A. Retention of Plutonium in Lung

Airborne radioactive particles are similar to most other particles when they are inhaled in that deposition in the respiratory tract is primarily dependent upon the physical properties of the particles and the respiratory characteristics of the individual inhaling the particles. The ICRP Task Group on Lung Dynamics (Morrow *et al.*, 1966) dealt with the deposition of particles in the respiratory tract in considerable detail.

Within the first week after exposure, a fraction of the deposited plutonium is cleared from the respiratory tract and excreted. The amount of plutonium cleared depends upon the fraction of readily solubilized material present and the distribution of the plutonium within the respiratory tract. Plutonium deposited upon the ciliated epithelium of the upper respiratory tract may be trapped in mucus and transported to the esophagus and swallowed. Plutonium deposited in the lower regions of the lung is not readily available for clearance and may be incorporated into the cellular structures of the lung and retained for a long time.

The kinetics of the clearance of plutonium from lung are complicated and difficult to quantitate. Because the clearance of plutonium from the lower lung appears to be exponential with time over a reasonably long period after exposure, retention half-times are estimated. Animal experiments and limited human data provide a range of values for the retention half-times of several plutonium compounds, Figure III–1. The retention half-times for organic complexes of plutonium, plutonium nitrate and plutonium fluoride range from less than 100 days to about 300 days in rats and dogs. The retention half-times for PuO_2 are substantially longer, ranging from 200 to 500 days in rats, 300 to 1000 days in dogs and 250 to 300 days in human beings. The wide range of values for dogs is largely due to extensive experimentation with a variety of plutonium oxides with different physical characteristics. For example, PuO_2 calcined at high temperatures is cleared more slowly than air oxidized plutonium; PuO_2 comprised of large particles ($\sim$ 3 μm AMAD) tend to be cleared more slowly than aerosols of small particles ($\sim$ 0.1 μm AMAD); and $^{238}PuO_2$ has a much shorter lung retention time than $^{239}PuO_2$. The relatively low value for human beings, compared with dogs, suggests either that man clears plutonium particles from his lung faster than dogs do or that the materials inhaled in the human

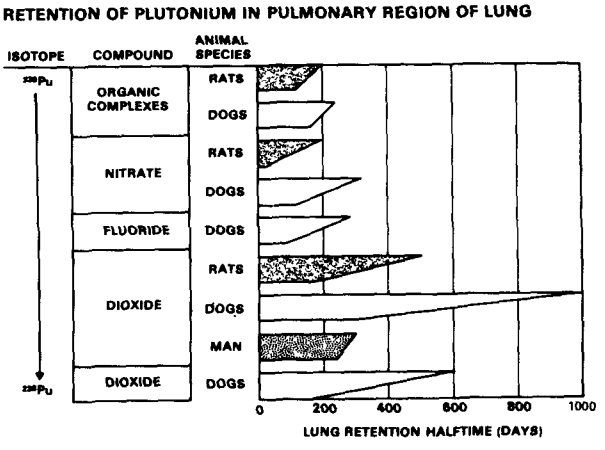

Figure III–1.—Retention of Plutonium in Pulmonary Region of Lung. Ranges of published values for retention half-times are indicated for each animal species and plutonium compound (Bair, in press).

accident cases, from which these data were obtained, were more soluble than plutonium dioxide.

Plutonium appears to be retained in the lower respiratory tract longer than most other materials that have been studied. Thorium dioxide and ruthenium dioxide show retention half-times comparable to those observed for plutonium. Uranium-oxide, cerium oxide and other metal oxides are retained at half-times of less than 200 days, some less than 100 days. The reason for the relatively long retention time of plutonium is not known, but may be due to its low solubility in tissue fluids, chemical binding with proteins and other constituents of lung, and the cytotoxic action of the emitted alpha radiation.

B. Spatial Distribution of Plutonium Within Lung

From the moment plutonium is deposited in the respiratory tract, biological and physical forces are at work to cause the removal of the plutonium. That these forces are not as effective for plutonium as for other inhaled material is indicated by the relatively long retention half-times observed for plutonium. Particles deposited in alveolar spaces may be cleared via the lymphatic system, mucociliary pathway of the tracheobronchial tree, or by dissolution and absorption into blood. With all of these processes at work removing plutonium from lung, although at low rates, it is difficult to visualize plutonium remaining static throughout its residence time in the lung. Techniques have not been developed to document the course of individual particles and aggregates of plutonium in lung. However, the temporal and spatial characteristics of plutonium within tissues can be inferred from autoradiographs of tissue sections prepared from animals exposed to plutonium aerosols.

The first observation is that plutonium and especially insoluble plutonium compounds are nonuniformly deposited throughout lung. Further, plutonium may deposit unequally among the lung lobes or among portions of lung lobes. Deposition of plutonium following inhalation, however, is more uniform than after intratracheal injection—an experimental technique often used when exposure of animals to plutonium aerosols is not feasible. Studies of inhaled plutonium nitrate in both rats and dogs show that immediately following the inhalation exposure, plutonium is present in both particulate and nonparticulate forms (Koshurnikova *et al.*, 1971; Sanders *et al.*, 1971; Ballou and Park, 1972; Lafuma, 1974), as evidenced by the presence of alpha stars and single tracks in autoradiographs, Figure III–2. Autoradiographs from dogs exposed to inhaled $^{239}PuO_2$ show an initial relatively diffuse distribution of plutonium throughout the entire lung (Clarke *et al.*, 1966).

Plutonium not rapidly removed from the respiratory tract by the mucociliary pathway or by absorption into the blood, may be engulfed by macrophages. Phagocytosis of particles deposited on the non-ciliated epithelium distal to the terminal bronchioles and in the alveoli usually occurs very rapidly (Sanders, 1969). The alveoli of the lung contain reticuloendothelial cells derived in part from circulating monocytes. These reticuloendothelial cells consist of mononuclear cells and histiocytes within the septal walls and alveolar macrophages in the air spaces, all of which are capable of phagocytizing plutonium.

Phagocytized plutonium particles are rapidly localized in the phagolysosomes of reticuloendothelial cells (Sanders and Adee, 1970). While the mechanism is not known (Casarett and Milley, 1964), the alveolar macrophage appears to be capable of transporting plutonium from the alveoli to the ciliated epithelium of the bronchioles. These phagocytic cells containing plutonium particles and aggregates can then be removed from the lung in the mucous blanket which is propelled up the respiratory passage by ciliary action. This mechanism of clearing plutonium from the lung is important early after an inhalation exposure and apparently continues to function long afterward, as evidenced by the appearance of macrophages containing plutonium in lung lavage fluid at long times after exposure (Sanders and Adee, 1968), and by the continued appearance of plutonium in feces, although the latter is only circumstantial evidence.

Both soluble and insoluble plutonium not immediately cleared from the lung tend to become further aggregated. This mobility and aggregation of plutonium may have large effects on the temporal and spatial distribution of the alpha radiation dose. A few days after inhalation of plutonium nitrate, single tracks in autoradiographs decrease, Figure III–3,

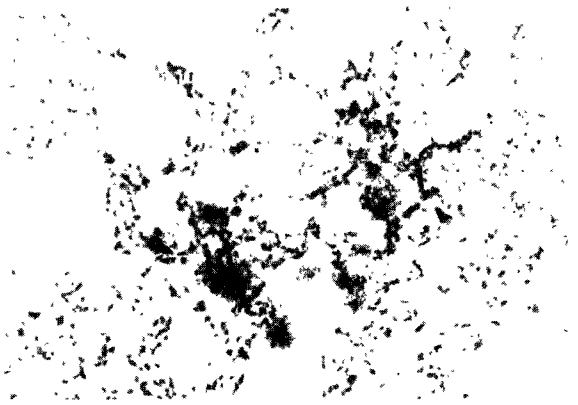

Figure III–2.—Autoradiograph of lung section from dog 1 day after inhalation of $^{239}Pu(NO_3)_4$. 320X. (Provided by J. E. Ballou, Battelle-Northwest).

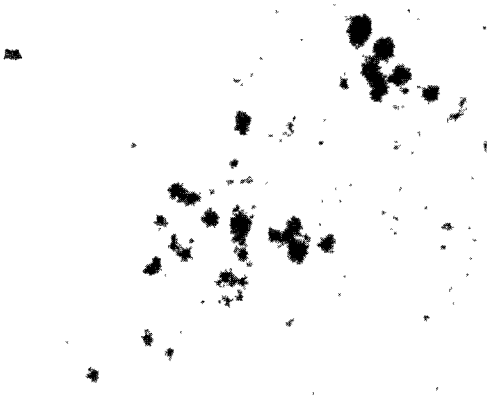

Figure III–4.—Autoradiograph of lung section from dog several weeks after inhaling $^{239}Pu(NO_3)_4$. 120X. (Provided by J. E. Ballou, Battelle-Northwest).

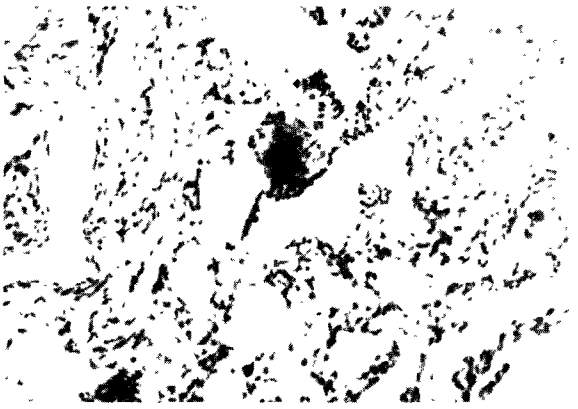

Figure III–3.—Autoradiograph of lung from dog 14 days after inhalation of $^{239}Pu(NO_3)_4$. 320X. (Provided by J. E. Ballou, Battelle-Northwest).

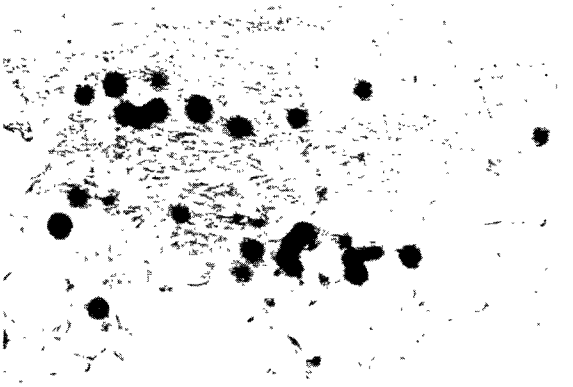

Figure III–5.—Autoradiograph of lung section from dog several months after inhalation of $^{239}PuO_2$, showing subpleural concentration of plutonium particles. 320X. (Provided by G. E. Dagle, Battelle-Northwest).

and after several weeks nearly all of the plutonium appears to be aggregated, Figure III–4. It is not known whether this represents continued aggregation, perhaps by chemical binding, of the plutonium in the lung or whether aggregation only appears to be increased as the non-aggregated plutonium is absorbed into the blood and thus disappears from the lung leaving only the aggregates.

Plutonium particles, and to a lesser extent aggregates of soluble plutonium, are transported to thoracic lymph nodes. Clearance of particles to lymph nodes occurs *via* lymphatic vessels in the thorax that drain interstitial spaces. Particles either penetrate the interstitium directly or gain access by transport in phagocytic cells (Morrow and Casarett, 1961; Casarett and Milley, 1964). Autoradiographs

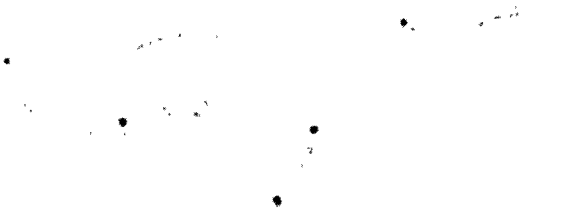

Figure III–6.—Autoradiograph of lung section from dog several months after inhalation of $^{239}PuO_2$, showing peribronchiolar accumulation of plutonium particles. 50X. (Provided by G. E. Dagle, Battelle-Northwest).

Erratum Sheet For

"A Radiobiological Assessment of the Spatial Distribution of Radiation Dose from Inhaled Plutonium"
(WASH-1320)

Please note that there is an error in the second sentence in column 2 on page 12.

The sentence now reads:

In experimental however, it is not known whether the plutonium can be found in the circulating blood; however, it is not know whether the plutonium has been absorbed from the lung directly or reabsorbed from liver or bone to which the plutonium had Been translocated previously from the lung.

The sentence should read as follows:

In experimental animals at long times after exposure, plutonium can be found in the circulating blood; however, it is not known whether the plutonium has been absorbed from the lung directly or reabsorbed from liver or bone to which the plutonium had been translocated previously from the lung.

of lung tissues taken from dogs several weeks and months after inhalation of PuO_2 show alpha stars concentrated in subpleural areas, apparently in lymphatic vessels, Figure III–5. Autoradiographs also suggest that some plutonium particles become immobilized in scar tissue in subpleural areas. Plutonium particles transported to lymph nodes are deposited in lymphatic sinuses of subcapsular and medullary areas. The particles eventually appear sequestered in "hot spots" of scar tissue and do not appear to be mobile. The residence time for plutonium in lymph nodes appears to be very long; there is no direct evidence for clearance of inhaled plutonium particles from thoracic lymph nodes although clearance of plutonium from cervical lymph nodes of dogs after subcutaneous injection (Lebel *et al.*, 1972) and from mesenteric lymph nodes of rats after intraperitoneal injection (Sanders, 1974) has been reported.

Plutonium particles not phagocytized by alveolar macrophages and removed by the mucociliary pathway or transported to the lymphatics can be found in Type I alveolar epithelial cells and in peribronchiolar vascular areas, Figure III–6. There is autoradiographic evidence of particles being immobilized in scar tissue in the alveolar and peribronchiolar areas. Although Type I alveolar epithelial cells phagocytize plutonium particles rapidly—within a few hours after deposition (Sanders and Adee, 1970), the fate of particles phagocytized by these cells is not known. The Type I cells do appear to be relatively radioresistant to alpha irradiation (Sanders *et al.*, 1971). It is possible that plutonium particles, other than those in lymphatics or trapped in scar tissue, retained in the lung for long periods, are cycled through generations of Type I or other cells.

Type II alveolar epithelial cells, or the so-called "granular pneumonocytes," do not phagocytize plutonium particles (Sanders *et al.*, 1971) and, thus, do not appear to be directly involved in clearance of plutonium from lung.

The intracellular localization of plutonium particles within pulmonary macrophages has been demonstrated by autoradiography of smears from pulmonary lavage fluid and of lung sections (Sanders, 1969). Lesions in macrophages have been observed as early as one hour after phagocytosis of large amounts of plutonium.

There is much experimental evidence for the absorption of plutonium into the blood almost immediately after deposition of soluble and even "insoluble" plutonium compounds in the respiratory tract (Bair and McClanahan, 1961; Bair and Willard, 1961). In experimental however, it is not known whether the plutonium can be found in the circulating blood; however, it is not know whether the plutonium has been absorbed from the lung directly or reabsorbed from liver or bone to which the plutonium had been translocated previously from the lung. Plutonium is also continuously excreted in urine after an inhalation exposure. Again it is not known whether the origin is the lung directly or the secondary liver and bone pools. Mercer (1967) suggested that dissolution of plutonium particles deposited in the deep alveolar lung region was the major pathway for clearence and that dissolution rates were directly proportional to the surface area of the particles and their chemical composition. It seems certain that dissolution of plutonium particles and aggregates does occur in the lung, although at low rates, and accounts for at least some of the mobility of plutonium in the lung as well as clearance from the lung.

Although the kinetics are unknown and even a qualitative description is still rather primitive, there is ample evidence that plutonium deposited in lung is subjected to biological and physical forces. This argues against either particles or aggregates of plutonium remaining static indefinitely, except for the plutonium that becomes immobilized in scar tissue. To the contrary, while the rates may be low, movement of plutonium within lung tissues, by several mechanisms, certainly occurs, as the lung attempts to expel the plutonium and other foreign material. The migration of deposited plutonium particles in lung is recognized in the USSR as at least partially compensating for the nonuniformity of the radiation exposure from plutonium particles and justifying acceptance of the concept of averaging the radiation dose over the entire lung mass (Zalmanzon and Chutkin, 1971).

C. Pulmonary Neoplasia

High doses of inhaled plutonium in experimental animals have been shown to cause severe radiation pneumonitis and fibrosis resulting in early death due to respiratory in-

sufficiency (Bair *et al.*, 1973). Lymphopenia is the earliest response seen in animals after inhalation of PuO_2 and has been observed in dogs with total lung deposition of 0.08 μCi (Park *et al.*, 1974). Cancer is a potential long-term response to plutonium in the body and has been observed in experimental animals to occur in lung, bone and liver, all of which are major repositories of plutonium deposited in the respiratory tract (Bair, 1974). However, lung cancer is the biological response of most relevance to this discussion of the spatial distribution of radiation dose from inhaled plutonium.

Experimental data on plutonium-induced lung cancer are summarized in Table III–A. In rats exposed to ammonium plutonium pentacarbonate or plutonium citrate, the incidence of pulmonary neoplasia was about 10% at doses of the order of 0.01 μCi/g of lung, and above 30% at 0.015 to 0.026 μCi/g lung. The lung tumors were squamous cell carcinomas, adenocarcinomas, and hemangiosarcomas. Sixty to 100% of the animals in the range of doses studied (40 to 7320 rads) developed pulmonary sclerosis. The maximum incidence of malignant neoplasms in the lungs (30–47%) was observed at an absorbed dose of 500–1000 rads. Studies with soluble plutonium in dogs have been concerned with acute effects and no tumors have been reported. Plutonium-239 oxide caused pulmonary neoplasia in mice given doses by intratracheal injection ranging from 0.02 to 1.0 μCi/gram lung (Wager *et al.*, 1956; Temple *et al.*, 1959, 1960). One tumor was seen in a mouse that inhaled about 0.25μCi $^{239}PuO_2$ per gram lung (Bair, 1960). In a larger study with nearly 800 mice that inhaled about 0.1 to 2 nCi per gram (Bair *et al.*, 1962), there was no shortening of life-span and no evidence of pulmonary neoplasia in the animals available for histopathological examination. Rats showed a 50% tumor incidence at inhaled (through a glass tube inserted into the trachea) $^{239}PuO_2$ doses of about 0.2 μCi/gram lung (Lisco, 1959). These tumors were epidermoid carcinomas, adenocarcinomas, and hemangioendotheliomas. No primary tumors of thoracic lymph nodes were seen in any of the rodent experiments.

In beagle dogs given a 10–30 minute exposure to $^{239}PuO_2$, deposition of more than 0.1 μCi/g lung caused death within about a year due to respiratory insufficiency (Park *et al.*, 1972). Thirty dogs died between 55 and 412 days postexposure due to plutonium-induced pulmonary edema, fibrosis, and bronchiolar and alveolar epithelial hyperplasia and metaplasia. The subsequent severe respiratory insufficiency was characterized by progressive hypercapnia and hypoxia. In another experiment with 40 dogs, 32 died or were sacrificed when death was imminent. Five were sacrificed for study of plutonium distribution in tissues. Of the 32 deaths, 30 were due to plutonium-induced pulmonary fibrosis and/or neoplasia. The three remaining dogs have died and all grossly showed lung tumors; however, the histopathology and radiochemistry results are incomplete (Park and Bair, 1974). Twenty-four dogs had pulmonary neoplasia in addition to fibrotic and metaplastic lesions, Figure III–7. The survival times of these dogs are plotted as a function of the estimated amount of plutonium initially deposited in the alveolar regions of the lungs of the dogs, expressed as nCi/g of blood-free lung. The curve was fitted to all the data by least squares analyses to describe the relationship between quantity of plutonium deposited and the time of death due to pulmonary neoplasia and/or pulmonary fibrosis-induced respiratory insufficiency. Another curve was fitted to just the pulmonary neoplasia data points by least squares analyses. In these dogs the development and growth of the pulmonary neoplasms were followed radiographically. In all cases tumors appeared to originate in the periphery of the lung, the location of most of the plutonium. This observation is consistent with the histopathology which showed that the predominant tumor type was bronchiolar-alveolar carcinoma. Epidermoid tumors similar to those generally attributed to cigarette smoking and/or exposure to radon daughters as in uranium miners, were incidental findings in a few dogs which also had bronchiolar-alveolar carcinoma (Howard, 1970). The estimated initial alveolar deposition in the dogs with plutonium-induced pulmonary neoplasia was 0.2 to 3.3 μCi or 3 to 45 μCi/gram of bloodless lung. Metastasis occurred to thoracic lymph nodes and to many systemic organs.

In addition to bronchiolar-alveolar carcinomas, other types of tumors were incidental findings in several dogs. Two dogs developed benign-appearing tumors of endothelial origin which were classified as hemangiomas. Thoracic lymph nodes, as well as a few hepatic

Table III-A
PLUTONIUM-INDUCED LUNG CANCER IN EXPERIMENTAL ANIMALS

Compound	Animal species	No. of animals	Exposure method*	Deposited in lungs (μCi)	Deposited in lungs (μCi/g)	Dose to lungs** (rads)	Mean survival time (days)	Lung tumor incidence No.	Lung tumor incidence %	Tumor type	Reference
^{239}Pu	Rat	258	Control	—	—	—	570 ± 8	1	0.39	Squamous cell cancer, adenocarcinoma, and hemangiosarcoma	Koshurnikova, Lemberg, and Lyubchansky, 1971
Citrate	Rat	157	Inhal.	0 008	0.0026	47	635 ± 3	11	7.1		
	Rat	124	Inhal.	0.02	0 0067	117	585 ± 12	3	2 5		
	Rat	203	Inhal	0 04	0.013	234	545 ± 11	17	8 4		
	Rat	31	Inhal.	0.08	0.026	467	546 ± 22	11	35 5		
	Rat	105	Inhal.	0.15	0.050	852	464 ± 12	27	25 7		
	Rat	113	Inhal.	0 25	0 08	1390	416 ± 12	27	24		
	Rat	39	Inhal	0.36	0.12	1740	221 ± 13	3	7 7		
	Rat	90	Inhal.	0.51	0 17	2370	124 ± 9	2	2.2		
	Rat	12	Inhal.	0.80	0.26	3090	69 ± 5	0	0		
	Rat	20	Inhal	1 03	0.34	3820	64 ± 2	0	0		
^{239}Pu	Rat	48	Inhal.	0 004	0.0013	41	571 ± 21	2	4 2	Squamous cell cancer, adenocarcinoma, and hemangiosarcoma	Koshurnikova, Lemberg, and Lyubchansky, 1971
Ammonium	Rat	101	Inhal.	0.007	0.0023	80	571 ± 16	7	7		
Plutonium	Rat	91	Inhal	0.017	0.0057	186	584 ± 12	12	13 2		
Penta-	Rat	126	Inhal	0 045	0.015	497	582 ± 11	48	38		
carbonate	Rat	83	Inhal	0.15	0 05	1065	484 ± 14	38	45.9		
	Rat	126	Inhal.	0 25	0.08	1615	361 ± 11	31	24.6		
	Rat	22	Inhal	0.35	0.12	2140	247 ± 21	2	9.0		
	Rat	65	Inhal.	0.46	0 15	2780	139 ± 10	3	4 6		
	Rat	23	Inhal	0 77	0 26	3900	78 ± 7	0	0		
	Rat	11	Inhal	1.46	0.48	7320	77 ± 6	0	0		
^{239}Pu	Rat	42	I T.(HNO_3)	—	—	- -	586 ± 20			Squamous cell cancer, adenocarcinoma, and hemangiosarcoma (Incidence calculated on animals at risk)	Erokhin, Koshurnikova, Lemberg, Nifatov, and Puzyrev, 1971
$Pu(NO_3)_4$	Rat	80	I.T.	0 00042	0 00014	2.7	541	2	2.5		
	Rat	17	I.T.	0 0042	0.0014	28	755	1	5.9		
	Rat	22	I.T.	0.01	0.003	62.5	793	2	9.9		
	Rat	88	I T	0.031	0.01	205	592	4	8.16		
	Rat	59	I.T.	0 048	0 016	318	704	7	17.5		
	Rat	62	I T	0 1	0 03	622	589	12	18.9		
	Rat	108	I T.	0 42	0.14	2760	426	33	33		
	Rat	86	I T.	1 0	0.3	5960	330	19	24 2		
^{239}Pu Plutonyl Triacetate	Rat	48	I T	1.0	0 3	1580	405	19	39.6	Squamous cell cancer, adenocarcinoma, and hemangiosarcoma	Erokhin, Koshurnikova, Lemberg, Nifatov, and Puzyrev, 1971
^{239}Pu	Rabbit	8	Inhal		0	0	1431.5 ± 201	- -	—	Malignant	Koshurnikova, Lemberg, and Lyubchansky, 1971
Ammonium	Rabbit	13+	Inhal	—	0.02	120	926.4 ± 96 8	- -	—		
Plutonium-	Rabbit	18+	Inhal.	- -	0.17	1010	673 9 ± 74 8	?	18 7		
Penta-	Rabbit	20+	Inhal.	-	0.50	2960	631.5 ± 61.5	1	5.0		
carbonate											
^{239}Pu	Rabbit	12	I T.		0.65	3840	665 7 ± 53 6	7	58.3	Malignant	Koshurnikova, Lemberg, and Lyubchansky, 1971
$Pu(NO_3)_4$	Rabbit	13	I.T	—	2.38	13950	428 2 ± 31 2	3	23.0		
$^{239}PuO_2$	Mouse	21	I.T.	0.003	0 008	115	500	1	5	Fibrosarcoma	Temple *et al.*, 1959
	Mouse	17	I T.	0.06	0 15	2300	400	2	12	Squamous cell carcinoma	Wager *et al.*, 1956
	Mouse	41	I T.	0 16	0 4	4000	100	1	2.5	Bronchiolar carcinoma	Temple *et al.*, 1959
	Mouse	73	Inhal.	0 1	0 25	—	500 +	1	1 4	Bronchiolar carcinoma	Bair, 1960
$^{239}PuO_2$	Rat	—	I T.	0 2-1	- -	- -	>250	- -	50-100	Epidermoid adenocarcinoma	Lisco, 1959
$^{239}PuO_2$	Dog	8	Inhal	0 6	0071 ± 0026	1230	2922 ± 732	7	87 5	Bronchiolar-alveolar carcinoma	Park and Bair, 1972
	Dog	13	Inhal	1.3	.0147 ± 0029	2086	1992 ± 437	11	84		
	Dog	6	Inhal	2	.0229 ± 0021	2498	1539 ± 388	4	67		
	Dog	5	Inhal	3 1	.0392 ± .0032	4094	1094 ± 236	2	40		
$^{238}PuO_2$	Rat	92	Inhal	0	0	0	825	1	1 1	Dose calculated to 700 days after exposure	Sanders, 1973
	Rat	30	Inhal	0.005	0 002	9	650	2	6.6		
	Rat	30	Inhal	0 018	0.0072	32	675	7	23 3		
	Rat	32	Inhal	0 2	0.092	375	550	8	25 0		

* Inhal. = Inhaled; I.T = intratracheal injection
** Calculated to time of death unless otherwise noted. Mean organ dose.

nodes, showed sclerotic lesions associated with accumulated plutonium. Three dogs had thoracic lymph node lesions of endothelial origin classified as hemangiosarcoma, lymphangiosarcoma and endothelioma. Another dog had a possible malignant lymphoma involving the mesenteric and mandibular lymph nodes. Autoradiographs of these nodes showed no radioactivity. This isolated case is not considered to be associated with the plutonium exposure.

In contrast to the results with $^{239}PuO_2$, preliminary data from a study of inhaled $^{238}PuO_2$ in dogs show a high incidence of osteosarcoma, although pulmonary neoplasia also occurred (Park *et al.*, 1974). This is consistent with the observed translocation of ^{238}Pu to bone following inhalation of $^{238}PuO_2$ in both dogs and rats.

Sanders (1973) has recently reported on the carcinogenicity of inhaled ^{238}Pu in rats. Three groups of 35 animals each inhaled an aerosol of ^{238}Pu in saline which gave initial lung burdens of 0.005 μCi, 0.018 μCi, and 0.2 μCi with associated cumulative radiation doses to lung of 9 rads, 32 rads and 375 rads, respectively, at 700 days postexposure. However, because of the rapid clearance of ^{238}Pu from lung, nearly all of the radiation dose was delivered to lung within 30 days after the inhalation exposure. The lung tumor incidence within the 0.005 μCi group was not significantly different from the control group. Groups receiving the two higher levels showed a statistically significant increased incidence of tumors but no increased mortality rate.

Osteosarcomas were observed in $^{238}PuO_2$ treated animals at the highest dose level only (i.e., greater than 50 rads accumulated dose to skeleton) which correlated with the translocation of plutonium to bone. The aerosol (crushed $^{238}PuO_2$ microspheres) was 72% ultrafilterable and was considered "soluble." Of the 19 pulmonary tumors found, there were 14 bronchiolar-alveolar tumors, two mixed carcinomas, one epidermoid carcinoma, one undifferentiated carcinoma and one malignant lymphoma.

There are limited data available on plutonium inhalation by nonhuman primates. Metivier *et al.* (1972) reported studies in which 19 baboons (Papio papio) were exposed at 2–3 years of age to an aerosol of $^{239}PuO_2$ with a count median diameter of 0.5 μm. The total lung burden at the time of death ranged from 0.01 to 0.1 μCi per gram of fresh

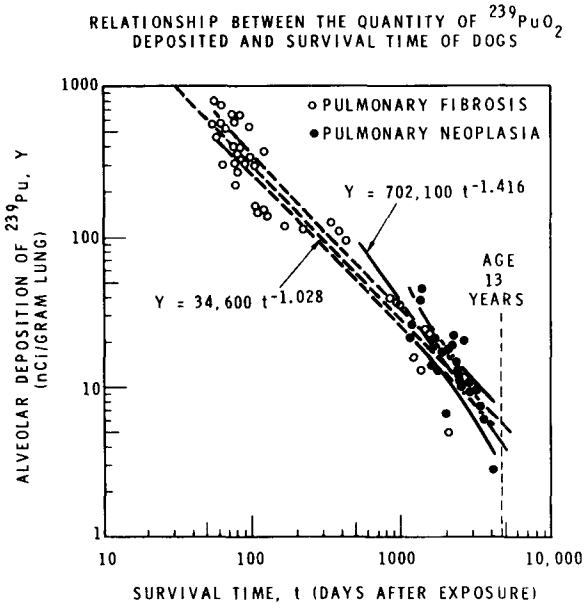

Figure III–7.—Relationship between quantity of $^{239}PuO_2$ deposited and survival time of dogs, Park *et al.*, 1972.

lung. Translocation was largely to tracheobronchial lymph nodes. All of the baboons had radiation pneumonitis. In addition, two epidermoid carcinomas of about 1.0 cm diameter were found after 80 days and two mucous-secreting adenocarcinomas of the same size were found after 180 days. Animals living past 80 days postexposure showed extensive areas of squamous metaplasia or nests of small "tumorlets." The authors concluded that baboons may be more sensitive than dogs to acute internal alpha irradiation.

Figure III–8 shows the incidence of lung cancer in the animal experiments described above as a function of the calculated total mean radiation dose to the lung. These data show an increased incidence of rat lung cancer occurring with doses as low as 10 rads. In rats and mice, the peak incidence probably occurs at doses between 200 and 1000 rads. The results from the only dog experiment show higher incidences than have been observed in rats.

The marked histopathologic changes in tracheobronchial and mediastinal lymph nodes of dogs that have inhaled plutonium (Clarke and Bair, 1964), and those occurring is superficial cervical and axillary lymph nodes of dogs given plutonium implants in the subcutaneous fascia over the dorsal metacarpus (Lebel *et al.*, 1972) were not observed to have been detri-

mental to the dogs. The only possible exception is one dog given a 5.8 μCi implant of air-oxidized plutonium in the dorsal metacarpus. This dog showed a generalized lymphadenopathy after four months and died of lymphosarcoma. However, because of the early development of this lesion the authors were hesitant to attribute it to the plutonium (Lebel *et al.*, 1970; Watters and Lebel, 1972). The calculated radiation dose to the superficial cervical lymph nodes was about 7000 rads. No other neoplasms were observed in these dogs, but they had been at risk for less than three years. In the plutonium inhalation studies at Battelle-Northwest, over 50 dogs have been at risk five to 11 years (Park *et al.*, 1972). Metastases of primary pulmonary tumors to tracheobronchial and mediastinal lymph nodes and lymphatics were common. However, as previously mentioned, only one dog had a possible malignant lymphoma, which was confined to the mesenteric and mandibular lymph nodes. It can be concluded from the relatively numerous rodent and dog experiments with ^{238}Pu and ^{239}Pu in which many lymph nodes have been exposed to a wide range of doses and dose rates from background

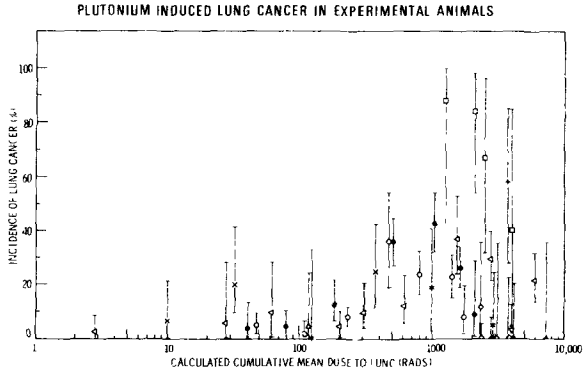

Figure III–8.—Plutonium-induced Lung Cancer in Experimental Animals. Mean incidence and radiation dose values are those reported in the literature. Binomial confidence limits were calculated from data included in the referenced literature.

- □ $^{239}PuO_2$—Dogs (from Park and Bair, 1972)
- ▽ $^{239}PuO_2$—Mice (from Temple *et al.*, 1959, 1960)
- △ $^{239}PuO_2$—Mice (from Temple *et al.*, 1959, 1960)
- ◇ $^{239}PuO_2$—Mice (from Wager *et al.*,1956)
- ○ ^{239}Pu Citrate—Rats (from Koshurnikova *et al.*, 1971)
- ● ^{239}Pu *Ammonium plutonium pentacarbonate*—Rats (from Koshurnikova *et al.*, 1971)
- × ^{238}Pu—Rats (from C. L. Sanders, 1973)
- ◁ ^{239}Pu—Rats—$Pu(NO_3)_4$ (from Erokhin *et al.*, 1971)
- \+ ^{239}Pu—Rabbits—$Pu(NO_3)_4$ (from Koshurnikova *et al.*, 1971)
- *^{239}Pu—Rabbits—Ammonium plutonium pentacarbonate (from Koshurnikova *et al.*, 1971)

to thousands of rads, that lymph nodes are much less susceptible than lung tissue to the oncogenic action of alpha radiation from plutonium.

D. Experiments of Special Relevance to Nonuniform Dose Distribution

A number of factors influence the biological effects that may be produced by radionuclides. If, for example, the material is readily translocated from the lung to other organs, the eventual damage to these other organs may well appear earlier than lung lesions. Thus, in considering lung dose we are focusing primarily on those materials that will be retained in the lung for reasonably long periods of time and possibly causing low dose effects such as cancer which may occur late in life. Increased incidences of pulmonary neoplasia have been observed in experimental animals when there was no statistically significant shortening of life-span.

In most of the experiments there appears to be a relation between the radiation dose and the time or occurrence of malignancies in animals. In general, the higher the dose rate, the shorter time required for cancer induction. However, when the lung dose rate is too high, the animal will die from other causes such as respiratory insufficiency before there is time for cancer to occur. The data plotted in Figure III–8 suggest there is an optimal dose for the production of malignancies.

The production of early death by causes other than cancer can be regarded as a result of "wasted radiation" in interpretations which consider oncogenesis to be the most sensitive end point. From this standpoint, doses which lead to death before cancer appears can be considered to be overkill of the organism since the full expression of the oncogenic effects is not attained. For a single radioactive particle of $^{239}PuO_2$ in the lung (or other tissue), the dose rate near the particle can be high enough to cause the death of all cells within a given radius even if the residence time of the particle is short. Such cells will not be able to reproduce and subsequently result in cancer.* Radiation from particles which led to such overkill

* The presence of dead cells, cellular products or fibrosis may be required before a cellular transformation can express itself as a cancer. However, this concept has not been generally accepted.

should be less hazardous than equivalent radiation energy distributed over a large tissue volume. In fact, such a concept would lead immediately to the conclusion that the larger the particle (in terms of activity) the less effective the radiation emitted would be in producing cancer because of the increased fraction of radiation energy wasted on dead cells. An experiment showing this effect was done by Passonneau *et al.*, (1952) using glass beads containing ^{90}Sr on rat skin. The same amount of activity was used for the same area of skin but the activity was distributed either in a uniform flat plate, in 50 beads, in 20 beads or in 10 beads. The results given in Table III–B indicate clearly a decrease in the tumor production efficiency as the radioactivity was concentrated in fewer sources irradiating a smaller total area of tissue. However, the beads with the most radioactivity produced the largest number of tumors per bead and the smallest number of tumors per microcurie. The relevant parameter is tumors per microcurie because the basic question is how the risk from hot particles compares with the risk from uniformly distributed radiation doses.

Dean and Langham (1969), using data derived by Albert (1967a) on the production of tumors in rat skin, predicted on an absolute basis the probability of tumor production from various sizes of plutonium particles. The results of this calculation predict a very high probability of tumor production from most particle sizes relative to a 0.016 μCi lung burden. The experiment of Albert on rat skin is not really applicable to radioactive particles deposited in lung because it did not deal with particles, while Passonneau's is applicable to the extent that it deals with particulate radioactive sources, yet it still requires extrapolation from skin to lung.

The recent Natural Resources Defense Council (NRDC) petition (Tamplin and Cochran, 1974) uses mainly the results obtained in radiation skin experiments (Albert *et al.*, 1967a, 1967b, 1967c) to infer alpha-particle risks in the lung. Hence, a critical test of their hypothesis is whether a hot particle pattern of alpha irradiation of the skin can produce tumors.

Two approaches have been used in skin experiments. The first was to determine whether isolated small areas of irradiated skin gave the same yield of tumors per unit as large-area skin irradiations. The focal irradiation pattern with low LET radiation, electrons (Albert *et al.*, 1967b), was less efficient than the large area exposure in producing tumors. However, with high LET radiation (protons) there was no difference (Burns *et al.*, 1972). If these results can be extrapolated to alpha radiation, they suggest that the risk from particulate sources is no greater than from uniformly distributed sources.

The second approach involved the irradiation of different depths in skin. In studies of electron radiation with varying energies and penetrating power, the occurrence of tumors and atrophic follicles suggested the existence of target cells at a depth of about 0.3 mm in the skin corresponding to the lower end of the resting hair follicle (Albert *et al.*, 1967a). This critical depth remained constant even when the skin was irradiated with the hair in the growing phase, i.e., when the follicles extend to a depth of 0 8 mm (Burns *et al.*, 1973a). There was a quantitative association between the incidence of tumors and atrophic follicles for various types of ionizing radiation, various spatial distributions of dose within the skin and for different phases of hair growth (Albert *et al.*, 1967c). A plausible explanation for the experimental results is that each follicle has a population of stem cells at a depth of 0.3 mm that are concerned with the production of sebaceous cells and hair. These stem cells apparently constitute the most sensitive potential oncogenic cell population to ionizing radiation in the rat skin since all the tumors were mainly of hair follicle origin (Albert *et al.*, 1969). Neoplastic transformation of a significant number of these target cells required

Table III–B

TUMOR PRODUCTION IN RAT SKIN FOLLOWING EXPOSURE TO FLAT PLATE AND POINT SOURCES OF $^{90}Sr/^{90}Y$*

Source	Activity	Number of rats	Number of tumors: Total	Per bead	Per μCi	Relative efficiency
Flat Plate (1000 μCi)	28.6 μCi/cm^2	71	89	—	0.00049	1.59
Flat Plate (1500 μCi)	42.9 μCi/cm^2	73				
50 Beads	30 μCi/bead	58	27	0 009	0.00031	1.00
20 Beads	75 μCi/bead	77	24	0 016	0.00021	0.671
10 Beads	150 μCi/bead	74	16	0.022	0.00014	0.464

Modified from Passonneau *et al.* (1952) by information given in NAS-NRC Publication 848 (NAS-NRC, 1961a).

large radiation doses which in turn killed most of the target cells and thus caused follicle atrophy.

Similar studies were reported (Albert *et al.*, 1972) in which the dorsal skin of mice was irradiated with electrons in single exposures at varying dose levels. Comparison of these data with the rat skin experiments showed that the radiation sensitivity of the mouse skin for hair follicle destruction was at least twice that of the rat, that the incidence of atrophic follicle formation in the mouse was considerably less than in the rat, and that as a consequence the incidence of epithelial skin tumors (adnexal tumors) is "markedly lower in mice than in rats." Thus the hair follicles in the mouse skin exhibit a lesser ability to form atrophic hair follicles and a greater sensitivity to the lethal action of the radiation. Furthermore, there are striking differences between strains of rats in the incidence of adnexal tumors resulting from similar doses of electron skin irradiation (Albert *et al.*, 1961).

Because alpha radiation from a plutonium particle has a range in unit density tissue of only about 40 microns, the effect of focal irradiation at different levels of the hair follicle is a crucial test of the recent NRDC proposal (Tamplin and Cochran, 1974). Alpha irradiation of the skin from the surface to a depth of about 0.15 mm did not produce tumors (Heimbach *et al.*, 1969). This result, however, is consistent with the existence of a target cell population at a depth of about 0.3 mm. However, selective irradiation of the lower end of the hair follicle at a depth of 0.3 mm by use of the Bragg peak from an alpha beam did not produce tumors or atrophic follicles unless there was substantial irradiation of the entire follicle. This observation suggests that even though the critical cell population is located at 0.3 mm, there are recovery mechanisms that block oncogenesis when only part of the "critical architectural unit of tissue" is irradiated. What these recovery processes might be is not understood. Nevertheless, this result does not support the contention that a single plutonium particle irradiating a "critical architectural unit" such as the hair follicle, will produce a tumorigenic risk of the magnitude assumed by Tamplin and Cochran (1974).

Richmond *et al.* (1970) investigated the effects of ^{238}Pu dioxide particles lodged in the rodent lung vasculature following intravenous injections. These particles averaged about 180 μm in diameter and gave average dose rates to the entire lung of about 3.5 rems per hour with the alpha particle dose rate at the surface of the particle on the order of 10^6 rads per hour. The longest exposure until sacrifice was a group of 6 rats which lived to 600 days. Examination of the lung following these exposures indicated the presence of a microlesion with complete degeneration of the cells close to the particle. However, the evidence indicated that this was not simply a stable type of scar tissue but rather that the lesion was in a dynamic state in which the collagen was renewed constantly with subsequent liquification. Within this time period there were no tumors produced nor were there any indications of effects that would be deleterious to the animal's overall well being. It is noteworthy that the energy delivered to the lung, if averaged over the entire lung, would be on the order of 2,000,000 rads in 600 days. This dose, if uniformly distributed, is much greater than that shown to cause deaths in relatively short times and is considerably above doses shown to produce lung cancers.

In the experiment of Richmond *et al.* (1970), the particles appeared to be firmly fixed in the blood vessels, and therefore were not representative of particles actually deposited in the alveoli. Although movement of such particles is known to occur, compared with inhaled plutonium they are relatively static. Cells located at the periphery of the zone of cellular destruction caused by the radiation may receive radiation doses ranging from just sublethal to essentially zero.

Experiments in which $^{238}PuO_2$ microspheres, similar to those used in the rodent studies, and $^{239}PuO_2$ microspheres were surgically implanted into the lung of beagle dogs yielded results that were qualitatively similar to those observed in rodents. The implanted plutonium particles produced small discrete microlesions but no lung malignancies were observed (Richmond *et al.*, 1974). It should be recognized that relatively few animals were used and that the times of exposure were not long. However, one dog was sacrificed at 4 years and 2 are still alive 7 years past implant. That lung malignancies have not been observed even though the local radiation doses were extremely intense is of considerable radiobiological interest.

Any repopulation of the volumes of destroyed tissue could result in rapid proliferation of damaged cells which have received sublethal doses of radiation. This situation would appear to have a high potential for producing cancer but is difficult to investigate experimentally without an understanding of the basic mechanism of cancer production and of the response of such damaged cells to an otherwise normal environment. Information on this possibility is limited but some indication that it is not a predominant problem can be obtained from the experiments of Passonneau (1952) and Richmond *et al.* (1970, 1974) which did involve just such conditions in several types of tissue.

Current work uses a similar experimental design but with 10 μm diameter zirconium oxide microspheres containing PuO_2 at specific activities corresponding to respirable particles of PuO_2. These experiments are directly applicable to the hot particle problem (Richmond and Voelz, 1972, 1973; Richmond and Sullivan, 1974). In these experiments every animal received 2000 plutonium-containing particles. Eight exposure levels and two control groups were used with particle specific activities ranging from 0.07 to about 60 picocuries. Of the 713 hamsters used in this experiment only two control animals and one injected animal are alive at present. Table III–C shows the radiation doses calculated by three dosimetric models and the number of expected tumors per group as calculated from a lung model (Coleman and Perez, 1969) based on Albert's skin data. This model is basically similar to those developed by Geesaman (1968) and Dean and Langham (1969) as the dose response function assumed in the calculation is based upon the Albert rat skin data. About 1% of the lung mass of the animals shown in Table III–C was irradiated, and the median dose rate to those cells within alpha range of a microsphere was estimated to be 20–1800 rad/day.

No aberrant clinical signs have been observed in any of the animals that have died or have been sacrificed to date. Blood samples have revealed no abnormalities even after long exposures and there have been no regional lymph node effects. Occasionally, small accumulations of macrophages are seen around spheres but the fibrous encapsulation previously described for the larger more radioactive (about 180 micron diameter) spheres (Richmond *et al.*, 1970, 1974) are not seen. Two rarely occurring tumors were observed among animals included in Table III–C. One hamster developed an angiosarcoma of the lung after 9.5 months exposure to 2000 microspheres each containing 0.42 picocurie alpha activity (level 2A). Another animal developed a lung sarcoma at the same exposure level after 12 months. Table III–C shows a predicted tumor incidence of 40 tumors for this group (level 2A). No other lung tumors have been observed in this experiment. Every animal in the experiment should have developed two lung tumors if the tumor probability is 10^{-3} per particle as speculated by Geesaman (1968).

Table III–C

EXPOSURE CONDITIONS FOR PRELIMINARY EXPERIMENT (2000 SPHERES/ANIMAL, ABOUT 70 ANIMALS/GROUP)

(Richmond and Voelz, 1972)

Isotope	Level Number	nCi/Animal	Specific Activity pCi/sphere	Equivalent Diameter Pure $^{239}PuO_2$ (μm)	Local Dose Rate at "Averaged Dose Rate"[b] (rads/yr)	Local Dose Rate at Surface of Sphere (rads/hr)	40 μm from center (rads/hr)	Expected Tumor Incidence[a] (tumors/group)
^{239}Pu	1	0.14	0.07	0.09	13	4.2×10^{1}	6.8×10^{-1}	2
	2	0.44	0.22	0.13	42	1.2×10^{2}	2.2×10^{0}	10
	2A	0.84	0 42	0.16	81	2.5×10^{2}	4.1×10^{0}	40
	3	1.82	0.91	0.21	175	5.5×10^{2}	1.0×10^{1}	60
	3A	3.2	1.6	0.26	310	1.0×10^{3}	1.7×10^{1}	40
^{238}Pu	4	8.6	4.3	0.36	875	2.5×10^{3}	4.2×10^{1}	10
	5	26.6	13.3	0.52	2710	8.4×10^{3}	1.3×10^{2}	0
	6	119.0	59.4	0.86	12100	3.6×10^{4}	5.8×10^{2}	0

[a] Using NUS structure lung, with a lung density of 0.19 g/cm^3 (Coleman and Perez, 1969.)
[b] Assuming 1 g of lung irradiated.

An additional 485 animals were injected with larger numbers of spheres, 6000–1,000,000 per animal, to irradiate over 98% of the lung. Lower specific activity spheres were used, and median dose rates ranged from 6–25 rad/day. One of these animals developed a primary lung tumor. Other animals have been injected with 50,000–900,000 spheres to extend the range of sphere specific activity down to 0.015 pCi/sphere. Lung burdens were 0.86–177 nCi, and median dose rates were 1.3–320 rad/day. There are about 2000 animals in this study.

Approximately 1150 animals have lived their full life spans or have been sacrificed to date as part of this experiment. About 5.7×10^6 spheres with specific activities in excess of 0.07 pCi each were injected into these animals. The observation of three primary lung tumors suggests a tumor risk of roughly 10^{-7} per particle as a preliminary estimate. These results are particularly significant in view of the demonstration by Little *et al.* (1970a, 1970b, 1973) that the Syrian hamster develops pulmonary neoplasms with high efficiency and short induction time following exposure to soluble ^{210}Po.

The distribution of all exposure conditions is summarized in Figure III–9 in which the ordinate is the number of spheres per animal (scale on left) or fraction of lung irradiated (scale on right), and the abscissa is sphere specific activity. The diagonal lines are loci of constant plutonium dose and are labeled with the lung burden in nCi. The special interest in burdens between 10 and 100 nCi is occasioned

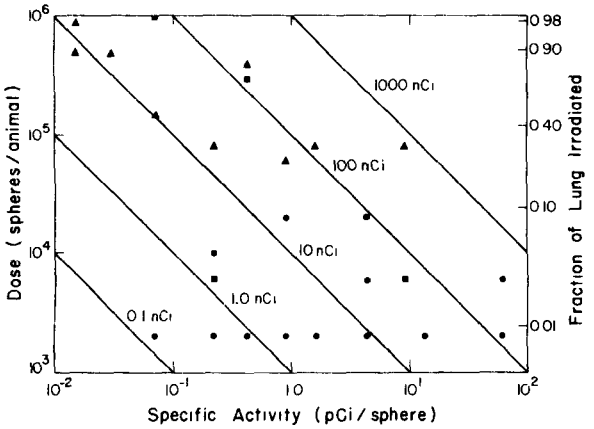

Figure III–9.—Distribution of exposure groups with respect to number of spheres per animal (ordinate) and specific activity of spheres (abscissa). The lines are loci of constant lung burden and are labeled with nCi of plutonium per animal. Symbols indicate year of injection: (●) 1971; (■) 1972; and (▲) 1973 (Richmond and Sullivan, 1974).

by the report of Little *et al.* (1970a) that a high tumor incidence develops rapidly in hamsters exposed to these levels of soluble ^{210}Po.

In a study of $^{210}PuO_2$ particles administered by intraperitoneal injection in rats, about 2% of the plutonium was found in the vasculature of the lung 300–500 days post-injection (Sanders, in press). The mean lung doses from these plutonium particles of > 0.3 μm diameter ranged from 10 to 600 rads for three treatment levels: 0.072, 0.360 and 2.900 μCi. Of 106 rats that survived longer than 200 days (life shortening occurred in the highest dose groups and was due to irradiation of the peritoneal cavity), one rat in the lowest dose group died with a bronchiolar-alveolar adenocarcinoma after 823 days. There was no other primary pulmonary neoplasia and little evidence of cellular reaction to the plutonium particles in the lung, even among those cells adjacent to the particles. Inflammation, fibrosis, and epithelial hyperplasia and metaplasia were not observed. In general these findings agree with the results from the current plutonium microsphere studies at Los Alamos (Richmond and Voelz, 1972, 1973; Richmond and Sullivan, 1974).

The liver has been used to determine the effectiveness of $^{239}PuO_2$ particles in producing chromosome damage relative to the amount produced by ^{239}Pu citrate in the ionic or monomeric form (Schubert *et al.*, 1961). Brooks *et al.* (1974) injected monodisperse $^{239}PuO_2$ particles (0.17, 0.30, 0.44 and 0.84 μm) intravenously into Chinese hamsters. About 90% were deposited and retained with a long effective half life in the liver. Using these four particle sizes and ^{239}Pu citrate, two cytogenetic studies were conducted. In the first, a constant total activity, 1×10^{-3} μCi/gm body weight, was injected using the three sizes of PuO_2 particles. Constant activity and variable particle size produced a constant average radiation dose to the liver with a varied local radiation dose and percent of the liver irradiated. In the second study, a constant particle size, 0.30 μm, was injected with activity ranging from 6×10^{-3} to 6×10^{-5} μCi/g body weight. The local radiation dose rate around each particle was constant in this case and the average radiation dose and number of particles were variable. Unexposed animals and animals administered ^{239}Pu citrate at a concentration of 6×10^{-4} μCi/g body weight were used for comparison purposes.

When the average dose was related to the aberration frequency for the ^{239}Pu citrate (Figure III–10), there was a linear increase according to the equation $Y = 0.02 + 4.8 \times 10^{-3}D$ where Y is aberrations per cell and D is dose in rads. This relationship implies that approximately 200 rads of irradiation from uniformly distributed ^{239}Pu were required to produce an average of 1 aberration per cell. Because cells with radiation-induced chromosome aberrations have poor reproductive potential, these cells can be considered as reproductively dead (Carrano and Heddle, 1974). Abnormalities observed following injection of the particles increased in an approximately linear manner over an average dose range up to about 200 rads, then plateaued at higher doses. The slope of the ascending portion of the dose-response curve for the particles was less than that observed following injection of ^{239}Pu citrate. The relationship between aberration frequency and average dose to a sphere of tissue within the range of alpha radiation from plutonium particles indicates that the efficiency of producing aberrations decreased as the particle size increased. At the smallest particle size, 0.1 μm, the response was close to that seen in animals exposed to ^{239}Pu citrate suggesting that the dose distributions in the liver were similar.

In addition to determining the aberration frequency per cell, the distribution of damage throughout the cell population was also determined. The distribution of damage among liver cells exposed to plutonium particles was non-Poisson, indicating that the damage was limited to relatively few cells, some of which were severely injured. The damage in cells exposed to ^{239}Pu citrate (Brooks *et al.*, 1974) was described by a Poisson distribution, indicating a large number of less severely damaged cells; similar results were observed in experiments with ^{241}Am (McKay *et al.*, 1972) and ^{252}Cf (Brooks *et al.*, 1972). This implies that a larger fraction of the irradiated cells were reproductively dead after nonuniform irradiation than after uniform irradiation, and perhaps also indicates a smaller risk for tumor induction.

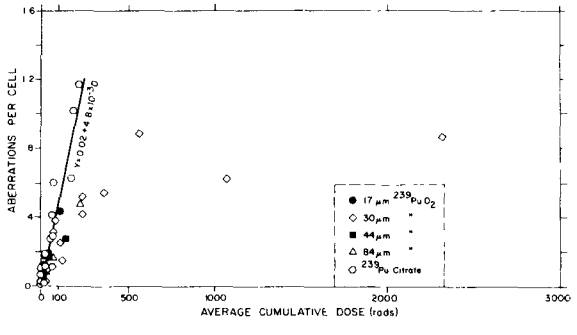

Figure III–10.—Chromosome aberration frequency in the liver of the Chinese hamster following intravenous injections of $^{239}PuO_2$ particles or ^{239}Pu citrate relative to average tissue dose in rads.

Little and co-workers (Little *et al.*, 1970a, 1970b; Grossman *et al.*, 1971; Little *et al.*, 1973) studied the effects of ^{210}Po chloride adsorbed onto hematite (ferric oxide) particles in Syrian golden hamsters following intratracheal instillation. Animals were given 15 weekly injections of 3 mg of hematite containing either 0, 0.01 or 0.2 μCi of ^{210}Po; the mean radiation doses calculated for the entire lung were 225 and 4500 rads, respectively, at the end of one year (Little *et al.*, 1970a). The earliest and highest incidence of pulmonary neoplasia occurred in those hamsters receiving the larger dose of ^{210}Po; the first lung cancer appeared in an animal sacrificed 15 weeks after administration. This experiment showed that lung cancer could be produced in hamsters by alpha radiation, but it did not consider the relative effectiveness of uniform versus nonuniform dose distribution.

In an experiment designed to consider uniform and nonuniform dose distributions (Grossman *et al.*, 1971), four groups of 50 hamsters each were given separate intratracheal instillations twice per week for seven weeks of either 3 mg hematite followed by 0.2 μCi ^{210}Po in saline, saline followed by 0.2 μCi ^{210}Po, saline followed by 0.2 μCi ^{210}Po adsorbed onto 3 mg hematite, or saline followed by 0.2 μCi ^{210}Po adsorbed onto 0.3 mg hematite. In an additional experiment (Little *et al.*, 1973) hamsters were given seven weekly injections of 0.2 μCi ^{210}Po alone in saline. The cumulative radiation dose to the lung was about 800 rads as compared with about 2000 rads when the same amount of activity was given adsorbed on either 3 or 0.3 mg hematite particles. The mean tumor induction time was considerably shorter for the group given ^{210}Po in saline, and the tumor incidence was lowest for the group with the most nonuniform distribution of ^{210}Po.

The major differences among the groups in these experiments was in the microscopic distribution of the ^{210}Po as shown by autoradiog-

raphy. Distribution throughout the lung was distinctly nonuniform for the ^{210}Po contained on hematite. Reduction of the mass of hematite particles from 3 to 0.3 mg should have had the effect of further increasing the nonuniformity of the ^{210}Po in the lung as there were 1/10 as many particles administered and each one contained 10 times as much activity. Preliminary results suggested that an equal amount of ^{210}Po adsorbed on 0.3 mg hematite was even less effective for lung tumor induction than when adsorbed on a larger number of carrier particles of lower specific activity (Table III–D and Fig. III–11).

Little *et al.* (1973) tentatively concluded that ". . . in the dose range studied, alpha radiation is more carcinogenic when a lower but relatively uniform dose is delivered to a large volume of lung tissue than when a similar amount of radioactivity is distributed nonuniformly such that the primary effect is to deliver much higher radiation doses to relatively small tissue volumes."

Studies of a beta-gamma emitter failed to confirm the existence of a unique carcinogenic hazard due to intense irradiation of tissue surrounding radiation particles in lung (Cember and Watson, 1958a, 1958b; Cember *et al.*, 1959; Cember, 1963; Cember, 1964a, 1964b; Cember and Stemmer, 1964). In a series of experiments with intratracheally administered $^{144}CeF_3$ and $^{144}CeCl_3$ in rats, the incidences of pulmonary neoplasia were similar to those observed at comparable radiation doses in experiments where ^{90}Sr containing glass beads were implanted in rat lungs.

Table III-D

INFLUENCE OF DOSE DISTRIBUTION ON ^{210}Po CARCINOGENESIS

Treatment Schedule*		Radiation Dose**	Number of Animals Autopsied 58th Week	Number Still Alive	Number with Lung Tumors	Tumor Incidence
Mon	Wed					
3 mg heme	^{210}Po alone	800 rads	37	0	22	60%
Saline	^{210}Po–3 mg heme	2000 rads	31	6	18	58%
Saline	^{210}Po–0.3 mg heme	—	25	12	9	36%

* Animals received two instillations each week for 7 weeks. Polonium-210 (0.2 μCi) given either alone in saline or bound to hematite particles in amounts indicated.

** Cumulative radiation dose averaged over whole lungs for period up to 1 week after last instillation. These doses tentatively assigned, based on preliminary radiochemical data.

When Cember gave 0, 4.5, 45 or 4500 microcuries of $Ba^{35}SO_4$ as a single intratracheal injection to rats, no lung cancer or any other lesion suggesting that cancer might develop was observed in any of the experimental animals during a nine-month observation period (Cember *et al.*, 1955). When the $Ba^{35}SO_4$ was given as 10 weekly doses of 375 microcuries each, 2 of the 16 rats which survived the injection regime died at 312 and 319 days later with extensive squamous cell carcinomas of the lung (Cember and Watson, 1958b). Calculated radiation doses were on the order of 12,000 rads.

Cember and Watson (1958a) implanted ^{90}Sr containing glass beads in the lungs of rats. The beads contained from 1.09 to 59.3 μCi ^{90}Sr and were 320 ± 110 μm diameter. Seven of the 23 rats (30%) developed primary pulmonary neoplasms: 4 had squamous cell carcinomas and 3 had lymphoid neoplasms. The earliest death in a tumor bearing animal occurred at 169 days following implant. The total radiation dose in these animals, calculated for a sphere of tissue with a radius equal to the range of the beta radiation, ranged from 47,000 to 260,000 rads. Murine pneumonia was a problem with the experimental animals. No acute deaths were due to radiation effects and no life-shortening was observed.

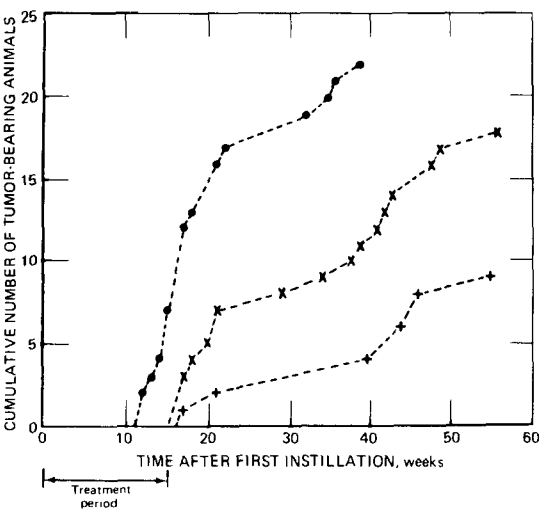

Figure III–11.—Influence of dose distribution on the induction time of lung tumors. Hamsters were given seven weekly intratracheal injections of 0.2 μCi of ^{210}Po and hematite particles by different treatment plans: ●- - -●, ^{210}Po in saline and 3 mg of hematite given on different days each week. x- - -x, ^{210}Po adsorbed onto 3 mg of hematite particles. +- - -+, ^{210}Po adsorbed onto 0.3 mg of hematite particles (see Table III-D).

The experiments of Cember are of considerable relevance to the problem of nonuniform dose distribution. Cember (1964a) stated that the question of the unique carcinogenic hazard associated with the high absorbed dose gradient around a single radioactive particle deposited in the lung seemed to be answered by the results of the acute $Ba^{35}SO_4$ exposures together with the ^{141}Ce experiments. He also pointed out that the negative results of the long term retention of several $Ba^{35}SO_4$ particles, under conditions suitable for testing the hypothesis that such focal radiation presents a unique carcinogenic hazard to the lung, imply the absence of such a hazard associated with one or a very small number of loci. His review also emphasized that, for a given total amount of absorbed energy, low-level, continuous exposure of the total lung may be more carcinogenic than the same amount of energy delivered acutely to a restricted volume of tissue.

Furthermore, Cember (1964a) realized that the quantitative relationship among total absorbed dose, the temporal and spatial distribution of the dose, and probability of developing radiogenic lung cancer had not been established at that time. However, the similarity of the lung tumor dose response curves for soluble $^{141}CeCl_3$ and insoluble $^{141}CeF_3$ suggested the absence of a hot particle effect. He states "should this be true, then it follows that radiation dose to the lung from inhaled radioactive dusts may be calculated, for purposes of estimating radiological risk, by assuming uniform absorption of energy throughout the lung." However, the ^{144}Ce experiments should be interpreted with caution since Cember (1964b) noted that the $^{144}CeCl_3$, which is soluble in solution, produced discrete focal areas of radioactivity in the lung following injection.

In the summary of his review Cember (1964a) states, "Experiments with rats have shown that radioactive substances deposited in the lung can lead to pulmonary neoplasia. Radiations from ^{35}S, ^{90}Sr–^{90}Y, and ^{144}Ce elicited bronchogenic carcinoma and alveolar cell carcinoma in addition to several other tumor types. These experiments did not confirm the existence of a unique carcinogenic hazard due to the intense concentration of absorbed energy in the lung tissue immediately surrounding an inhaled radioactive particle."

Studies reviewed by Moskalev (1972) with inhaled ^{239}Pu citrate or ammonium ^{239}plutonium pentacarbonate have shown a significant increase in the incidence of lung tumors in rats at cumulative absorbed radiation doses to the lung of about 50 rads. Studies in rats reported by Sanders (1973) indicated increased lung tumor formation at 9 and 32 rads following inhalation of ^{238}Pu although the number of tumors in the 9 rad dose group were not statistically significant as compared with unirradiated controls. According to Koshurnikova *et al.* (1968) the microdistribution of ^{239}Pu in the lungs and regional lymph nodes at long times after exposure is characterized by nonuniformity. This has also been observed in dogs, Figure III–3. Therefore, it is likely the radiation dose from the ^{238}Pu in Sanders' study was more distributed in lung tissue than the ^{239}Pu in the studies reviewed by Moskalev, thus irradiating a relatively larger number of sensitive cells. This could account for Sanders finding lung cancer occurring at lower radiation doses from ^{238}Pu than has been associated with ^{239}Pu. However, dose rate cannot be excluded as a contributing factor because the ^{238}Pu in Sanders' experiment was cleared very rapidly from the lungs; nearly all of the radiation exposure occurred within 100 days after inhalation of the ^{238}Pu aerosol.

Preliminary results from studies by Lafuma (1974) and his colleagues with compounds of ^{238}Pu, ^{239}Pu, ^{241}Am and ^{244}Cm in rats indicate that the toxicity increases with the dispersion of the inhaled radionuclide in lung. Curium-244 nitrate was the most highly dispersed and the most toxic at equivalent radiation doses. Curium-244 was also cleared from lung more rapidly than the other radionuclides with a pulmonary retention half-time of only eight days.

The conclusion which results from a careful consideration of these experimental animal studies is clear. None of the results unequivocally prove that plutonium distributed in lung tissue as particles is more hazardous than the same amount of plutonium distributed uniformly. To the contrary, experimental results lead to the conclusion that the hazard of plutonium increases with the dispersion of plutonium within the lung. Although inhaled plutonium is seldom if ever uniformly distributed in lung but is aggregated, a model based on uniform distribution is probably the conservative approach for radiation protection purposes.

IV. HUMAN EXPERIENCE

There has been no recorded incidence of cancer in man resulting from the internal deposition of any plutonium isotope in the more than three decades that plutonium has been used. This excellent record has resulted from extremely effective control methods. The absence of tumors is also significant evidence concerning the tumorigenic potential of plutonium in the lung because a number of wartime accidental exposures occurred three decades ago—a time comparable with probable tumor induction times. Data from occupationally exposed Pu workers, limited as it is, constitutes human experience of the most relevant kind for establishing value judgments where experimental data are not always conclusive for formulating risk evaluations.

During late 1944 and 1945, at what is now the Los Alamos Scientific Laboratory, 29 men associated with the Manhattan Project as plutonium workers were identified on the basis of nose swipes or urine radioassay as having received plutonium exposures (Hempelmann *et al.*, 1973b). Of these, 3 were later dropped from the series as the result of improved assay techniques which indicated lower plutonium burdens than estimated earlier, and 1 died of coronary heart disease. These individuals were all young men involved in four basic operations related to the development of the first nuclear weapons: plutonium purification (wet chemistry); fluorination (dry chemistry); reduction to metal; and recovery.

Clinical and laboratory data from this group of men have been collected periodically since 1953. These data consisted of medical histories, physical examinations, blood counts and chemistry, urine radiochemistry, routine urinalysis, and roentgenograms (Hempelmann *et al.*, 1973b). Studies of sputum cytology, lymphocyte karyology, and chest counting for uranium L x-rays were begun in 1970. Table IV–A shows information on estimated date of exposure and estimates of the body burden as determined by urine radiochemistry measurements made in 1953 and 1972 (Hempelmann *et al.*, 1973a). In all cases, the values represent estimates of the body burden based on a urine excretion model obtained from human data (Langham, 1957). In all cases but two, the 1972 estimates are higher than those for 1953, usually by a factor of 2–3 and occasionally by a factor of 5–6. The 1972 estimates are considered to be more relevant as they are based

Table IV–A

PLUTONIUM BODY BURDEN ESTIMATES FOR MANHATTAN PROJECT PLUTONIUM WORKERS

Subject Number†	Average Date of Exposure	ESTIMATED SYSTEMIC BODY BURDEN* 1953	1972
1	Late 1944	0.03–0.06	0.206
2	Late 1944	0.006–0.032	0.03
3	May 1945	0.08	0.42
4	June 1945	0.08	0.26
5	June 1945	0.08	0.18
6	June 1945	0.06	0.14
7	June 1945	0.06	0.15
8	June 1945	0.04	0.11
9	July 1945	0.06	0.11
10	July 1945	0.05	0.10
11	July 1945	0.03	0.05
12	July 1945	0.03	0.12
13	July 1945	0.02	0.005
16	July 1945	0.006	0.03
17	August 1945	0.04	0.13
18	August 1945	0.04	0.10
19	August 1945	0.03	0.02
20	August 1945	0.02	0.05
21	August 1945	0.02	0.04
22	August 1945	0.02	0.05
23	September 1945	0.02	0.04
24	September 1945	0.006	0.03
25	September 1945	0.006	0.01
26	October 1945	0.02	0.006
27	October 1945	0.02	0.05

Microcurie ± approximately 50% at the year indicated.

† Subjects #14 and #15 were dropped because of the death of one subject from coronary heart disease and the low body burden of the other as determined by modern assay techniques. Two others, not shown, were dropped from the original 29.

upon more excretion data and improved analytical techniques. High plutonium levels of nose swabs at the time of exposure suggested that most of the subjects received their exposure via inhalation.

Based on data shown in the last column of Table IV–A, the 25 men shared a total systemic plutonium burden of approximately 2.5 μCi in 1972. If one assumes, as a rough approximation, that 25% of the initial lung burden was translocated from the lung to the systemic circulation and then to organs such as the liver and bone, it follows that the total initial lung burden for this group of men was approximately 10 μCi.

During the most recent examinations performed at Los Alamos (Hempelmann *et al.*, 1973a) estimates were made of the amount of plutonium in the chest (lung and respiratory lymph nodes) of each man using *in vivo* chest counting techniques. At 27 years following contamination, 14 of the 21 men measured had calculated chest burdens ranging from 0.003 to about 0.010 μCi. This observation indicates that some of the plutonium was inhaled or retained in a relatively insoluble form, which is consistent with the fact that some of the individuals were known to have been exposed to $^{239}PuO_2$ because of the work they performed. Studies of these and other men are continuing.

Except for the ailments one would expect in a group of men mostly in their early fifties, all of the Manhattan Project workers are in remarkably good health. This is additional information that tends to support the general argument that the radiation protection guides for plutonium have not been grossly in error. Although the study group is relatively small (25 men), the magnitude of the plutonium burdens, the long time since exposure, and the cooperativeness of the men make it unique and extremely valuable. However, because something like 16 to 20% of all deaths annually in the United States are from cancer, one might be concerned about the size of the group, as 4 or 5 might be expected to die from "naturally occurring" cancer had they never been exposed to plutonium. However, evidence obtained from experimental animal studies indicates that plutonium induces specific kinds of cancer, primarily lung carcinomas, bone sarcomas, and to a lesser extent bile duct tumors, depending on the route of exposure.

Although the particle size distribution of the inhaled material is unknown, an estimate can be made on the basis of aerosols produced by somewhat similar incidents. The value of 0.32 μm for the mass median diameter was measured for an incident involving a fire at the Rocky Flats facility in 1965 (Mann and Kirchner, 1967) and is similar to values found in a glovebox at a fuel fabrication plant by Raabe (in preparation) and by Moss *et al.* (1961) for plutonium aerosols in plant and laboratory operations. Ettinger *et al.* (1973) report various particle sizes for several operations. For a recovery operation, a submicron aerosol had a typical activity median aerodynamic diameter of 0.3 μm.

If one assumes a log-normal particle size distribution with a mass median diameter of 0.32 μm, standard geometric deviation (σ_g) of 1.83, and a density of about 10 g/cm^3, the number of particles above a given size can be calculated. In this case, about 15% of the mass can be shown to be associated with particles larger than 0.6 μm real diameter (about 2 μm aerodynamic equivalent diameter). One can then calculate that each person in the group of 25 men might have retained about 4×10^5 particles above 0.6 μm diameter (0.07 pCi or more per particle) from the orginal 10 μCi. If the cancer risk for such "hot particles" were 5×10^{-4} per particle, as postulated by the Natural Resources Defense Council report (Tamplin and Cochran, 1974), the 4×10^5 particles should yield about 200 cancers per man or about 5000 for the group. Even the residual plutonium (average of 6 nCi per man) measured in 14 of the original Manhattan Project plutonium workers should yield 3 cancers per person. One could also argue that the number of cancers predicted from such a risk estimate might be ten times larger as the product of 10^8 particles (10 μCi $\div$ 0.07 pCi), each 0.6 μm real diameter, and the risk estimate of 5×10^{-4} per particle yields 5×10^4 tumors for the group. The observed lung cancer incidence after almost 30 years since exposure is zero.

Because of observations of chronic lymphopenia in dogs exposed to plutonium oxide aerosols, one might expect to observe chromosome damage in lymphocytes of exposed plutonium workers. This observation led Dolphin (1971) to investigate the possibility of chromosomal aberrations in lymphocyte cultures obtained from workers in England known to have been

exposed to plutonium. He compared the findings in eight plutonium workers who had been exposed to plutonium plus 14 rad of external irradiation over a 7-year period with workers who had received external irradiation only and found that the dicentric yield of lymphocytes of the plutonium workers could be accounted for by the external radiation dose received by the workers. Dolphin (1971) also cites another case in which a plutonium worker was found, by chest-counting, to have 10 to 20 times the permissible level of plutonium in the lung about three years after an inhalation accident. Chromosome analysis indicated minimal radiation exposure to the lymphocyte series even at a high level of exposure of the subject.

Brandon *et al.* (1973) reported an increased incidence of chromosomal aberrations in plutonium production workers at the Dow Rocky Flats plant. These investigators contrasted chromosomal aberrations observed in lymphocyte cultures from six unexposed controls, seven workers exposed to penetrating radiation, and 27 men thought to have internal deposition of plutonium. Although the workers with lung burdens of plutonium had levels of chromosome aberrations greater than those observed for controls, the highest incidences of chromosomal aberrations were observed in plutonium workers who were thought to have primarily liver and bone burdens rather than significant lung burdens. Because some of these individuals worked around hot cells, the contribution to the total radiation dose (plutonium plus penetrating radiations) from the penetrating radiation is uncertain and complicates the analyses.

The most recent physical examinations were performed on 24 of the 25 Manhattan Project workers during the past several years (Hempelmann *et al.*, 1973a). In addition to the usual hematological procedures, blood samples were obtained from these men for chromosomal studies. Utilizing established cytogenetic techniques for cultured lymphocytes, no chromosomal abnormalities were found in any of the subjects. However, it is planned that recently developed chromosomal banding techniques will be utilized in the future in evaluating the presence or absence of lymphocyte chromosomal aberrations.

Despite their relative rarity, much useful information has been obtained from accident cases. Information obtained from the AEC's Division of Operational Safety indicates that, during the period 1957–1970, there have been on the order of 200 contractor personnel exposed to 25% or more of the maximum permissible body burden (MPBB) for plutonium. These data also indicate that inhalation is the major portal of entry and that more than half of the cases are below 50% of the MPBB (0.04 μCi).

It may be instructive to look at a specific instance of an industrial accident which was reported by Mann and Kirchner (1967). On 15 October 1965, a fire in a plutonium fabrication plant resulted in a large-scale spread of plutonium oxide. The Rocky Flats body counter was used to measure the plutonium in the lungs of all employees working in the area and, of approximately the 400 employees counted, 25 were found to have enough plutonium in their lungs to deliver a dose of 15 rem per year or greater (i.e., at least 0.016 μCi). Data from each employee were obtained with a pair of scintillation detectors in contact with the subject's chest; the 60 keV photon peak of ^{241}Am was used in the measurements. The ^{241}Am content of the plutonium released in the fire was determined, and the plutonium quantity was then estimated from calibrations using a chest phantom with similar ^{241}Am/^{239}Pu ratios. The plutonium consisted of "high-fired" PuO_2; particle size measurements of air samples collected after the fire indicated a 0.32 μm mass median diameter (MMD) with a geometric deviation (σ_g) of 1.83. Lung counting data to date show a slow clearance of plutonium, confirming the high degree of insolubility of the inhaled material. On the average, 30% of material initially deposited in the lung was cleared in 2 to 3 months, with the remaining material clearing slowly with little or no measurable absorption into the bloodstream.

Of the 25 people who were involved in the Rocky Flats incident, two had burdens as high as 0.16 μCi, a factor of 10 above the current maximum permissible lung burden. Of those available for follow-up, most are measured for retained activity several times each year. Information from these cases should ultimately be included in the U.S. Transuranium Registry (USTR).

By using the same assumptions employed above for the Manhattan Project workers, one can estimate the number of "hot particles" [e.g., more than 0.07 pCi per particle as de-

fined by Tamplin and Cochran (1974)] retained in the deep lung of each of the involved Rocky Flats personnel to be about 10^4 to 10^5. Again, if the cancer risk were 5×10^{-4} per particle, as postulated by the Natural Resources Defense Council report (Tamplin and Cochran, 1974), these particles should yield 5–50 lung cancers per person. To date, none of these workers has shown detrimental effects associated with his inhalation exposure of "insoluble" plutonium oxide in 1965. In this regard, an increased incidence of lung cancer has been reported as early as 5 to 9 years after uranium miners were exposed to radon decay products and other biological stressing agents such as tobacco smoke and diesel fumes (Lundin *et al.*, 1971).

The local dose to tissue from each of the approximately 10^4 to 10^5 "hot particles" retained in the lungs of the Rocky Flats workers, assuming a sphere of lung tissue at risk (180 μm radius) around each particle, is about 1200 rad/yr. Assuming an effective half-life for lung clearance of 500 days, the cumulative local dose to some cells over the 8.5 years for each particle might be 2400 rad. This calculation assumes a static particle irradiating a fixed group of cells. Calculations based upon other models (e.g., moving particles) would result in smaller doses. Based on this information, one might expect detectable biological effects in the lung to have occurred in some of these exposed workers, yet none has been reported to date.

One case of plutonium contamination resulting from a puncture wound is extremely interesting, as it has been interpreted by some as resulting in a "precancerous lesion" (Tamplin and Cochran, 1974). In this reference, the following statement is made: "This precancerous lesion indicates that a single plutonium-239 particle irradiates a significant (critical) volume of tissue and is capable of inducing cancer." Information on this case was originally published in 1962 (Lushbaugh and Langham, 1962) and appeared again with additional information in 1967 (Lushbaugh *et al.*, 1967).

The radiation dose around the plutonium implanted in the palmar skin was estimated to be 75,000,000 rad for the 4.25 year period between contamination and excision. However, this kind of estimate may be meaningless, as we do not know which cells were exposed or for what time periods. The entire lesion was small, being of the order of 2.8×10^{-5} cm^3.

The authors (Lushbaugh and Langham, 1962) stated:

> "Although the lesion was minute, the changes in it were severe. Their similarity to known precancerous epidermal cytological changes, of course, raised the question of the ultimate fate of such a lesion should it be allowed to exist without surgical intervention. Although no malignancies of the skin of man have ever been shown autoradiographically to be associated with such alpha-emitting foreign bodies, the changes here would seem to indicate that the development of such a lesion is possible."

This particular case has been referred to as representing a "precancerous" condition resulting from plutonium (Tamplin and Cochran, 1974) and might have been the basis of a recent statement (Gillette, 1974) which reads as follows: "Only one human cancer case is clearly linked to plutonium exposure." Actually, no human cancer case has ever been 'clearly linked" to plutonium exposure. The U.S. Transuranium Registry (Norcross and Newton, 1972) continues to attempt to correlate postmortem findings with body plutonium measurements.

Cytologic changes have been described in cells in the vicinity of embedded plutonium particles in man. However, the malignant cellular transformation required for the diagnosis of actual cancer has never been found next to "hot particles" in human tissue (Lushbaugh and Langham, 1962; Lushbaugh *et al.*, 1967). Similar results have been reported for several animal experiments designed to study the biological effects of hot particles (Richmond *et al.*, 1970, 1974). On the other hand, under certain exposure conditions, plutonium is an efficient cancer-producing agent in experimental animals.

For many years, several AEC contractor laboratories have conducted tissue analysis programs to determine plutonium levels in various tissues of both occupationally exposed personnel and members of the general population (Lagerquist *et al.*, 1972; Nelson *et al.*, 1972; Campbell *et al.*, 1973). For example, as shown in Table IV–B, plutonium concentrations have been determined for lung, liver, lymph nodes, kidney, and bone for the period 1959–1971 for nonoccupationally exposed persons from several regions of the United States and for occupationally exposed persons. Similar data have been obtained from nonoccupationally exposed persons for the period 1972–1973, as shown in

Table IV–C (Richmond and Sullivan, 1974). The average lung concentration for the latter period is about 0.3 pCi for the 1000 g lung, and the lymph node concentration (per kilogram) is about 11 pCi. The increase in lymph node concentration is due to greater care in lymph node excision; the mass of relevant tissue excised was reduced 5–7 fold, with consequent apparent increase in Pu concentration.

Plutonium is present in extremely small quantities in various organs of contemporary adult humans. Although most of the plutonium was produced from atmospheric testing of nuclear weapons prior to the 1963 limited test ban, some material from contemporary atmospheric weapons testing by China and France adds to the total human burden. The current lung burden estimate for persons in the United States is about 0.3 pCi ^{239,240}Pu, and an estimate of the total amount in the body is about 3.2 pCi (Bennett, 1974).

The AEC's Health and Safety Laboratory (HASL) recently has used information obtained from the International Commission on Radiological Protection to model the intake and body burden from fallout plutonium and to estimate the radiation dose to man from this source (Bennett, 1974). The cumulative lung and bone dose estimated from the period 1954–2000 is 16 and 34 mrem, respectively. Bennett (1974) also compared the body burden based on their model with that actually obtained from the tissue sampling programs. The agreement between the Colorado-New Mexico tissue data and the model predictions for 1970 and 1971 was good.

Table IV–B

50th Percentile Distribution of Plutonium in Human Tissue (1959-1971)

	Plutonium Disintegrations per Minute per Kilogram				
	Lung	Liver	Lymph Node	Kidney	Bone
Nonoccupationally Exposed:					
Los Alamos	1.3 (57)*	1.1 (58)	5.0 (52)	0.1 (54)	0.4 (35)
New Mexico and U.S.	1.0 (76)	0.9 (73)	4.0 (66)	0.2 (66)	0.5 (41)
Colorado	0.5 (66)	1.7 (60)	2.0 (46)	1.4 (45)	0.9 (65)
New York	0.4 (26)	1.7 (26)	†	†	2.0 (25)
All Populations	0.8 (217)	1.4 (217)	3.0 (164)	0.6 (163)	0.6 (166)
Occupationally Exposed: ‡					
Potential	4.0 (44)	1.0 (41)	15.0 (42)	0.1 (42)	0.3 (25)
High Potential	100.0 (15)	100.0 (15)	700.0 (14)	10.0 (13)	50.0 (11)

* Number of samples (in parentheses).
† Samples not requested.
‡ Data cannot be compared as a group because of differences in type and duration of exposure.

Table IV–C

50th Percentile Distribution of Plutonium in Human Tissue (1972-1973)

	Plutonium Disintegrations per Minute per Kilogram					
	Lung	Liver	Lymph Node	Kidney	Vertebrae	Gonad**
Nonoccupationally Exposed:						
Los Alamos	0.8 (8)*	1.6 (5)	35 (4)	0.2 (5)	1.6 (5)	
New Mexico and U.S.	0.4 (17)	0.7 (10)	20 (15)	1.2 (10)	0.4 (16)	
Colorado	0.7 (29)	1.8 (25)	15 (22)	3.0 (25)	1.1 (25)	
Savannah River	0.4 (20)	1.2 (14)	40 (6)	2.2 (11)	0.7 (12)	
All Populations	0.6 (74)	1.5 (54)	25 (47)	1.5 (51)	0.7 (58)	0.4 (30)

* Number of samples (in parentheses).
** 7 samples from Savannah River
9 samples from New Mexico and U.S.
14 samples from Colorado

V. THEORETICAL CONSIDERATIONS

A. Dosimetry

The distributions and interactions of the absorbed energy from alpha-emitting plutonium particles among the cellular elements in lung tissue are difficult to examine experimentally and, therefore, have to be considered on a theoretical basis. This requires integrating our knowledge of the properties of alpha radiation with our understanding of the dynamic characteristics of lung, the cell types which populate lung tissue and the interactions which occur between cellular constituents and plutonium particles.

1. Alpha Particle Irradiation of Cells and Tissues

The two plutonium isotopes of primary concern are ^{238}Pu and ^{239}Pu which emit alpha particles of average energy 5.5 MeV and 5.15 MeV, respectively. In passing through a medium such as tissue or air, alpha particles lose energy by collisions with electrons of atoms, producing charged atoms and free electrons or delta rays. The delta rays cause further ionization events. Alpha particles from plutonium have a range of about 40 μm in soft tissue of unit density. The energy of the alpha particle drops to zero at the end of its range. The average loss of energy per unit of path (Linear Energy Transfer, LET) is about 140 keV/μm. However, the loss of energy per unit of path length and the number of ionizing events it produces actually increase along the path of the alpha particle as the energy of the particle approaches zero (the Bragg effect). Ninety percent of the ionization events occur within a cylindrical volume of about 0.01 μm radius around the alpha particle track; most of the remaining 10% occur out to about 0.2 μm.

This pattern of energy dissipation differs greatly from that of electrons (beta radiation or secondary to x and gamma radiation) which are characterized by values of LET that are two or three orders of magnitude smaller. Consequently equal absorbed doses of alpha and electron radiation, although by definition are depositions of equal energy per unit mass of irradiated material, produce drastically different energy distributions at the microscopic level which can be numerically expressed in terms of the quantities of microdosimetry.

The *specific energy*, z, is the energy imparted to the matter in a specified volume divided by its mass. The average or expectation value of specific energy, $\bar{z}$, is equal to the absorbed dose but z may fluctuate greatly around this value (ICRU Report 19, 1971). If a region in tissue is traversed by a particle, the resulting increment of z depends on the LET of the particle and on the length of track within the sphere but a mean always can be specified for a given set of conditions. Thus, for the alpha particles under consideration, and 2.5 μm diameter nuclei (within essentially spherical "cells"), the mean z deposited in such a nucleus is about 500 rads and this value is independent of the absorbed dose, $\bar{z}$. At absorbed doses that are much less than 500 rads most nuclei experience no traversals; the number of nuclei that are traversed is proportional to the absorbed dose and the mean value of z in these nuclei is independent of dose. When absorbed doses are comparable to 500 rads, the probability for multiple traversals becomes appreciable and higher average values of z in traversed cells result (Rossi, 1967).

The same considerations apply to electrons but the numerical values are quite different. Thus, an electron having an LET of 0.3 keV/μm will in traversing the 2.5μm diameter volume impart an average increment of z that is about 1 rad. Hence, at an absorbed dose, $\bar{z}$, of 50 rads where one in 10 nuclei is traversed by an alpha particle delivering an average z (dose to the nucleus) of 500 rads, electrons will traverse almost all nuclei and z will differ little from 50 rads.

2. Biological Factors in Alpha Radiation Dosimetry

In Part III of this report it was pointed out that all inhaled particles, including plutonium and aggregates of plutonium, are subjected to numerous physical and biological forces which tend to remove the particle from the respiratory tract. Therefore, plutonium does not remain static in lung tissue unless the plutonium becomes immobilized in scar tissue, bound to biochemical moieties, or otherwise trapped. However, as evidenced by the relatively long retention time of plutonium in lung, much of the plutonium deposited is made inaccessible for ready clearance by some mechanism such as immobilization or recycling through generations of the several types of cells capable of phagocytizing particles. All of this contributes to the complexity of the spatial and temporal distribution of the absorbed radiation dose from plutonium in lung.

Lung tissue surrounding particles will be irradiated at relatively constant rates, assuming the particles are fixed intracellularly, extracellularly or trapped in alveoli blocked by cellular products or debris. The amount of radionuclide and solubility of the particles will influence the biological damage to the cells. However, relatively soluble plutonium may be chemically bound in cellular material and be retained in lung for a long time, e.g., studies with inhaled $Pu(NO_3)_4$ (Ballou and Park, 1972).

The degree of isolation of particles by cellular debris, fibrosis, and similar changes consequent to biological damage caused by irradiation or physical and chemical irritation of the surrounding tissue is an important consideration. Because alpha emissions from ^{238}Pu and ^{239}Pu have a range of approximately 40 μm in unit density tissue, the degree of this walling-off effect will be a major factor in dosimetric considerations. Complete "walling-off" of the particle might reduce the risk from the alpha emissions to lung epithelial cells greater than 40 μm from the particle boundary, but the risk from the delta rays, X, and gamma radiation accompanying the ^{238}Pu and ^{239}Pu will not be reduced proportionally. Work at Los Alamos (Richmond *et al.*, 1970) and studies at Battelle (Sanders and Park, 1972) indicate this "walling-off effect" is present but variable in thickness. This "walling-off" effect has not been observed in recent studies in which lower specific activity alpha-emitting particles are used (Richmond and Sullivan, 1974).

Another factor is cell turnover. With any given radiation dose rate, the total radiation dose to a given cell will be determined by the time interval between cell divisions. The consequence of a cell being irradiated will be expressed at each cell division by selection against badly damaged cells (i.e., cell death) and by replication of surviving damaged and transformed cells. Thus, to some extent the frequency of cell division will have a bearing on the cellular response to radiation from internally deposited radionuclides. Values for turnover time for the various lung cell types are 5 to 80 days for epithelial cells and a few hundred days for endothelial and mesothelial cells (Shorter, 1970). Of equal importance is the relative radiation sensitivities of the cells. There are little or no useful data available to establish a quantitative relationship between the radiation dose to specific cell types in lung tissues and subsequent biological effects of a health risk nature. It is inevitable that knowledge of the relationship between the dose rate, the probability of sublethal "hits" by alpha particles, the identity of the cells sensitive to the carcinogenic action of radiation and the cell turnover time could lead to a more accurate assessment of the health risks from inhaled alpha-emitting radionuclides.

Consideration of air absorption in the small sphere of lung tissue irradiated by a radioactive particle can be ignored because of the small amounts of air in that volume and the relatively low energy loss in air. The average range of a 5.1 MeV alpha particle in lung tissue with a specific gravity of 0.22 is on the order of 180 μm, and the fraction of the alpha particle energy deposited in air is 4×10^{-3}. An alpha particle can travel about 4 cm in a long, straight airway such as a bronchus. Thus, a small portion of tissue interactions with alpha emissions from plutonium particles can occur at some distance from the source. For example, about 2% of alpha particles penetrate beyond 400 μm from their source (Richmond and Voelz, 1973) and about 40% penetrate beyond 180 μm. About 50% of the alpha energy is absorbed within the confines of one alveolus or within 100 μm of the source (Sanders and Dionne, 1970). Interactions of these long-range alpha particles tend towards dispersal of the absorbed radiation energy in lung tissue.

A minor factor in dosimetric considerations of radioactive particles in the lung is movement during the respiratory cycle of tissue relative to a deposited radioactive particle. For the most part, tissue movement would be such as to increase or decrease the radius of the exposure field concentric with the particle. While the volume would change somewhat during these movements, the mean volume would apply for dosimetry calculations as they relate to possible biologic effects. During a respiratory excursion, particles will tend to move with the tissue in which they are contained. The same cells will be at risk, regardless of the variability of the volume of the tissue sphere.

These biological considerations emphasize the importance of the dynamic characteristics of lung tissue and of particles deposited in this tissue. Although the kinetics of the interactions of plutonium particles and their alpha emissions with cells in lung are not known, they are certainly more complicated than a fixed source of plutonium particles irradiating a static population of cells within a 40–50 μm range.

3. Models for Dosimetry and Tumor Probability

There have been a number of attempts to understand the spatial distribution of energy from alpha emitters deposited in lung by development of models using computer technology applied to various representations of lung architecture. From the preceding discussion it will be obvious that all of these models are deficient in respect to biological considerations.

Scientists at Los Alamos (Richmond and Voelz, 1973) developed a model to determine the number of cells which receive given radiation doses as a function of distance from plutonium microspheres. A first objective of this model was the identification of the effect of lung structure on radial distribution ("radial interaction" function) of encounters between alpha tracks and cells for calculation of dose. Photomicrographs of thin sections of hamster lungs were scanned by a high resolution densitometer, and the digitized images were stored on magnetic tape. Numerical evaluation of the radial interaction function was accomplished by a Monte Carlo technique operating on the digitized images. Mean intercept lengths of alpha tracks in air and tissue were varied by digital manipulation of the images to determine the effects of such parameters as lung density, alveolar size, and wall thickness. These investigators found that lung density could be eliminated as a parameter by appropriate normalization (e.g., expressing "distance" as mass per unit area) but that the scale factor of lung structure (ratio of characteristic dimensions to the range of alphas in tissue) had a profound effect on the radial distribution of energy deposition.

Dean and Langham (1969) developed a theoretical approach to estimating tumorigenic risk from exposure of skin and lung to high specific-activity particles of ^{235}U, ^{238}Pu, and ^{239}Pu. The radiation dose from discrete sources was treated in such a manner that an estimate of the individual cellular response can be made. Dose averaging was not used in the model. Particle movement within the lung was taken into consideration (500-day half-time) and lung density of 0.26 g/cm^3 was assumed. The tumor probability versus dose-response curves, which are the basic ingredients of the model, were taken from the rat skin tumor data (Albert *et al.*, 1967a, 1967b, 1967c). Dean and Langham (1969) point out that the rat is sensitive to skin tumor development and that sensitivity may be different for the human lung. In their model, calculations of the lung tumor probability per particle as a function of particle size show peak responses at about 10^{-1} for a 1 μm diameter ^{238}Pu particle and about 10^{-1} for a 5 μm diameter ^{239}Pu particle.

At the 1 μm diameter size, the tumor probability for ^{239}Pu is three orders of magnitude lower (10^{-4}) as compared with ^{238}Pu (10^{-1}). Dean and Langham (1969) compared the lung dose from 0.016 μCi of ^{239}Pu for 720 days following an acute exposure using the dose averaging technique (3.2 rad) and their model (1.6×10^6 rad absorbed by 3×10^5 cells). This model, like others, makes no allowance for cell repair, turnover and replacement; it does provide for "wasted radiation" and assumes that the Albert data for rat skin (Albert *et al.*, 1961; Albert, 1962; Albert *et al.*, 1967a, 1967b, 1967c) can be applied to lung.

Geesaman (1968) proposed a cubical lattice model to represent clusters of alveoli with elastic walls of uniform thickness. The geometrical representation was a honeycomb-like structure comprised of truncated spheres (the alveoli) wrapped around a duct (the bronchioles). The volume of "tissue" irradiated by a 1 μm $^{238}PuO_2$

particle embedded in the lattice was calculated by considering the angular dependence of the geometrical range of alpha emission in the cubical lattice. Alpha radiation emitted along the lattice axes, in the lattice, and in a sphere about the particle would penetrate about 100 alveoli, according to this model, and irradiate about 10^5 endothelial and epithelial cells. Using published values for turnover times of lung cells and observation of the response of lung cells to a high dose of x-rays, of cultured kidney cells to alpha particle radiation, and of cell cytoplasm to protons, Geesaman estimated that, unless the $^{238}PuO_2$ particle is less than about 0.25 μm diameter, the yearly alpha flux will be lethal for all epithelial cells in the exposed volume of tissue. The equivalent "critical" size for a $^{239}PuO_2$ particle was 1.75 μm. The calculations are for a static source. A moving source will expose a larger volume of tissue, but, according to Geesaman (1968), if the distance traversed is only to an adjacent ciliated bronchiole, the irradiated volume would probably not increase by an order of magnitude. However, one can calculate the distance from an alveolus to the ciliated epithelium to be about 8000 μm (Weibel, 1963) or about 45 times larger than the 180 μm range of a 5.1 MeV alpha particle in lung tissue of density 0.22 g/cm^3. Therefore, the irradiated volume would increase by several orders of magnitude, but the duration of exposure would be drastically shortened as the particle would be removed from the lung after reaching the ciliated epithelium. On the basis of his model, Geesaman concluded that the carcinogenic risk does not scale with the total energy from a plutonium particle.

Using Davies' (1961) model of the alveolar region of the lung, Coleman and Perez (1969) developed a cylindrical model of the nonciliated region of the lung comprised of the respiratory bronchi, alveolar ducts, atria, alveolar sac, and the alveoli. The structure of the lung was assumed to consist of parallel, cylindrical air ducts arranged in such a way that the minimum distances between any adjacent ducts are equal and with maximum ratio of air volume to total volume. The space between air ducts is the tissue volume. This model was deemed adequate for calculation of "smeared" doses but was refined for "local" dose considerations to include "cellular" structures lining the alveoli and a coordinate system. Dose rates in rads per second were calculated for tissue surrounding a static particle from point sources of ^{238}Pu and from volume sources.

Plutonium particles do not reside for long periods of time in the tracheobronchial region of the lung. However, the possibility for exposure of these tissues occurs during inhalation of plutonium and during transport of particles cleared from the lung on the ciliated epithelium. Animal experiments have shown the bronchiolar-alveolar region of the lung rather than the bronchial epithelium to be the primary site of particle retention and the major site of damage induced by inhaled plutonium. However, in addition to tumors of bronchiolar-alveolar origin, a few epidermoid carcinomas were incidental findings at necropsy in beagle dogs at long times after the inhalation exposures (Howard, 1970). To compare the relative radiation doses to the bronchiolar, bronchial and tracheal epithelium from inhaled plutonium, Harley and Pasternack (in press) derived dose curves for 0.06 μm and 2 μm $^{239}PuO_2$ particles from which the dose in rads per minute at any depth in the epithelium of the trachea and terminal bronchioles could be computed. The difference in the dose rates for the largest airway (trachea) and the smallest airway (terminal bronchioles) was small and, therefore, dose rates for intermediate airways were inferred to be about the same. For continuous exposure to the ICRP maximum permissible concentration of 10^{-11} μCi/cm^3 air, the maximum annual dose from 0.06 μm diameter $^{239}PuO_2$ particles is 0.014 rad at a depth of 22 μm in the epithelium of terminal and subsegmental bronchioles. The maximum annual dose from 2 μm particles was similarly calculated to be 1.2×10^6 rad, delivered to the segmental bronchioles.

Recently Mayneord and Clarke (1974) completed a mathematical study of the carcinogenic risks associated with radioactive particles using a nonlinear peaked cellular dose-response function, a power law response. Assuming that all cells of a tissue are equally at risk, it was concluded that beta radiation from a point source of ^{86}Rb or ^{35}S is more hazardous at low source strengths than the same activity uniformly distributed; however, the opposite is true at high source strengths. The mean dose at which the transition occurs increases with the beta energy emitted by the particles and with increasing organ mass and

power law cellular response. However, if the tumorigenic response is a linear function of dose, the uniform tissue irradiation rather than the point source gives the greatest expectation. Under the most pessimistic conditions of numbers of hot particles of both high and low beta energy, the authors conclude that the carcinogenic risk is not more than about a factor of 10 greater than predicted by a linear hypothesis. With alpha radiation the expectation of events which might lead to cancer from a point source is greater than that from uniform irradiation of the same amount of energy for point source strengths up to that at which cell killing predominates. However, because of the small number of particles emitted the authors question the application of this macroscopic method and suggest that the stochastic methods of microdosimetry might be a better approach. The authors conclude, that in the light of present knowledge of cellular response, spatial distribution of cells at risk and localization of particles within tissue, the use of mean organ doses and the assumption of a linear relationship between dose and effect is a reasonable guide to estimating the carcinogenic risks from radioactive particles.

These dosimetric models can be useful in understanding how a given biological effect such as cancer occurs following deposition of plutonium in lung and might even lead to identification of possible mechanisms for cancer induction. However, because these models are deficient with respect to the biological aspects of plutonium in lung (in most cases for the simple reason that the biology is not adequately known), the models are not dependable for predicting the health consequences of plutonium. In fact these models can be used to yield almost any answer desired.

B. Radiation Carcinogenesis Relative to Spatial Distribution of Dose

The calculated radiation doses around hot particles are an unreliable base for the calculation of biological effects because of the lack of adequate biological models for carcinogenesis. Experimental data, meager as it is in some instances, is more valuable than models based upon *calculated* radiation doses, which in themselves may be very uncertain, and upon inferences from other organ systems that may have no relevance to the organ system in question. This latter point is particularly true for the use of dose-effect models derived from rat skin data as the basic input for models of human lung carcinogenesis arising from radiation.

The importance of understanding wasted radiation before trying to solve the "hot particle" problem cannot be overemphasized. Because of the pattern of alpha energy deposition in a tissue volume around a given plutonium particle, the nearest cells are virtually all killed while those more distant are either exposed to very low radiation doses or are not irradiated. Because of the short range of the alpha particle, most of the deposited energy is absorbed within extremely small tissue volumes. Depending on the number of particles and their dispersion and mobility, much of the lung may be unaffected.

These observations lead one to a hypothesis to explain the relative sparing effects on tissue of alpha particle radiation associated with plutonium particles as compared with a more uniform distribution of energy. The following discussion considers primarily those cells that are affected in some manner but not killed by the alpha irradiation (Richmond *et al.*, 1970). A large variety of cellular changes can result from alpha irradiation, yet only a small percentage of these changes can lead to carcinogenesis. Because of the many possible alterations, the chance of the specific change or combination of changes required to produce an oncogenic response is extremely unlikely to occur in any single cell. There is a large probability that death of a cell would precede the occurrence of the critical random events that would result in an oncogenic response; however, if one administers sublethal radiation doses to a sufficiently large number of cells, it becomes more probable that oncogenic changes would occur, depending upon the cell number and the radiation dose. This idea has been mentioned by numerous authors, including Archer and Lundin (1967).

A common hypothesis is that a direct linear relationship exists between radiation-induced neoplasms and ionizing events per cell multiplied by the number of cells irradiated. However, for nonuniformly distributed alpha radiation the "wasted radiation" must be considered. Although the quantification may not be clear, it is obvious that the amount of

tissue irradiated is an important factor in the production of cancer. Cember (1964a) stated:

> ". . . , the likelihood of inducing lung cancer seems to increase as the volume of irradiated lung tissue increases—that is, as the number of radiation foci increase and overlap. Furthermore, the experimental results imply that the carcinogenicity of a given amount of absorbed radiation energy increases, up to a point, as the absorption of energy is spread out both time- and space-wise. From a practical point of view this means that, for a given amount of absorbed energy, low-level, continuous exposure of the total lung may be more carcinogenic than the same amount of energy delivered acutely to a restricted volume of tissue."

Others have postulated models for cancer induction in which a "threshold" volume or minimal mass of tissue must be damaged before the carcinogenic process of unlimited cellular proliferation overrides the inhibitory mechanisms regulating growth processes (Rashevsky, 1948). There is evidence that transformed cells in physical contact with normal unaffected cells are prevented from dividing (Sivak and Van Duuren, 1970). Widespread tissue damage, such as could occur with a more uniform distribution of the same amount of energy, could release transformed cells from this growth restraint. As Mayneord (1968) points out, "Radiation must be much more effective in killing cells or in interfering with their ability to multiply than in causing the alleged specific malignant transformation of individual cells or of small foci of cells."

Mechanisms for preventing or mitigating errors in replication which can produce somatic mutations must exist, because there are probably on the order of 10^{12} to 10^{13} mitoses every day in the human body (Burnet, 1964). Therefore, even for those cells damaged by radiation in such a way as to be transformed there are processes that prevent the development of a malignant growth. Each change does not produce a malignant growth. Thus, a carcinogenic agent may induce an event in a single cell or a group of cells which is followed by the development of clones of cells which gradually but rarely free themselves from growth controls exerted by the entire organism (Mayneord, 1968). In some tissues these controls may result from the autoimmune response or from cellular contact inhibition of division (Burrows and Horning, 1953). It is suggested that normal cells can act as mitotic inhibitors; thus, one cell bearing a malignant potential might be prevented from dividing by the influence of surrounding normal cells. Uncontrolled mitosis would be prevented unless the inhibition were removed in some way.

The free movement of transformed cells in culture stops when they are in contact with normal cells, suggesting that the transformed cells are responsive to inhibitory signals from normal cells (Stoker, 1964, 1967). Although transformed cells may be inhibited by contact with normal cells, they can continue to grow and move when in contact with other transformed cells. The requirement of cell-to-cell contact for transfer of materials between cells is known, and the presence of growth inhibitors in normal cells has been postulated, but this mechanism is apparently deficient in transformed cells (Burk, 1966).

Thus, both acute and late effects of the same quantities of plutonium in the lung might reasonably be predicted to be less hazardous when the plutonium is nonuniformly distributed as compared with a more uniform distribution for the following reasons. For nonuniformly distributed plutonium, the volume of irradiated tissue is much less, much of the radiation dose is wasted, in most cases cells are either killed or not irradiated, many fewer cells are irradiated but not killed, and the ratio of damaged (transformed) cells to normal cells is much smaller than for uniformly distributed plutonium. All the above factors are important, yet the last may prove to be the most important, especially for extremely nonuniform dose distribution patterns.

One can also consider the mechanisms of carcinogenesis from the standpoint of pathological changes in tissue irradiated both by uniform and by nonuniform distributions of energy. The following is a discussion of carcinogenic mechanisms that may be applicable to irradiation of skin and lung (Casarett, 1965, 1973a, 1973b). The mechanisms of most, if not all, types of cancer appear to be multi-event, multi-stage processes including cellular initiating events which confer cancer potential upon cells and promotional events or conditions which stimulate or permit proliferation of the tissue in which the cancer originates (including the cancer-potentiated cells) and/or permit proliferative advantage or autonomy of the cancer-potentiated cells.

In the development of some cancers, for example those of lung or skin, the promotional as

well as the cellular initiating events appear to be closely associated at the sites of origin of the cancers and to be largely independent of extraordinary influence of remote factors generated in other organs. In such cancers, the promoting events or conditions appear to consist of tissue damage and disorganization (cell degeneration and necrosis, vascular degeneration, fibrosis, compensatory cellular proliferation, and metaplasia) the so-called "precancerous lesion."

Radiation in sufficient doses to a large enough volume can cause both the cellular initiating events and the promotional events. The most likely candidates for cellular initiating events are certain types of mutations or chromosomal aberrations. High frequencies of such changes can be caused by relatively modest doses of radiation, and also by other mutagenic agents. However, increasing the radiation dose increases the incidence of reproductive sterility among cells, even in cell types that are relatively resistant to destruction. Such permanently sterilized cells cannot be the source of cancer. Thus, a maximum in the dose response curve is to be expected.

On the other hand, the so-called precancerous lesions, if they are to be caused largely by the radiation and not by other pathologic conditions or aging, require large doses of radiation; that is, doses capable of inducing the progressive vascular changes and connective tissue reactions sufficient to reach a degree and extent of tissue disorganization that is cancer-promoting prior to the time when such lesions might have developed if radiation had not been involved. Such large doses sterilize many cells and eventually lead indirectly to non-selective cell necrosis secondary to the vasculoconnective-tissue-circulatory degeneration, with persistent and abortive attempts by some of the nearby and less affected cells, even in normally low-turnover tissues, to proliferate in compensatory fashion, often atypically. The probability that damage will overwhelm restorative mechanisms and produce gross local tissue breakdown increases with the size of the area exposed, in particular, when the linear scale exceeds the size of the sensitive structure or target. This critical size might be determined by the ability of the local restorative mechanisms to compensate for such injury.

The character of the precancerous lesions in this type of mechanism is such that they progress to a particular degree of severity faster after higher doses than after lower doses, thereby accounting at least in part for the shorter latent period after the higher doses. If, however, the promotional condition is supplied by means other than the radiation dose in question, the size of the radiation dose required to assure the development of a particular cancer within the remaining life expectancy, if that expectancy is long enough to accommodate at least the minimal latent period, is the size of the dose required to cause or to complete the cellular initiating events in sufficient incidence.

For this type of mechanism, if the promotional condition is to be supplied largely by the radiation exposure, the optimum carcinogenic dose is likely to be that which provides a net optimum balance between effective promotional tissue damage and incidence of reproductively capable cancer-potentiated or transformed cells. Larger doses sterilize and/or kill excessive numbers of cells and reduce or even abolish induction effectiveness. The volume of irradiated tissue, with respect to numbers of reproductively capable cancer-potentiated cells and amount or critical volumes of tissue involved in the promotional precancerous lesions, is likely to be an important factor influencing the probability of development of cancer.

For cancer induced by local exposure of the tissue of origin there is, in general, an increase in incidence and reduced latent period with increasing radiation dose within a certain dose range. With further increase in dose, there tends to be a decline in the rate of increase in incidence per unit dose. This decline at high dose levels is represented first by a plateau in the dose-incidence curve at peak incidence level, and then by a fall in the curve at still higher dose levels. The fall in the incidence curve at the highest dose levels has been attributed to degrees of tissue destruction, including cell reproductive sterilization, that reduce or eliminate cancer induction.

Although the germinal cells of the hair follicles in the dermis are rapidly renewing cells relatively sensitive to the direct necrotizing actions of ionizing radiation, the epithelial cells of the lung are slowly renewing cells relatively resistant to the direct necrotizing actions of ionizing radiation. Both of these epithelial cell types can be reproductively

sterilized by irradiation and both can be depleted indirectly by interference with their microcirculatory support as a consequence of substantial progressive vasculoconnective tissue changes. Such changes increase the histohematic connective tissue diffusion barrier and reduce effective blood circulation in the processes of widespread fibrosis.

Radiation-induced lung cancer or skin cancer apparently is preceded by a considerable degree and extent of local tissue damage, disorganization, and fibrosis, that is, the so-called precancerous lesion. The experimental induction of cancer in either of these organs by irradiation of the normal organ apparently requires large radiation doses. That is, there seems to be a large minimal or "threshold" dose, but the required doses are reduced if the promotional local tissue damage and disorganization is caused by means other than the radiation. As discussed earlier, the dosimetric models used to predict lung tumor response to alpha particle radiation (see section V.B) are based upon dose response data obtained from experiments using rat skin.

In the experiments by Albert *et al.* (1961, 1967a, 1967b, 1967c, 1969) and Burns *et al.* (1968, 1973a, 1973b) involving induction of cancer in rat skin by intense electron irradiation, most of the cancers were said to be similar to hair follicle epithelium, and the promoting condition was apparently the tissue damage and disorganization in the dermis, including the tissue of hair follicles. The field of irradiation was large, relative to the follicle size, and in one experiment was 24 cm^2. The fact that there was a relationship between the incidence of cancer and the number of atrophied hair follicles in the large field of dermis irradiated and damaged at or about the level of hair follicles, and elsewhere to some extent, may be related only incidentally, in part or wholly, to the achievement of the required degree and volume of disorganized dermis. The required volume may be considerably larger and qualitatively broader than the volume of a single hair follicle and the structures contained within the hair follicle. The geometrical effect of exposure with sieve patterns observed in Albert's experiments, notably the suppression of cancer induction at 1700 R but not at 2300 R, may be a suggestive indication of the importance of distinguishing between effects on hair follicles as individual structural units and the more general effects on volumes of dermis and its vasculature as promoting conditions.

At present there is no compelling reason to believe that the critical structure or volume required for radiation-induced promotion of cancer arising from cancer-potentiated cells of hair follicles is limited to the hair follicle. There is also no cogent evidence that the lung has analagous discrete susceptible architectural units with critical tissue volume as small as the sphere of alpha particle range from an isolated "hot particle."

Increase in the risk of lung cancer with increase in the number of inhaled particles (for example, insoluble PuO_2 particles) retained in deep lung tissue may not be simply a function of increasing numbers of retained particles that are widely separated from one another in location and tissue effect, but possibly a function of the frequency with which certain minimal numbers of particles become lodged within sufficient proximity of one another to cause relatively confluent tissue disorganization throughout a promotionally effective tissue volume that is larger than the sphere of effect of a single particle (or sub-minimal number of closely associated particles), and at the same time, to increase substantially the number of cancer-potentiated, reproductively capable cells near and within the volume of disorganized tissue.

With protracted, nonuniform exposure of tissue to alpha particles, there is uncertainty not only as to the tissue component dose relevant to carcinogenesis, but also as to the portion of the total accumulated dose that effectively contributes to the induction of the cancer. In cases of intense irradiation, some of the total accumulated dose is "wasted" and irrelevant, as regards the induction of a cancer. Some of the dose in excess of the minimal induction dose conceivably may shorten the latent period to some extent by substituting for other contributing factors that would have occurred eventually but later.

Considering the amount of human data available for carcinogenic risk estimates, and the variability and uncertainty concerning dosimetric factors (e.g., relevant doses, differences in spatial and temporal dose distribution, etc.), it has thus far been regarded as necessary to select single values of quantities that

characterize the exposure of an organ or that organ in a group of individuals. Mean accumulated tissue dose is the only criterion that can be used practically at present until adequate knowledge of more relevant criteria becomes available. Furthermore, when the energy is deposited nonuniformly and its influence in the exposed organ or a group of individuals is not known, the nonuniformity cannot be dealt with until more adequate data are available. The linear (proportional) hypothesis is the only one that normally permits the use of mean dose as the significant dose factor for conditions of nonuniform exposure and exposure rate in an organ or among individuals, for purposes of estimating risk or setting dose limits in the absence of adequate data on distribution of dose and dose rates.

It is highly questionable that the ratio of induced cancers to atrophied hair follicles in Albert's experiments with large volume external irradiation of rat skin can be taken as the basis for the risk of cancer induction from a radioactive particle in or near a hair follicle in skin or isolated in deep respiratory tissue. It is also highly questionable that the existing standards for uniform radiation exposure of the whole body or lung can be used as the basis for establishing particle exposure standards by simply equating the risk of cancer induction between the two types of exposures, that is, uniform vs. grossly nonuniform. The risk for uniform irradiation of man as represented in the NAS-NRC BEIR report (1972) is based on the linear hypothesis as applied to data from uniform low LET irradiation of all cells in the lung over a dose range associated with a rising dose-incidence relationship. This dose range did not involve doses so large as to greatly reduce the carcinogenic effectiveness by excessive cell sterilization and killing, but was capable of contributing to tissue disorganization anywhere in the irradiated lung. As indicated earlier, there are many more cells at risk in the case of uniform distribution of dose than with nonuniform distribution, for the same amount of radiation dose. Also, the bulk of the available evidence suggests that in the radioactive particle situation the great majority of cells surrounding a single isolated particle within its sphere of irradiation are likely to be reproductively sterilized if not destroyed.

C. Assessment of Experimental Animal Data

The question of whether the practice of expressing the radiation exposure to lungs from inhaled plutonium as an average dose is reasonable can be considered empirically by examining the results from experimental animal studies in which the late effects, such as lung cancer, were observed in several animal species.

In reports of the carcinogenic response of experimental animals to inhaled radionuclides the authors generally calculated mean radiation doses to the total lung. To avoid hand drawing the "best" line through the data, a logarithmic probit curve was selected from among possible transforms and was fitted to data from a number of experiments in which there were several dose groups showing a progressive increase of cancer incidence or a single dose group if the lifespan was not substantially reduced compared with the controls (Thomas and Bair, submitted for publication). Binomial confidence limits were also calculated. Results from studies of beta-gamma emitting radionuclides are plotted in Figure V–1. The heavy line is the curve fitted to the composite data. The thin lines were fitted to individual multidose experiments and provide a kind of experimental error band. No statistical validity is ascribed to this procedure; however, it is a useful expedient by which to summarize the nature and magnitude of the dose effect curve. A similar treatment of data from experiments with plutonium is shown in Figure V–2.

The composite curves for the experiments with beta-gamma emitters and for alpha emitters are redrawn in Figure V–3. At all doses the incidence of lung cancer was greater for alpha emitters (plutonium) than for the beta-gamma emitters; however, the differences between the two curves were greater with increasing dose. At a mid-point tumor incidence of 20 percent, the corresponding doses are 300 rads for alpha emitters and 3500 rads for beta-gamma emitters. Thus, based on calculated mean lung doses, alpha emitters were about 10 times more efficient for lung tumor induction than were beta-gamma emitters. At 10 and 30 percent incidences, the alpha emitters were about 5 and 20 times more efficient, respectively, than beta-gamma emitters. Since the RBE for alpha particles ranges from 1 to 20, depending upon the biological system and

response studied (NCRP, 1971), and is often given as 10, this greater efficiency of alpha radiation in producing lung cancer in experimental animals appears reasonable.

Consider now the dose to the lungs of the animals that inhaled the alpha emitter, plutonium, calculated on the basis of a "critical volume" of lung tissue, that fraction of lung tissue actually irradiated by static dispersed or aggregated particles in the lung. It was pointed out in the discussion of experimental animal studies that nearly all plutonium compounds deposited in lung tend to form aggregates and are never uniformly distributed. Table I gives the calculated fractions of lung irradiated by a lung burden of 0.016 μCi $^{239}PuO_2$ of different particle diameters. For purposes of this discussion it will be assumed that 0.1 percent of the lung is irradiated. On this basis the calculated alpha doses for the experimental animal data would be increased by a factor of 1000 and the lung cancer incidence curve is transposed to the right of the beta-gamma dose effect curve, Figure V–3. Now it would appear that alpha radiation from particulate sources in lung is about 100 times less efficient than beta-gamma radiation in causing lung cancer in experimental animals. This factor of 100 would become 10 if one assumed an irradiated lung volume of 1 percent. The curve would still be to the right of the beta-gamma curve, which is radiobiologically unrealistic, i.e., it implies an RBE for alpha particles of less than 1.

One can conclude from these considerations that the mean dose to lung from plutonium

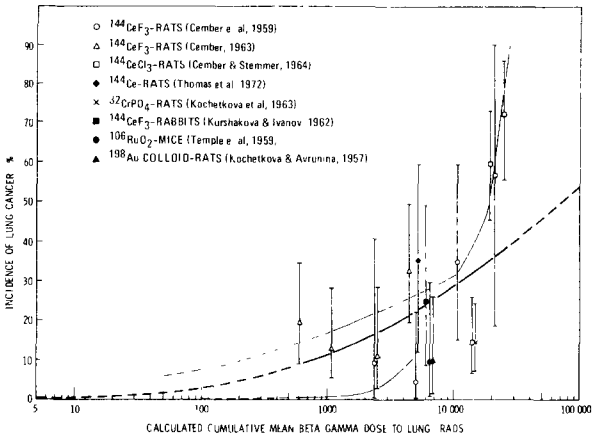

Figure V–1.—Relationship between incidence of lung cancer and radiation dose to lung from inhaled beta-gamma emitting radionuclides in experimental animals.

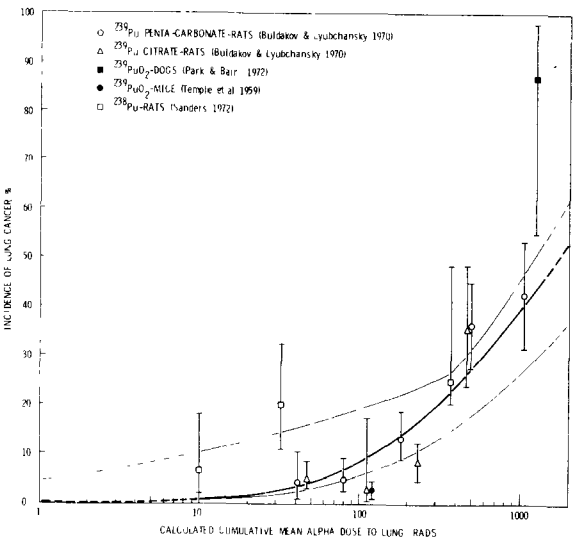

Figure V–2.—Relationship between incidence of lung cancer and alpha radiation dose to lung from inhaled plutonium in experimental animals.

particles is a biologically reasonable basis for expressing the quantitative relationship between tumor incidence and alpha radiation dose. Also, one can conclude that the mean dose concept represents a conservative approach to the establishment of permissible limits for plutonium provided the radiation protection criteria for lung exposure is based on a limiting rad dose.

It is significant that the dose-effect curves for beta-gamma emitters and alpha emitters

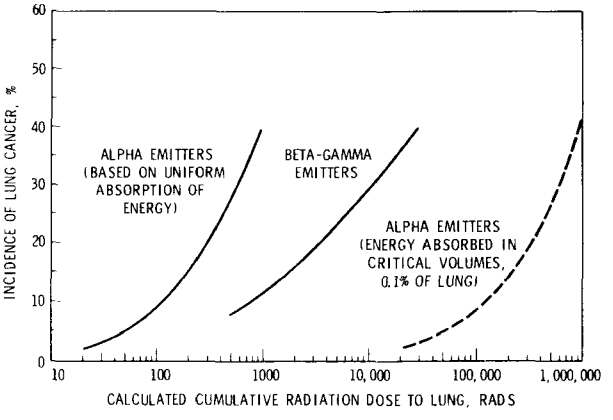

Figure V–3.—Comparative relationships between the incidences of lung cancer and radiation doses from inhaled beta-gamma and alpha emitters in experimental animals. The dose to the lung from alpha emitters was calculated in two ways: assumed absorption of energy in the total lung mass and assumed absorption of total energy in only 0.1% of the lung mass. The radiation energy from beta-gamma emitters was assumed to be absorbed throughout the total lung mass.

are "parallel." Regardless of the nonuniform distribution of the alpha dose the mean rad dose ratios between beta-gamma and alpha emitters for comparable tumor incidences range between only about 5 and 20, and no assumptions regarding the carcinogenicity of individual particles are needed or implied. Thus, a comparison of relatively uniform beta-gamma irradiation with nonuniform alpha irradiation can be derived solely from toxicity data. The appropriate models needed to describe the complete sequence of events leading to cancer are of secondary importance to a valid determination of the relative toxicity of the two radiations—the most fundamental criteria in any hazard assessment.

According to Geesaman (1968), tissue damage rather than radiation is the proximate cause of cancer. Tamplin and Cochran (1974) suggest that irradiation of a critical architectural unit of a tissue (e.g., a hair follicle) at a sufficiently high dose rate is a requirement for cancer induction. The results of experimental animal studies which bear upon these two views are from studies of low LET radiation in which the entire lung and, therefore, all the "critical architectural units," regardless of the number, are irradiated, and from studies in which a specific target tissue is irradiated.

Figure V–4 shows that lung tumor incidence increases with dose for rats given bronchial implants containing ^{32}P or ^{106}Ru. Tumor incidence is virtually zero at 10^3 rad and about 60% at 10^6 rad. The radiation dose was calculated for a specific target tissue, that is, the basal layer of the bronchial epithelium. Because of the size of the implanted pellet it is likely that many of these target cells were irradiated.

Data in Figure V–4 for five species of animals given ^{60}Co wire implanted in their lungs show lung tumor incidences ranging from about 8 to 40%, in all but one instance, for total doses of 10^5–10^6 rad to either the entire lung or to the esophagus. It is of interest that the entire lung is irradiated, including any and all possible "critical architectural units," at high dose rates, yet the tumor incidence is not unity. Also of interest is the similar response shown for the several species used with the possible exception of the rat lung, the highest cancer incidence point. The observation of tumor incidences well below unity is true also for the whole-body exposures to X-irradiation in which the entire lungs and body of rats received doses near 10^3 rad. Although these were acute exposures, the entire lung was irradiated.

The high doses from the implanted sources and the process of implanting the sources as well caused severe localized reactions. However, such lesions do not appear to be a requirement for cancer induction, because the whole-body exposures from external sources do not involve severe necrosis although pneumonitis and fibrosis can result at high exposure levels.

These data from experimental animal studies involving low LET radiations lead one to conclude that there probably is not a critical structure in the lung analagous to the hair follicle in the skin of a specific strain of rat which, if irradiated at a dose of 10^3 rad, will produce lung tumors in high yields.

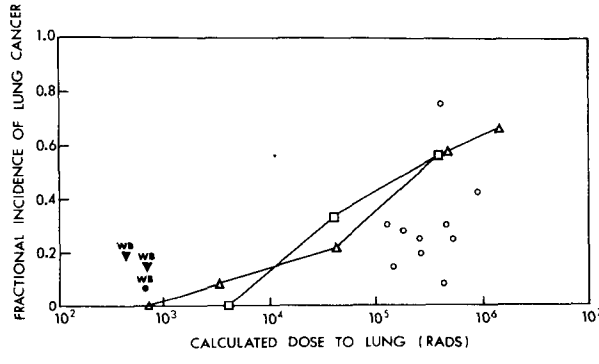

Figure V–4.—Fractional Incidence of Lung Cancer in Animals Exposed to Low LET (β,X,γ) Radiation

- ○ ^{60}Co implant. Rats, mice, hamsters, rabbits, guinea pigs (Warren and Gates, 1968).
- △ ^{106}Ru implant. Rats (Laskin *et al.*, 1963).
- □ ^{32}P implant. Rats (Laskin *et al.*, 1964).
- ● X-ray. Rats (Koletsky and Gustafson, 1955).
- ▼ X-ray. Rats (Castanera *et al.*, 1968).

VI. BIBLIOGRAPHY

Albert, R. E., (1962), "The Tumorigenic Action of Beta Radiation on the Rat Skin," Progress Report TID-15118.

Albert, R. E., Burns, F. J., and Bennett, P., (1972), "Radiation-Induced Hair-Follicle Damage and Tumor Formation in Mouse and Rat Skin," J. Nat. Cancer Inst. *49:* 1131.

Albert, R. E., Burns, F. J., and Heimbach, R. D., (1967a), "The Effect of Penetration Depth of Electron Radiation on Skin Tumor Formation in the Rat," Radiat. Res. *30:* 515.

Albert, R. E., Burns, F. J., and Heimbach, R. D., (1967b), "Skin Damage and Tumor Formation from Grid and Sieve Patterns of Electron and Beta Radiation in the Rat," Radiat. Res. *30:* 525.

Albert, R. E., Burns, F. J., and Heimbach, R. D., (1967c), "The Association Between Chronic Radiation Damage of the Hair Follicles and Tumor Formation in the Rat," Radiat. Res. *30:* 590.

Albert, R. E., Newman, W., and Altshuler, B., (1961), "The Dose-Response Relationships of Beta-Ray-Induced Skin Tumors in the Rat," Radiat. Res. *15:* 410.

Albert, R. E., Phillips, M. E., Bennett, P., Burns, F., and Heimbach, R., (1969), "The Morphology and Growth Characteristics of Radiation-Induced Epithelial Skin Tumors in the Rat," Cancer Res *29:* 658.

Archer, V. E and Lundin, F. E., (1967), "Radiogenic Lung Cancer in Man: Exposure—Effect Relationship," Environ. Res. *1:* 370.

Bair, W. J., (1960), "Radioisotope Toxicity: from Pulmonary Absorption," In: Radioisotopes in the Biosphere (R. S. Caldecott and L. A. Snyder, eds.), 431, publ. by the Center for Continuation Study, University of Minnesota, Minneapolis.

Bair, W. J., (1974), "Toxicology of Plutonium," In: Advances in Radiation Biology, Volume 4, (J. T. Lett, H. Adler and M. Zelle, eds.), Academic Press.

Bair, W. J., (in press), "Considerations in Assessing the Potential Harm to Populations Exposed to Low Levels of Plutonium in Air," In: Seminar on Radiological Safety Evaluation of Population Doses and Application of Radiological Safety Standards to Man and the Environment (L. A. Self, ed.), IAEA-SM-184/14, Portoroz, Yugoslavia.

Bair, W. J., Ballou, J. E., Park, J. F., and Sanders, C. L., (1973), "Plutonium in Soft Tissues with Emphasis on the Respiratory Tract," In: Handbook of Experimental Pharmacology (H. C. Hodge, J. N. Stannard and J. B. Hursh, eds.), Springer-Verlag, Berlin.

Bair, W. J. and McClanahan, B. J., (1961), "Plutonium Inhalation Studies II. Excretion and Translocation of Inhaled $^{239}PuO_2$ Dust," Arch. Environ. Health *2:* 648.

Bair, W. J., Wiggins, A. D., and Temple, L. A., (1962), "The Effect of Inhaled $Pu^{239}O_2$ on the Life Span of Mice," Health Phys. *8:* 659.

Bair, W. J. and Willard, D. H., (1961), "Plutonium Inhalation Studies III. Effect of Particle Size and Total Dose on Retention and Translocation," HW-68645.

Ballou, J. E. and Park, J. F., (1972), "Disposition of Ingested, Injected and Inhaled ^{239}Pu Citrate and ^{239}Pu Nitrate," Pacific Northwest Laboratory Annual Report for 1971 to the USAEC, Division of Biology and Medicine, BNWL-1650, Vol. 1, part 1: 146.

Bennett, B. G., (1974), "Fallout ^{239}Pu Dose to Man," In: Fallout Program Quarterly Summary Report, Health and Safety Laboratory, U. S. Atomic Energy Commission Report HASL-278.

Brooks, A. L., Mewhinney, J. A., and McClellan, R. O., (1972), "The *In Vivo* Cytogenetic Effects of ^{252}Cf in Liver and Bone Marrow of the Chinese Hamster," Health Phys. *22* · 701.

Brooks, A. L., Retherford, J. C., and McClellan, R. O., (1974), "The Effect of $^{239}PuO_2$ Particle Number and Size on the Frequency and Distribution of Chromosome Aberrations in the Liver of the Chinese Hamster," Radiat. Res. (in press).

Brandon, W. F., Bistline, R. W., Bloom, A. D., and Archer, P. G., (1973), "Preliminary Findings: Chromosomes of Plutonium Workers," Mutat. Res. *21:* 211 (abstract).

Buldakov, L. A., Lyubchansky, E. R., Moskalev, Y. I., and Nifatov, A. P., (1969), In "Problemy Toksikologii Plutoniya," Atom Publications, Moscow (translated as "Problems of Plutonium Toxicology," U. S. Atomic Energy Commission LF-tr-41, 1970).

Buldakov, L. A. and Lyubchansky, E. R., (1970), "Experimental Basis for Maximum Allowable Load (MAL) and Pu-239 in the Human Organism, and Maximum Allowable Concentration (MAC) of Pu-239 in Air at Work Locations," Original source unknown, Report ANL-trans-864, Argonne National Laboratory, Argonne, Illinois, (Translated from a Russian Report).

Burk, R. R., (1966), "Growth Inhibitor of Hamster Fibroblast Cells," Nature *212:* 1261.

Burnet, Sir M. B., (1964), "Immunological Factors in the Process of Carcinogenesis," Brit. Med. Bull. *20:* 154.

Burns, F. J., Albert, R. E., Bennett, P., and Sinclair, I. P., (1972), "Tumor Incidence in Rat Skin After Proton Irradiation in a Sieve Pattern," Radiat. Res. *50:* 181.

Burns, F. J., Albert, R. E., and Heimbach, R. D., (1968), "The RBE for Skin Tumors and Hair Follicle Damage in the Rat Following Irradiation with Alpha Particles and Electrons," Radiat. Res. *36:* 225.

Burns, F. J., Albert, R. E., Sinclair, I. P. and Bennett, P., (1973b), "The Effect of Fractionation on Tumor Induction and Hair Follicle Damage in Rat Skin," Radiat. Res. *53:* 235.

Burns, F. J., Sinclair, I. P., and Albert, R. E., (1973a), "The Oncogenic Response of Anagen Phase Rat Skin to Electron Radiation of Various Penetrations," Proc. Amer. Ass. Cancer Res. *14:* 88 (abstract).

Burrows, H. and Horning, E., (1953), "Oestrogens and Neoplasia," Blackwell, Oxford.

Campbell, E. E., Milligan, M. F., Moss, W. D., Schulte, H. F., and McInroy, J. F., (1973), "Plutonium in Autopsy Tissue," Los Alamos Scientific Laboratory Report LA-4875.

Carrano, A. V. and Heddle, J. A., (1974), "The Fate of Chromosome Aberrations," J. Theor. Biol. (in press).

Casarett, G. W., (1965), "Experimental Radiation Carcinogenesis," Progr. Exp. Tumor Res. *7:* 49.

Casarett, G. W., (1973a), "Pathogenesis of Radionuclide-Induced Tumors," In: Radionuclide Carcinogenesis (C. L. Sanders, R. H. Busch, J. E. Ballou, and D. D. Mahlum, eds.), CONF-720505: 1, AEC Symposium Series 29, U. S. Atomic Energy Commission, Office of Information Services, Springfield, Virginia.

Casarett, G. W., (1973b), "Possible Effects of Relatively Low Levels of Radiation," Current Problems in Radiology *3:* 1.

Casarett, L. J. and Milley, P. S., (1964), "Alveolar Reactivity Following Inhalation of Particles," Health Phys. *10:* 1003.

Castanera, T. J., Jones, D. C., Kimeldorf, D. J. and Rosen, V. J., (1968), "The Influence of Whole-Body Exposure to X-Rays or Neutrons on the Life-Span Distribution of Tumors Among Male Rats," Cancer Res. *28:* 170.

Cember, H., (1963), "Further Studies on Lung Cancers from $^{144}CeF_3$," Health Phys. *9:* 539.

Cember, H., (1964a), "Radiogenic Lung Cancer," In: Progr. Exp. Tumor Res. Vol. 4 (F. Hamburger, ed.), 251, Hafner Publishing Co., Inc., New York.

Cember, H., (1964b), "Empirical Establishment of Cancer-Associated Dose to the Lung from ^{144}Ce," Health Phys. *10:* 1177.

Cember, H., Hatch, R. F., Watson, J. A., and Grucci, T. B., (1955), "Pulmonary Effects from Radioactive Barium Sulfate Dust," AMA Arch. Indust. Health *12:* 628.

Cember, H. and Stemmer, K., (1964), "Lung Cancer from Radioactive Cerium Chloride," Health Phys. *10:* 43.

Cember, H. and Watson, J. A., (1958a), "Carcinogenic Effects of ^{90}Sr Beads Implanted in the Lungs of Rats," American Ind. Hyg. J. *19:* 36.

Cember, H. and Watson, J. A., (1958b), "Bronchogenic Carcinoma from Radioactive Barium Sulfate," AMA Arch. Ind. Health *17:* 230.

Cember, H., Watson, J. A., and Spritzer, A. A., (1959), "Bronchogenic Carcinoma from Radioactive Cerium Fluoride," AMA Arch. Indust. Health *19:* 14.

Clarke, W. J. and Bair, W. J., (1964), "Plutonium Inhalation Studies: VI. Pathologic Effects of Inhaled Plutonium Particles in Dogs," Health Phys. *10:* 391.

Clarke, W. J., Park, J. F., and Bair, W. J., (1966), "Plutonium Particle-Induced Neoplasia of the Canine Lung. II. Histopathology and Conclusions," 345, In: Lung Tumours in Animals, (Lucio Severi, ed.), University of Perugia, Perugia, Italy.

Coleman, J. R. and Perez, L. J., Jr., (1969), "Consideration of a Tumor Probability Function and Micro-Dosimetry for the Lower Pulmonary Compartment," Nuclear Utility Services Report NUS-654, Rockville, Maryland.

Davies, C. N., (1961), "A Formalized Anatomy of the Human Respiratory Tract," In: Inhaled Particles and Vapours, (C. N. Davies, ed.), 82, Pergamon Press, London.

Dean, P. N. and Langham, W. H., (1969), "Tumorigenicity of Small Highly Radioactive Particles," Health Phys. *16:* 79.

Dolphin, G. W., (1971), "Biological Problems in the Radiological Protection of Workers Exposed to ^{239}Pu," Health Phys. *20:* 549.

Erokhin, R. A., Koshurnikova, N. A., Lemberg, V. K., Nifatov, A. P., and Puzyrev, A. A., (1971), In: "Remote Aftereffects of Radiation Damage," (Y. I. Moskalev, ed.), 315, Atomizdat, Moscow (Translated in AEC-tr-7387, 344).

Ettinger, H. J., Elder, J. C., and Gonzales, M., (1973), "Performance of Multiple HEPA Filters Against Plutonium Aerosols," Los Alamos Scientific Laboratory Report LA-5349-PR.

Geesaman, D. P., (1968), "An Analysis of the Carcinogenic Risk from an Insoluble Alpha-Emitting Aerosol Deposited in Deep Respiratory Tissue," USAEC Documents UCRL-50387 and UCRL-50387 Addendum.

Gillette, R., (1974), "Plutonium and the 'Hot Particle Problem': Environmental Group Proposes a Draconian Answer," Science *183:* 834.

Grossman, B. N., Little, J. B., and O'Toole, W. F., (1971), "Role of Carrier Particles in the Induction of Bronchial Cancer in Hamsters by Polonium-210 Alpha Radiation," Radiat. Res. *47:* 253 (abstract).

Harley, N. H. and Pasternack, B. S., (in press), "Experimental Absorption Applied to Lung Dose from Plutonium-239," Health Phys.

Healy, J. W., (1974), "Contamination Limits for Real and Personal Property," Los Alamos Scientific Laboratory Report No. LA-5482-PR.

Heimbach, R. D., Burns, F. J., and Albert, R. E., (1969), "An Evaluation by Alpha Particle Bragg Peak Radiation of the Critical Depth in the Rat Skin for Tumor Induction," Radiat. Res. *39:* 332.

Hempelmann, L. H., Langham, W. H., Richmond, C. R., and Voelz, G. L., (1973a), "Manhattan Project Plutonium Workers: A Twenty-Seven Year Follow-up Study of Selected Cases," Health Phys. *25:* 461; see also Los Alamos Scientific Laboratory report LA-5148-MS (1973).

Hempelmann, L. H., Richmond, C. R., and Voelz, G. L., (1973b), "A Twenty-Seven Year Study of Selected Los Alamos Plutonium Workers," Los Alamos Scientific Laboratory report LA-5148-MS.

Howard, E. B., (1970), "The Morphology of Experimental Lung Tumors in Beagle Dogs," In: Morphology of Experimental Respiratory Carcinogenesis (P. Nettesheim, M. G. Hanna, Jr., and J. W. Deatherage, Jr., eds.), CONF-700501: 147, AEC Symposium Series No. 21, U. S. Atomic Energy Commission, Office of Information Services, Springfield, Va.

ICRU Report 19, (1971), "Radiation Quantities and Units," International Commission on Radiation Units and Measurements, Washington, D.C.

International Commission on Radiological Protection, (1966), "Recommendations of the International Commission on Radiological Protection (Adopted September 17, 1965)," ICRP Publication 9, Pergamon Press, Oxford.

International Commission on Radiological Protection, (1969), "Radiosensitivity and Spatial Distribution of Dose, Reports Prepared by Two Task Groups of Committee 1 of the International Commission on Radiological Protection," ICRP Publication 14, Pergamon Press, Oxford.

Kochetkova, T. A. and Avrunina, G., (1957), "Veranderungen in den Lungen und in anderen Organen bec intratrachealev Einfuhrung einiger Radioisotope," Arch. Gewerbepathol. Gewerbehy. *16:* 24.

Kochetkova, T. A., Avrunina, G. A., and Sagaidak-Chernyak, N. D., (1963), "Experimental Lung Cancer Induced with Radioactive Compounds P^{32}, Au^{198} and Fe^{59}," Acta Unio. Intern. Contra Cancrum *19:* 684. (Cited in Morken, D. A., (1955), University of Rochester Report UR-379).

Koletsky, S. and Gustafson, G. E., (1955), "Whole-Body Radiation as Carcinogenic Agent," Cancer Res. *15:* 100.

Koshurnikova, N. A., Lemberg, V. K., and Lyubchansky, E. R., (1971), In: "Remote Aftereffects of Radiation Damage," (Y. I. Moskalev, ed.), 305, Atomizdat, Moscow. (Translated in AEC-tr-7387, 334).

Koshurnikova, N. A., Lemberg, V. K., Nifatov, A. P., and Puzyrev, A. A., (1968), "Pneumosclerosis in Rat Following Intratracheal Introduction of Soluble Pu^{239}Compounds," Gig. Tr. Prof. Zabol. *11:* 27.

Kurshakova, N. N. and Ivanov, A. E., (1962), "A Model of Experimental Lung Cancer Caused by Intratracheal Introduction of Radioactive Cerium," Bull. Exp. Biol. Med. *54:* 787.

Lafuma, J., (1974), "Les Radioelements Inhales," Seminaire de Radiobiologie sur le théme de "La Contamination Radioactive Interne," 18, 19 et 20 Mars 1974-Paris-organisé par la Societé Francaise de Radioprotection.

Lagerquist, C. R., Hammond, S. E., and Hylton, D. B., (1972), "Distribution of Plutonium and Americium in the Body 5 Years after an Exposure via Contaminated Puncture Wound," Health Phys. *22:* 921.

Langham, W. H., (1957), "The Application of Excretion Analyses to the Determination of Body Burden of Radioactive Isotopes," Brit. J. Radiol. Suppl. *7.* Part V, 95.

Laskin, S., Kuschner, M., Altschuler, B., and Nelson, N., (1964), "Tissue Reactions and Dose Relationships in Rats Following Intrapulmonary Beta Radiation," Health Phys. *10:* 1229.

Laskin, S., Kuschner, M., Nelson, N., and Altschuler, B., (1963), "Carcinoma of the Lung in Rats Exposed to the Beta Radiation of Intrabronchial Ruthenium-106 Pellets," J. Nat. Cancer Inst. *31:* 219.

Lebel, J. L., Bull, E. M., Johnson, L. J., and Watters, R. L., (1970), "Lymphosarcoma Associated with Nodal Concentration of Plutonium in Dogs: A Preliminary Report," J. of Vet. Res. *31:* 1513.

Lebel, J. L., Watters, R. L., Bistline, R. W., Dagle, G. E., and Gomez, L. S., (1972), "Fourth Technical Progress Report of the Department of Radiology and Radiation Biology," COO-1787-16, Colorado State University, Fort Collins.

Lisco, H., (1959), "Autoradiographic and Histopathologic Studies in Radiation Carcinogenesis of the Lung," Lab. Invest. *8:* 162.

Little, J. B., Grossman, B. N., and O'Toole, W. F., (1970a), "Respiratory Carcinogenesis in Hamsters Induced by Polonium-210 Alpha Radiation and Benzo-(α)Pyrene," In: Morphology of Experimental Respiratory Carcinogenesis, (P. Nettesheim, M. G. Hanna, Jr., and J. W. Deatherage, Jr., eds.), CONF-700501: 383, AEC Symposium Series No. 21, U. S. Atomic Energy Commission, Office of Information Services, Springfield, Va.

Little, J. B., Grossman, B. N., and O'Toole, W. F., (1970b), "Induction of Bronchial Cancer in Hamsters by Polonium-210 Alpha Radiation," Radiat. Res. *43:* 261 (abstract).

Little, J. B., Grossman, B. N., and O'Toole, W. F., (1973), "Factors Influencing the Induction of Lung Cancer in Hamsters by Intratracheal Administration of ^{210}Po," In: Radionuclide Carcinogenesis, (C. L. Sanders, R. H. Busch, J. E. Ballou, and D. D. Mahlum, eds.), CONF-720505: 119, AEC Symposium Series No. 29, U. S. Atomic Energy Commission, Office of Information Services, Springfield, Va.

Lundin, F. E., Wagoner, J. K., and Archer, V. E., (1971), "Radon Daughter Exposure and Respiratory Cancer Quantitative and Temporal Aspects," National Institute for Occupational Safety and Health/National Institute for Environmental Health Sciences, Joint Monograph No. 1, Public Health Service, U. S. Dept. of Health, Education and Welfare.

Lushbaugh, C. C., Cloutier, R. J., Humason, G., Langham, J., and Guzak, S., (1967), "Histopatholgic Study of Intradermal Plutonium Metal Deposits: Their Conjectured Fate," Ann. N.Y. Acad. Sci. *145:* 791.

Lushbaugh, C. C. and Langham, J., (1962), "A Dermal Lesion from Implanted Plutonium," Arch. Dermatol. *86:* 461.

Mann, J. R. and Kirchner, R. A., (1967), "Evaluation of Lung Burden Following Acute Inhalation Exposure to Highly Insoluble PuO_2," Health Phys. *13:* 877.

Marshall, J. H. and Finkel, M. P., (1959), "Autoradiographic Dosimetry of Mouse Bones Containing Ca^{45}, Sr^{90}, and Ra^{226}," Argonne National Laboratory Report ANL-6104: 48.

Marshall, J. H. and Finkel, M. P., (1960), "Autoradiographic Dosimetry of Mouse Bones Containing Ca^{45},

Sr^{90}, and Ra^{226}, II. The Sensitive Region in the Induction of Osteogenic Sarcomas," Argonne National Laboratory Report ANL-6199: 44.

Mayneord, W. V., (1968), "Radiation Carcinogenesis," Brit. J. Radiol. *41:* 241.

Mayneord, W. V. and Clarke, R. H., (1974), "A Mathematical Investigation Into the Carcinogenic Risks Associated with Particulate Sources of Activity," Central Electricity Generating Board, RD/B/N2878, London, England.

McKay, L. R., Brooks. A. L., and McClellan, R. O., (1972), "The Retention, Distribution, Dose and Cytogenetic Effects of ^{241}Am Citrate in the Chinese Hamster," Health Phys. *22:* 633.

McMurtrie, G. E. (Secretary), (1950), "Permissible Doses Conference held at Chalk River, Ontario (Sept., 1949)," Report RH-10, May.

Mercer, T. T., (1967), "On the Role of Particle Size in the Dissolution of Lung Burdens," Health Phys. *13:* 1211.

Metivier, H., Nolibe, D., Masse, R., and Lafuma, J., (1972), "Cancers Provoquoes chez le Singe Babouin (Papio papio) par Inhalation de PuO_2," C. R. Acad. Sci. (Paris), *275:* 3069 (translated by Howath, A. A., LF-tr-80).

Morrow, P. E., Bates, D. V., Fish, B. R., Hatch, T. F., and Mercer, T. T., (1966), "Deposition and Retention Models for Internal Dosimetry of the Human Respiratory Tract," Health Phys. *12:* 173.

Morrow, P. E. and Casarett, L. J., (1961), "An Experimental Study of the Deposition and Retention of a Plutonium-239 Dioxide Aerosol," In: Inhaled Particles and Vapors, (C. N. Davies, ed.), Pergamon Press, London.

Moskalev, Y. I., (1972), "^{239}Pu: Problems of its Biological Effect," Health Phys. *22:* 723.

Moss, W. D., Hyatt, E. C., and Schulte, H. F., (1961), "Particle Size Studies on Plutonium Aerosols," Health Phys. *5:* 212.

NAS-NRC Subcommittee on Inhalation Hazards, Committee on Pathologic Effects of Atomic Radiation, (1961a), "Effects of Inhaled Radioactive Particles," Publication 848, U. S. National Academy of Sciences-National Research Council, Washington, D.C.

NAS-NRC Subcommittee on Internal Emitters, Committee on Pathological Effects of Atomic Radiation, (1961b), "Internal Emitters," Publication 883, U. S. National Academy of Sciences-National Research Council, Washington, D.C.

NAS-NRC Report of the Advisory Committee on the Biological Effects of Ionizing Radiations, (1972) "The Effects on Populations of Exposure to Low Levels of Ionizing Radiation," National Academy of Sciences-National Research Council, Washington, D.C.

National Council on Radiation Protection and Measurements, (1971), "Basic Radiation Protection Criteria," NCRP Report No. 39, Washington, D.C.

Nelson, I. C., Heid, K. R., Fuqua, P. A., and Mahony, T. D., (1972), "Plutonium in Autopsy Tissue Samples," Health Phys. *22:* 925.

Norcross, J. A. and Newton, C. E., Jr., (1972), "U.S. Transuranium Registry: A Progress Report," Health Phys. *22,* 887.

Park, J. F. and Bair, W. J., (1972), Personal Communication (referenced in Bair, W. J., 1974).

Park, J. F. and Bair, W. J., (1974), Personal Communication.

Park, J. F., Bair, W. J., and Busch, R. H., (1972), "Progress in Beagle Dog Studies with Transuranium Elements at Battelle-Northwest," Health Phys. *22:* 803.

Park, J. F., Catt, D. L., Dagle, G. E., Hackett, P. L., Olson, R. J., Powers, G. J., and Ragan, H. A., (1974), "Late Effects of Inhaled $^{238}PuO_2$ in Dogs," Pacific Northwest Laboratory Annual Report for 1973 to the USAEC Division of Biomedical and Environmental Research, BNWL-1850, Part I.

Passonneau, J. V., Brues, A. M., Hamilton, K. A., and Kisieleski, W. E., (1952), "Carcinogenic Effects of Diffuse and Point Source Beta Irradiation on Rat Skin: Final Summary," USAEC Document ANL-4932: 31.

Raabe, O. G., In Preparation.

Rashevsky, N., (1948), "Outline of a Mathematical Approach to the Cancer Problem," In: Mathematical Biophysics, University of Chicago Press, Chicago.

Richmond, C. R., Holland, L. M., Drake, G. A., and Wilson, J. S., (1974), "Biological Response to Small Discrete Highly Radioactive Sources, III. Effects of Surgically Implanted $^{238}PuO_2$ and $^{239}PuO_2$ Microspheres in Beagles," Abstract P/127, Presented at the Nineteenth Annual Meeting of the Health Physics Society, Houston, Texas, July 1974.

Richmond, C. R., Langham, J., and Stone, R. S., (1970), "Biological Response to Small Discrete Highly Radioactive Sources, II. Morphogenesis of Microlesions in Rat Lungs from Intravenously Injected $^{238}PuO_2$ Microspheres," Health Phys. *18:* 401.

Richmond, C. R. and Sullivan, E. M., (eds.), (1974), Annual Report of the Biomedical and Environmental Research Program of the LASL Health Division for 1973 to the USAEC, Division of Biomedical and Environmental Research, Los Alamos Scientific Laboratory Report LA-5633-PR.

Richmond, C. R. and Voelz, G. L., (eds.), (1972), Annual Report of the Biological and Medical Research Group (H-4) to the USAEC, Division of Biology and Medicine, Los Alamos Scientific Laboratory Report LA-4923-PR.

Richmond, C. R. and Voelz, G. L., (eds.), (1973), Annual Report of the Biological and Medical Research Group (H-4) of the LASL Health Division for 1972 to the USAEC, Division of Biomedical and Environmental Research, Los Alamos Scientific Laboratory Report LA-5227-PR.

Rossi, H. H., (1967), "Energy Distribution in the Absorption of Radiation," Adv. in Biol. and Med. Res. *11:* 27, Academic Press, New York.

Sanders, C. L., (1969), "The Distribution of Inhaled Plutonium-239 Dioxide Particles Within Pulmonary Macrophages," Arch. Environ. Health *18:* 904.

Sanders, C. L., (1972), "Deposition Patterns and the Toxicity of Transuranium Elements in Lung," Health Phys. *22:* 607.

Sanders, C. L., (1973), "Carcinogenicity of Inhaled Plutonium-238 in the Rat," Radiat. Res. *56:* 540.

Sanders, C. L., (1974), "Clearance of PuO_2 from Mediastinal Lymph Nodes," Pacific Northwest Laboratory Annual Report for 1973 to the USAEC, Division of Biomedical and Environmental Research, BNWL-1850, Part I.

Sanders, C. L., (in press), "Effects of PuO_2 Particles Deposited in the Lung Following Intraperitoneal Injection," Health Phys.

Sanders, C. L. and Adee, R. R., (1968), "Phagocytosis of Inhaled Plutonium Oxide—^{239}Pu Particles by Pulmonary Macrophages," Science *162:* 918.

Sanders, C. L. and Adee, R. R., (1970), "Ultrastructural Localization of Inhaled $^{239}PuO_2$ Particles in Alveolar Epithelium and Macrophages," Health Phys. *18:* 293.

Sanders, C. L., Adee, R. R., and Jackson, T. A., (1971), "Fine Structure of Alveolar Areas in the Lung Following Inhalation of $^{239}PuO_2$ Particles," Arch. Environ. Health *22:* 525.

Sanders, C. L. and Dionne, P. N., (1970), "Distribution of Alpha Energy in Alveoli Following Deposition of $^{239}PuO_2$ Particles," Pacific Northwest Laboratory Annual Report for 1968 to the USAEC, Division of Biology and Medicine, BNWL-1050, Part 1: 3.40.

Sanders, C. L. and Park, J. F., (1972), "Pulmonary Distribution of Alpha Dose from $^{239}PuO_2$ and Induction of Neoplasia in Rats and Dogs," In: Inhaled Particles, (C. N. Davies, ed.), Vol. III: 489, Pergamon Press, London.

Sanders, C. L., Thompson, R. C., and Bair, W. J., (1970), "Lung Cancer: Dose Response Studies with Radionuclides," In: Inhalation Carcinogenesis, (M. G. Hanna, Jr., P. Nettesheim, and J. R. Gilbert, eds.), CONF-691001: 285, AEC Symposium Series No. 18, U. S. Atomic Energy Commission, Office of Information Services, Springfield, Va.

Schubert, J. J., Fried, F., Rosenthal, M. W., and Lindenbaum, A., (1961), "Tissue Distribution of Monomeric and Polymeric Plutonium as Modified by a Chelating Agent," Radiat. Res. *15:* 220.

Shorter, R. G., (1970), "Cell Kinetics of Respiratory Tissues, Both Normal and Stimulated," In: Morphology of Experimental Respiratory Carcinogenesis, (P. Nettesheim, M. G. Hanna, Jr., and J. W. Deatherage, Jr., eds.), CONF-700501: 45, AEC Symposium Series No. 21, U. S. Atomic Energy Commission, Office of Information Services, Springfield, Va.

Sivak, A. and Van Duuren, B. L., (1970), "A Cell Culture System for the Assessment of Tumor-Promoting Activity," J. Nat. Cancer Inst. *44:* 1091.

Stoker, M., (1964), "Regulation of Growth and Orientation in Hamster Cells Transformed by Polyoma Virus," Virology *24:* 165.

Stoker, M., (1967), "Contact and Short-Range Interactions Affecting Growth of Animal Cells in Culture," Current Topics in Developmental Biology, (A. A. Moscona and A. Mouroy, eds.), Vol. II: 108, Academic Press, New York.

Tamplin, A. R. and Cochran, T. B., (1974), "Radiation Standards for Hot Particles: A Report on the Inadequacy of Existing Radiation Protection Standards Related to Internal Exposure of Man to Insoluble Particles of Plutonium and Other Alpha-Emitting Hot Particles," Natural Resources Defense Council report, Washington, D. C.

Temple, L. A., Marks, S., and Bair, W. J., (1960), "Tumors in Mice After Pulmonary Deposition of Radioactive Particles," Int. J. Radiat. Biol. *2:* 143.

Temple, L. A., Willard, D. H., Marks, S., and Bair, W. J., (1959), "Induction of Lung Tumors by Radioactive particles," Nature *183:* 408.

Thomas, J. M. and Bair, W. J., (submitted for publication), "An Analysis of Experimental Data on Carcinogenic Effects of Inhaled Radionuclides."

Thomas, R. L., Scott, J. K., and Chiffelle, T. L., (1972), "Metabolism and Toxicity of Inhaled ^{144}Ce in Rats," Radiat. Res. *49:* 589.

Wager, R. W., Dockum, N. L., Temple, L. A., and Willard, D. H., (1956), Biology Research Annual Report for 1955, HW-41500, Hanford Atomic Products Operation, Richland, Washington.

Warren, S. and Gates, O., (1968), "Cancers Induced in Different Species by Continuous Gamma Radiation," Arch. Environ. Health *17:* 697.

Watters, R. L. and Lebel, J. L., (1972), "Progress in the Beagle Studies at Colorado State University," Health Phys. *22:* 811.

Weibel, E. R., (1963), "Morphometry of the Human Lung," Springer-Verlag, Berlin.

Zalmanzon, Y. E. and Chutkin, O. A., (1971), "Radiation Absorbed Dose in the Lungs from Radioactive Aerosols," translated from the Russian by The Ralph McElroy Co., Custom Division, 2102 Rio Grande Street, Austin, Texas 78705.

(Note: Following is further questioning of the AEC conducted at the end of the hearing.) Dr. Mills: We appreciate the members of the biomedical group sticking around. We will try not to hold you much longer.

Probably the best thing to do will be to have Dr. Richmond and Dr. Bair, if they would, to come up; and Dr. Burr, if he is still around.

I would suggest that we try to comfine this within the next half hour.

Before we start, I assume, Dr. Bair, you have cancelled your plane?

Dr. Bair: It just left.

Dr. Mills: We appreciate that. Ed, you seem to have most of the questions that you would like to address, so why don't you begin?

Dr. Radford: Are there other questions that you had in mind?

Dr. Garner: I have just one.

A very short question that I did not get to last time: Do your results shed any light at all on the einsteinium problem going into the bone?

Dr. Bair: We have some preliminary results showing that einsteinium which has a 20.5 day half-life is less effective in causing lung cancer in rats and more effective in causing bone cancer than PU-239.

This is an interesting preliminary finding in an attempt to study possible dose rate effects of alpha irradiation. I believe these parti-

cular bone tumor data are contrary to what would be expected on the basis of current concepts of protracted radiation exposures.

Dr. Radford: I apologize, gentlemen, and I do appreciate your willingness to stay with us. I regret that we did not have time to complete the discussion.

It seems to me that the principal value of this questioning at this stage, from my standpoint, is to determine, is there a hot particle problem or isn't there, because, to be honest, I was not very convinced by the presentation comparing skin and alveolar cell radiation that was already presented.

I would like to address a few questions -- I think maybe we can shorten this down in view of the circumstances.

Bill, would you want to comment on your feeling as to whether the particles that you show in your photomicrograph as being deposited in the lung are likely to produce cancer, and if so, what kinds of cancer?

Dr. Bair: The photomicrographs that I have shown did not include areas of cancerous tissue. Therefore particles present in these sections, as indicated by the autoradiograph, cannot be directly related to cancer induction. Similar particles certainly have been associated with cancer in some of our experimental animals.

Dr. Radford: When the cancers are produced by these transuranics, where do they arise?

Dr. Bair: In our plutonium experiments, and also in the

experiments being conducted at Fontenay aux Roses, France, with plutonium and other transuranics nearly all of the cancers originate in the lung periphery.

Dr. Radford: What is the cell type, do you know?

Dr. Bair: The tumors are practically all bronchiola-alveolar and squamous cell carcinomas.

Dr. Radford: But they arise from a cell type associated with terminal bronchioles?

Dr. Bair: I am not sure what cell types they originate from but they certainly originate in the alveolar and bronchiolar areas.

Dr. Radford: Which is it, alvelolar or bronchiolar?

Dr. Bair: I do not know, except that the tumors appear to originate in the alveolar and bronchiolar areas of the lung.

Dr. Radford: I see. I know this has been a continuing battle for the experimental lung cancer. Would you agree, either you or any other member of the panel, that in man, the bulk of the cancers do not arise from whatever environmental causes may be related to them -- They do not appear to arise very often in this terminal bronchiolar or alveolar region?

Dr. Bair: That is my understanding.

Dr. Marks is here from the Atomic Energy Commission. He is a pathologist quite more qualified to comment on this than I am.

Dr. Marks: I am a former pathologist, but I have been with the AEC for a few years now. I was part of the team that worked on the early experimental pulmonary exposures at Hanford.

At that time, the doses that were involved were quite large. There was metaplasia and also bronchiolar proliferation that went into the alveoli in the animals.

Even though we were dealing with bronchiolar origins for the carcinomas, they were sometimes associated with these very heavy tissue changes that took place in the alveolar part of the lung.

Dr. Radford: The question is about human cancers.

Dr. Marks: In human cancers, the bulk of the tumors are actually epidermoid carcinomas, with the exception of the uranium miners who have shown a number of anaplastic carcinomas.

Dr. Radford: The point of origin, was it more proximal bronchial?

Dr. Marks: Yes. Very definitely. The customary site of origin of the carcinomas in the human is in the proximal bronchi.

Dr. Radford: Again, for whoever wants to answer this: The relevant information that one would need, if you were going to estimate the risk from an inhaled particle for man, would probably therefore be the dose delivered to those bronchial cells?

Dr. Marks: I would agree with that.

Dr. Radford: Would you agree, Bill?

Dr. Bair: I am not sure. What you are actually saying, I think, is that we should not expect plutonium to produce cancer in man of the same type seen in experimental animals. I assume that plutonium would be deposited in the lung of man in the same way as in the experimental animals -- that is the plutonium would accumulate in the peripheral

areas of the lung. That is where the radiation dose would be delivered and, as in experimental animals, that is where I would expect tumors to originate.

I think you are telling me that because cancer seldom originates in the lung periphery of man plutonium may not cause cancer in man. I would not expect plutonium to induce cancer readily in the relatively unirradiated areas of the lung such as the bronchi where plutonium has not accumulated.

Dr. Radford: I am not telling you anything. I am asking you, do you think the relevant dose that has to be applied, if you are talking about dosimetry around the hot particle, the dose that is pertinent to cancer production will be the dose delivered to those bronchial tissues, not to periphoral tissues where it might have to be.

Dr. Bair: I do not think I can answer the question. I believe radiation generally induces cancer in areas of the irradiated tissue.

Dr. Radford: Let me put it in a slightly different tactic. You showed a number of slides today, but I noticed you did not slide Figure 36, from page 11 on the WASH 1320 report.

I do not know if you have it in front of you. It's this one, showing the plutonic particles on the radiographic lung section from dogs after several months of inhalation of plutonium 239 oxide, showing a pair of bronchial accumulation of plutonium particles.

Now right above that, Figure 35, which shows it out in the

periphory -- I think you did show that slide. The point I am making is, if I look at this, some of these particles are parabronchial, but some look like they are in the bronchi.

Dr. Bair: The autoradiograph shows peribronchiolar accumulation of plutonium particles, not peribronchial. These are accumulations of particles near the alveolar regions.

Dr. Radford: That is a pretty big bronchus, if it's 50 times.

Dr. Bair: I accept the word of our pathologists.

Dr. Radford: The point is, one of the questions has been whether particles can migrate from the mucusiliar screen into the bronchus, ephithelium; or conversely, whether they can migrate from the sub-bronchioli and lymphatics into the bronchial epithelium.

There has been some recent evidence that has shown that the first mechanism does not occur, at least for hematype particles. A rather significant amount can become embedded, especially, say, in regions of the bronchi, where they would not necessarily meet with cleansing mechanisms.

Are you familiar with this concept?

Dr. Bair: Vaguely, yes.

Dr. Radford: The question, then, that would come up, if one is talking about cancer, is from any inhaled material, what is the dose to the sensitive tissue? That is what we say in the case of bone, in the case of thyroid, in the case of lung.

So we are basically concerned here with a dose to the bronchial epithelial, right?

Dr. Bair: If there is only one sensitive tissue, I am not sure that is necessarily the case. Certainly, in the animal experiments, the sensitive tissue is not -- Let me put it this way, the tumors arise in the areas where the dose is delivered.

We do not see bronchiogenic carcinomas very often in experimental animals. This really does not tell us anything about relative sensitivity of the two tissues.

I would be surprised if plutonium caused a lung tumor in man which was not the same kind of tumor originating in the same area of the lung as in these animals.

Dr. Radford: Except in the case of radium, anaplastic types of tumors arising in animals are not the same type of tumors produced by radionuclides in man, to the extent that we have any human experience in this. You do not get the periphoral types of tumors with radon daughters.

Dr. Bair: The dose is delivered in a different tissue in the case of radon daughters. In the case of inhaled radon, they are delivered to the bronchial epithelial.

Dr. Radford: Let me try a different tack.

The French data that you cited has shown squamous carcinoma and alveolar-bronchiolar carcinoma. Do you recall the proportions?

Dr. Bair: About 50 percent each, but they nearly all originate in the bronchiolar-alveolar regions.

Dr. Radford: I do not think there is any argument that animal exposures generally are in the periphory of the lung, where the

tumors occur. This also is true in the case of plutonium exposure to a large extent.

On the other hand, it has been possible to produce radiogenic cancers in the large bronchi by putting the material there directly. So it is a matter then, perhaps, of the physiology of the bronchial tree being different in the two situations.

Would you agree that is a possibility?

Dr. Bair: That is a possibility.

Dr. Radford: Another possibility, of course, is that the human being, exposed as he is to viruses and a lot of other things, has a different bronchial clearance mechanism than the experimental animal kept under relatively managed conditions.

Would you agree that is a possibility, too?

Dr. Bair: I would agree that is a possibility.

Dr. Radford: That is not getting us very far.

The basic question is really getting to the point you raised: If plutonium particles do not reach the bronchial epithelial of man, then they will not be carcinogenic. This is the point I am trying to get at, precisely this point.

Dr. Bair: That may very well be the case. I am not aware of lung cancer being attributed to plutonium in any human exposure case so far.

Dr. Radford: This brings me to the next point, which now impinges on Dr. Richmond's comments. What we need to know is the dose that is relevant to the tissue that is likely to produce cancer, that is, to the bronchial epithelium.

That was the basis of my statements earlier today, or questions about how the sampling is done on these autopsy specimens.

I was really trying to make a plea that in the subsequent work, where these rather valuable opportunities to measure the local tissue dose, that it not be lost, that indeed a special effort be made to dissect out the bronchial tree and to measure the local concentration in the bronchial tree as distinct from the paren.

If we find they are not present there, then this is a further reduction in the probability of cancer, in my opinion.

Would you agree with that, Dr. Richmond? Or Dr. Marks?

Dr. Richmond: I am not sure I understand what your real question is, frankly. But let me set the record straight for something I said earlier today.

You asked a question about whether or not the entire lung was sampled in the tissue analysis programs. My comment, as I remember, was that probably larger samples were obtained farther back in time. I have been told by Herb Parker, who is here and has written an excellent article on this question recently, that this is not true.

In fact, if you look at five year increments, the amount of tissues obtained is increasing as time has progressed by five year increments.

I hope I did not give you the impression that only the lung periphory is used in the analyses.

Dr. Radford: But no effort is made to specifically dissect out the bronchi in any of those?

Dr. Marks: That is correct, as far as I know.

In one case, they have tried to separate out the pleura from the bronchi, but no effort has been made to separate out the bronchi. The bronchi are included within the lung tissue in the analysis of whole lungs, which is done quite frequently now; but this, again, is not what you are seeking.

Dr. Radford: If, for some reason, the concentration in the bronchi were lower than we expected or if for some reason the concentration in the bronchi were higher, you would not be able to detect it because you have averaged it over the whole lung.

Dr. Marks: We will make this recommendation to the people who are doing this work. They may have done so in special cases, but, if so, we are not aware of it.

Dr. Radford: I think you can see the purpose of my comments on this. If we are going to talk about radiation exposure to sensitive tissue just as in the case of the hair follicle, we ought to be talking about sensitive tissue in man.

It seems to be the most sensitive, the bronchial epithelial, influenced by a lot of other things.

Dr. Bair: I should mention that Dr. Park has done some dissections on lungs provided by the Transuranium Registry, but I cannot give you the results.

Dr. Radford: But they are separting out separate tissue?

Dr. Bair: Yes.

Dr. Radford: I think that makes the main point.

Dr. Richmond: I think I would be remiss if I did not say something as a scientist. I do not wish to engage in polemics right now, but a lot of comments were made previously about work that I had done.

I feel quite disappointed, actually, that Dr. Tamplin did not make the point that of the two pieces of research that he referred to, one was specifically done to check the theoretical speculations or model, whatever you prefer, for the hot particle case. I was rather distressed that he did not point out that in each case, when the animals were given 2,000 particles, each of which qualified for hot particle, tumors did not develop, except in several cases, when the theory predicted that every animal should have produced a tumor. The other evidence related to cytological changes with earlier experiments which I did. It is true, there were cytological changes produced, but the thrust of the paper was that tumors were not produced.

I find this rather distressing. I think I would be remiss if I did not point this out.

I would also like to point out, for the benefit of the committee, that the people in the United Kingdom have examined the petition and have commented on it in the radiological protection bulletin of the National Radiological Protection Board.

I urge you strongly to read it, as another view on this subject. There is also the report (LA-5810-MS)(Note: This report is located in Vol. 3 of in these proceedings) which has been sent recently to the chairman of the panel and to other people, including Mr. Speth, from

NRDC, which was prepared by Healy and others at Los Alamos. It is a review of the NRDC petition.

The WASH 1320 was not meant to be a specific review of the NRDC petition, but the Los Alamos document which is now available is meant to be a review of the NRDC petition.

Dr. Bair: I have one further comment regarding the hot particle problem. I am beginning to feel that the hot particle issue is becoming something of a red herring because we are spending so much effort arguing about the uniform and non-uniform distribution of dose that we are beginning to ignore the real problem, and that is the public health consequence of a given deposition of plutonium. I hope we can get away from the hot particle issue, and deal directly with the toxicity or carcinogenic properties of inhaled plutonium.

The sudden attention recently given the hot particle issue is really misleading, because it was recognized more than 10 years ago that plutonium is nearly always present in lung as particles or aggregates, even if it is inhaled as a soluble compund.

So we are, in fact, dealing with a hot spot problem, but the important issue is the relationship between and the amount of plutonium deposited in the lung rather than whether the plutonium in the lung qualifies as "hot particles."

Dr. Radford: I would like to add just a couple of notes.

First, with regard to the experiments that Dr. Richmond and his colleagues carried out, I think it is unfortunate that the test was made, although it did speak to the issue that has been raised today by

Dr. Tamplin, but still I do not think it answers the issue.

I do not know if Dr. Richmond would agree, but the fact that tumors were not contained when the material was injected intravenously would not necessarily rule out the possibility, if they happened to be close to the tissue which might be more radiosensitive, that, by way of introducing the point again, that if we are concerned about inhaled particles, we should be concerned about exposure to the sensitive tissues.

At least, in man, it appears to be largely the proximal bronchio epithelial rapidly dividing cell system, not too dissimilar to skin, but probably having very different characteristics.

The question, basically, as I see the hot particle problem is if you have a radiation source which at its circumference is leading to a few hundred rads per day or even a few hundred rads per year, and then decreasing off to a lower dose -- and I would hope that someone would present a dose distribution for a variety of particles -- I think this would be a useful exercise, mixed oxide and so on with different alpha energies -- The question is, do you have an extremely high probability of finding just the right dose applied to cells that are sensitive. That, to me, is the hot particle issue.

Can a few cells irradiated with just a critical dose lead to a cancer? Unfortunately, I do not think we have addressed that issue very thoroughly in this hearing.

Dr. Richmond: Just to comment very briefly, I understand your concern because of your personal research interest, obviously, but I may point out you might be interested, if you get a chance some time, to visit Los Alamos and talk to the pathologist and look at some of

their slides because that particular technique does offer you the opportunity to have exposed a wide distribution of various tissues types within the lung since the particles are filtered out by capillaries, and the capillaries occur in all different portions of the lung.

You can see from the radiographs, for example, or the microscopy, that these particles do indeed lodge near many target tissues in the lung.

Dr. Burr: I just want to mention, this came up earlier in the afternoon, whether or not comments were available from Dr. Lushbaugh. We have a letter written to Mr. Rogers from Dr. Lushbaugh.

I know Dr. Lushbaugh would be pleased to have it introduced into the record. (Note: see preceding material submitted by the AEC.)

Dr. Mills: There will be a small change in the program. Mr. Frederick Forscher from the Energy Management will have some time.

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Testimony of

Dr. Frederick Forscher

Chairman of Standards Committees
N 46.4 Design Criteria for Fuel Fabrication Facilities
N 46.8 Fireprotection for Fuel Cycle Facilities.

at a public hearing of the

U.S. E P A - Office of Radiation Programs

on

Plutonium and the Other Transuranic Elements : Information Required for Standards Development.

At the EPA Offices , Washington, D.C.

December 10 and 11, 1974.

MEMBER: ASME AIME ANS ASM AIF INMM AAAS ANSI ASTM

My name is Frederick Forscher, I am a Consulting Engineer, specializing in the area of energy management, a new profession involving economics, engineering and ecology. I am testifying today in my capacity as chairman of ANSI's subcommittee N 46.4 whose subject matter covers criteria and standards for nuclear fuel fabrication facilities.

Since early in 1972 a working group of this subcommittee has worked on the development of an A+ priority standard: N287 "Criteria for the Siting, Design and Operation of Plants for the Manufacture of Mixed Oxide (U-Pu) Fuels," The standard has gone through five drafts and a formal balloting. The committee is now in the process of resolving any and all comments received from the balloting action and plans to submit the final version of the standard to the BSR (Board of Standards Review) early next year.

I believe that some of the background, considerations, and conclusions of the deliberations of our subcommittee should be of interest to this hearing. In presenting this testimony I'd like to emphasize that this standard has not yet been approved by the AEC, EPA, nor the BSR of ANSI, and that the manadatory "shall" provisions in N 287, as in any voluntary consensus type technical standard, are not to be construed as regulatory conditions. They merely represent the considered judgment of well informed and interested members of the working group made up of representatives of a multitude of societal interests.

The purpose of the standard is defined in Section 1.0 as "These criteria establish the necessary siting, design, fabrication, testing, and performance requirements for structures, systems and components important to safety, to the physical security and accountability of special nuclear materials, and to the protection of the environment; thus to provide reasonable assurance that a facility, meeting these criteria, can operate without undue risk to the health and safety of employee and the public, to the national security, and to the natural environment."

BACKGROUND

Early in 1972 I became chairman of N 46.4 and established, with the help of the nuclear insurance pools (NEPIA-Maerp, and NELIA-Maelu), the subcommittee whose work I am about to report on. At the annual meeting of the ASME in November 1972 I presented a talk "Toward Criteria and Design Standards for Large (U-Pu)-Oxide Fuel Fabrication Plants." The introduction to this paper is quoted here to serve as a still appropriate background to this standard development effort.

The continued progress of the nuclear industry depends on its performance, safety record, and public acceptance. We will achieve public acceptance if we show reliable performance and demonstrate safety in all phases of the industry.

Public concern and regulatory emphasis over the past years has concentrated on power reactors. Too little attention has been devoted to the remainder of the fuel cycle, particularly all aspects of plutonium utilization. It is clear that in the near future public concern and regulatory surveillance is going to shift toward the other facilities in the fuel cycle, such as reprocessing plants and fuel fabrication plants, as well as the associated waste disposal.

"It should be noted that reprocessing plants are covered under 10CFR50 and by practically all other regulations that apply to reactors as well, including Price-Anderson coverage. On the other hand, fuel fabrication facilities are not so covered, and their performance, experience, and safety evaluation are not generally available. The most important of these facilities, from the public Health and Safety point of view, as well as because of its national security aspects, is the next generation of plutonium fuel manufacturing plants (PFMP's). By PFMP is meant a facility with production capability for power reactor fuel elements at the rate of, at least, 50 metric tons of mixed oxide per year.

"No such facility exists in this country today, but several are needed by the late 1970's. True, their number and cost will not approach those of power reactors. Yet, the absence of PFMP's effectively prevents the utilization of plutonium for recycle in LWR's, as well as its use in breeder reactors. Without such fuel fabrication plants, the era of breeders remains sterile.

"Why has so little been done in such an important area? The answer lies in lack of leadership. The nuclear industry just did not provide the necessary technical and social/economic leadership that is called for. It is generally conceded that plutonium hazards are the most serious hazards to the public in the long run. Plutonium will be the battle-cry of the anti-nuclear forces for many years.

"Segments of the nuclear industry that are, or should be, concerned with the PFMP design include the fuel manufacturers, the cognizant regulatory agencies, also A/E's, Insurance pools, environmental protection agencies and consultants, and some people in the area of breeder technology. This diversity of interest has been pre-occupied with more serious problems, causing expensive delays in the power reactor area. There is also much uncertainty how NEPA will apply to the PFMP's and what the Environmental Impact Statement should contain. Futhermore, there is the confusion associated with the license requirements for material protection, safeguards, and national security, and also with the implementation of the Non-Proliferation Treaty that opens our domestic PFMP's to teams of interantional inspectors from the IAEA.

"Perhaps the most significant aspect of the work connected with standards development is the need to come to grips with a variety of judgmental factors in numerical, or at least quantitative, form. Only quantitative and measurable requirements can avoid interminable procedural disputes, which are the results of vague language, such as "as low as practicable," or "as reasonably safe," or "as technically available and feasible," etc. Standards ought to be clear enough (and so should be laws and regulations) to allow a competent designer to use it as his design objective. Not stating these factors explicitly in the first place, but then challenging the chosen limits in public hearings or in the courts, just does not make any sense.

DESIGN BASIS ACCIDENTS AND EVENTS

"Every engineering design involves judgmental factors. The lack of public acceptibility of these factors, and the lack of industry's credibility with the

public have been a source of agony. Much could have been avoided had there been a body of voluntary consensus standards that could replace some or most of these judgmental factors in design.

"The best known of these factors are in the economic domain, because engineers are trained to produce a "safe design at lowest cost." But, how safe is safe enough? What is the numerical value of the safety factor and how is it arrived at? In addition, the designer must now also consider emission limits and exposure levels over the total life time of the facility, counter-sabotage protection, physical security, etc. They must be properly balanced and developed quantitatively by consensus of experts.

It may seem to some novice in standards' work that this multitude of requirements can never be met by general design criteria or standards without referencing a specific plant design. However, this dilemma arouse before in reactor design, and it was resolved by the introduction of the concept of a Design Basis Accident. For the LWRs the design basis accident was considered to be a postulated Loss of Coolant Accident (LOCA). In the case of the PFMPs the matter is even more complex. The following definition was adopted:

THE DESIGN BASIS ACCIDENT is a postulated event or sequence of events leading to a condition for which the confinement system must meet its functional goals. The confinement system is a series of physical barriers, which together with an operating ventilation system minimizes the release of radioactive materials to the environment under normal and abnormal conditions.

The confinement system is further defined. The primary confinement is the barrier which is or can be directly exposed to plutonium, e.g. sealed process equipment (pipes, tanks, hoppers, etc.) gloveboxes, caissons, and cells, and their ventilation systems. Fuel rod cladding, and other sealed containers can be considered as primary confinement. The secondary confinement is a barrier enclosing a room or compartment in which the primary confinement is located.

Ventilation zone I is the space within the primary confinement and its associated ventilation system. Any space, that during the course of normal operations, may contain plutonium. Ventilation zone II is the space within the secondary confinement and its associated ventilation system, serving as operating areas and potentially contaminted areas adjacent to ventilation zone I.

Perhaps the most difficult part of the committee's work was the development of the seven specific design basis accidents and events, the latest version of which is attached to this testimony. The postulated accidents and events consist of the DBA-Fire, the DBA-Explosion, the DBA-Criticality, the DBA-Power Failure, the DB-Water, the DB-Natural Phenomana, and the DB-Diversion. Remember that the number and sequence of these events is not specified, but that the confinement system (i.e. last barrier) must prevent the escape of plutonium into the environment under any conceivable combination of these quantitative postulated design bases.

The DBA's have to be specific enough to allow the designer to proceed, while at the same time not to restrict his ingenuity and application of new tech-

nology. Two examples are cited to illustrate this point.

The DBA-Fire is that fire which results from the burning of all flammable and combustible materials within an area enclosed by a fire resistant barrier of at least a two-hour rating (ASTM E119-71). The rates of combustion for the flammable and combustible materials shall be as specified by the Fire Protection Handbook, 13th Edition, NFPA.

The DB-Diversion is a postulated scenario, by which at least two "effective kilograms of special nuclear materials" (defined in 10CFR70) are removed from the facility, either at once or within less than a year's time. This scenario(s) includes also any act of "industrial sabotage" (defined in 10CFR73). The scenario(s) shall only be disclosed on a "need to know" basis.

ACCIDENT CONDITIONS

The facility has to be designed and operated in such a manner that the probability of the Design Basis Accident (as defined above) is less than (10) to the -6 percent. The Appendix to the standard defines four accident conditions of which the DBA is the most severe.

In the consideration of the risk associated with postulated accidents, the probability and severity of their occurences and their consequences must be taken into account. The risk is equal to the product of frequency and consequence. Design considerations should provide mitigating engineered safety features and/or redundant plant services to achieve reliability in the intended safety function. Since it is not practicable to consider all possibilities, the spectrum of accidents, ranging in severity from the trivial to the very serious, is divided into four Accident Conditions. Each condition can be characterized by an occurance rate and a set of consequences.

Condition 1 - Normal Operational Occurances

Accidents of this type do not result in the release of plutonium to areas outside of the primary confinement. The probability of such events occurring is relatively higher than other accident conditions considered, and are considered part of "normal operations." The consequences of accidents of this nature are relatively minor.

Condition 2 - Small Release of Plutonium from Primary Confinement

Accidents under condition 2 result in the release of small quantities of plutonium to the secondary confinement, without release to the environment. They are less frequent and have lower probabilities of occurence then condition 1 accidents. The consequences of a condition 2 accident would require operational downtime to make repairs, to replace damaged equipment, and to effect decontamination within the plant structure.

Condition 3 - Release of Plutonium from Secondary Confinement

Condition 3 accidents result in the release of small amounts of plutonium outside

of the secondary confinement. These accidents are less probable than either of the previous accident conditions and should have a probability of occurrence of less than (10) to the -2 per year. The consequences shall be limited to dose commitments no greater than the values shown in Table 1, Appendix B as medium type accidents. The consequences of condition 3 accidents require considerable operational downtime of the total processing line, possibly the entire facility. Condition 3 accidents could result in minor environmental effects beyond the building.

Condition 4 - Small Release of Plutonium from Confinement System

Condition 4 accidents are equivalent to design basis accidents. Condition 4 accidents may result in releases of plutonium beyond the site boundary, but not in excess of the maximum accident release limits. A person spending two hours (or the total time of the accident) at the site boundary shall not incur a dose commitment of more than 25 rem total body, 150 rem to the bone, or 75 rem to the lung. (Table 1, Appendix B, severe accidents) Condition 4 accidents are much less probable than the foregoing accident conditions and have a probability of less than (10) to the -6 per year. The consequences of a condition 4 accident may be an extended shutdown of the whole facility and an extensive cleanup operation.

More severe accidents, while possible, have a probability of less then (10) to the -6 per year. They are equivalent to probabilities of accidents beyond LOCA in LWRs. The consequences would be orders of magnitude smaller than for a past-LOCA accident.

The values in Table 1 and Table 2 (attached to this testimony) were selected to meet the following specific objectives: They must provide guidance for site selection, design and operation of the facility; project employees, the public and the environment; are comprehensive, covering the full range of possible conditions; are generally consistent with other regulatory criteria (such as 10CFR20, 50 and 100); and are attainable with present technology.

The dose commitment and end-point criteria are summarized in Table 1. Typical release limits are shown in Table 2. Considerable judgment has to be exercised to develop an independent method to connect release limits with end-point criteria. The meteorological models and atmoshperic dispersion estimates for a specific site could lead to slightly different release limits. The release limits shown in Table 2 are based on the consensus judgment of the committee and are reported for guidance to the designer. Without such release limits and other quantitative criteria provided by N 287, the designer would be at a loss for any or all of the limiting conditions on his design.

CONCLUSION

In my opinion, the nuclear industry is grossly underrating the public impact that the plutonium economy can have on the progress of nuclear power. It includes such subheadings as: the diversion of special nuclear materials, the

advent of the breeder, choice of commercial isotope separation, physical security in plants and during transport, and the processing, fabrication and storing of plutonium fuels. The significance of this issue resides in the fact that plutonium is not an element found in our natural environment and that the biological effects of microquantities of plutonium are known to be serious. Consequently we must exclude this material permanently from our biosphere. The quantity that may seep into the biosphere from the various plutonium operations must approach zero.

This standard N287, goes beyond the mere concern for the health and safety of the public; it includes in its objective - as any plutonium standard should - the long range quality of our environment and the difficult aspects of safeguarding plutonium for reason of national security. The fact that three or more different regulatory and security agencies of the Federal government are cognizant of the various aspects of plutonium utilization tends to push industrial reaction into similar compartmentalized thinking. But the social effects of plutonium are not easily divisible. This standard is a first, and perhaps too brave, holistic approach.

In the final analysis it will be the public that determines the trade-offs between what may be called a "healthful" environment, and what may be called a "reasonable" cost for electric power. This determination is made in an ongoing adversary, political process. The chances against plutonium dispersion and diversion must be better than a million-to-one to overcome a public attitude that would rather freeze in the dark than take a chance on plutonium. To achieve this goal of an acceptable plutonium economy, promptly and reliably, will take the best technical, economic and organizational skills this country has to offer.

732

5.0 DESIGN BASIS

5.1 Design Basis, Accidents and Events

5.1.1 The DBA-Fire is that fire which results from the burning of all flammable materials within an area enclosed by a fire resistant barrier of at least a two-hour rating (ASTM E119-71). The rates of combustion for the flammable materials shall be as specified by the Fire Protection Handbook 13th Edition, NFPA.

5.1.2 The DBA-Explosion is the rupture of a primary confinement barrier with an energy release equivalent to an internal pressure of 105 psig. (This will result not only in a pressure wave, but may also generate missiles within the process area.)

5.1.3 The DBA-Criticality is an accidental excursion of heterogeneous liquid-powder mixture with a neutron spike yield of 10-exp-18 fissions, releasing about 30,000 Btu in less than one second, or an accidental pulsating excursion with a total fission yield of 10-exp-20 fissions. (This energy release may disperse unencapsulated plutonium from a typical glove box and may pressurize the room.)

5.1.4 The DBA-Power Failure is the loss of "total" electric power for 60 seconds, and the loss of "normal" electric power for 48 hours. Total electric power means all sources of electric energy, delivered, as well as auxilliary and standby. Normal electric power means the services usually supplied by a utility company.

5.1.5 The DBA-Water is the result of an Uncontrolled Water Hazard: that is, water which is intentionally supplied to the plant from a controlled external source and which, through a mishap within the plant, is released for 30 minutes in a manner which results in loss of a system, subsystem, structure or component important to the integrity of the confinement system. This concept includes both the effect of accidental flooding within the plant and the loss of feedwater to any equipment which, without adequate water supply, would prevent the function of the confinement system.

5.1.6 The DB-Natural Phenomena is the effect of site related conditions, such as, postulated earthquake, tornados, floods, etc.

5.1.7 The DB-Diversion is a postulated scenario, by which at least two "effective kilogram s of special nuclear materials" (defined in 10CFR 70) are removed from the facility, either at once or within less than a year's time. This scenario(s) includes also any act of "industrial sabotage" (defined in 10CFR 73). The scenario(s) shall only be disclosed on a "need to know" basis.

TABLE 1

RADIOLOGICAL CRITERIA FOR MIXED OXIDE NUCLEAR FUEL FABRICATION FACILITIES

CONDITION ("Accidents" includes environmental stresses)	PROBABILITY OF OCCURRENCE LIMITS, year^{-1}	CONSEQUENCE LIMITS		
		Dose Commitments: Individual, & Population, **man-rems		
		Whole Body	Skin, bone & thyroid	Other critical organs
Normal Operations for 1 year	1	10	60	30
Medium Accidents*	10^{-2}	500	3,000	1,500
Severe Accidents*	10^{-6}	25,000	150,000	75,000
Accidents in which the above dose limits are exceeded	10^{-8}			

ADDITIONAL REQUIREMENTS: Probabilities and Consequences shall be as low as practicable.
Exclusion Distance shall be at least 500m.
Population Center Distance shall be at least 10 km.
Effluents shall not significantly effect biota populations.
Occupational Exposure shall be as low as practicable.

* The individual is assumed to remain at the site boundary for two hours.

** The calculation of population exposure need not be extended beyond 100 km.

Table 2

RELEASE LIMITS

Condition	Release Limit, mCi Pu-239 Equivalent[1]			
	0.1 km Exclusion Radius		1.0 km Exclusion Radius	
Stack Height, m	0	100m	0	100m
Normal Operations Annual Release 2	0.02	10	0.4	10.
Medium Release-Medium Probability Accidents 3	0.2	2	10.	20.
Maximum Release-Low Probability Accidents 4	7.	70.	350.	700.

Footnotes to Table 2

[1]Equivalence based on radiotoxicity; for example, 50 Ci of Pu-241 is equivalent to 1 Ci Pu-239. The postulated Pu contains 14 Ci total and is equivalent to 0.4 Ci Pu-239 so a mCi Pu-239 equivalent is 2.5 mgm.

2 Condition 1, Accident Classification (Section 5.2)
3 Condition 3, Accident Classification
4 Condition 4, Accident Classification

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Toward Criteria and Design Standards for Large (U-Pu)-Oxide Fuel Fabrication Plants

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By the mid-seventies plutonium will become available in ton quantities from the reprocessed fuel of our domestic light water reactors (LWRs). The key to the effective utilization of this fuel is to get sufficient fuel fabrication capacity on stream. All of the present facilities are only of pilot plant scale. Criteria and design standards have to be set promptly and safely to avoid the licensing delays and public reactions that have become a way of life in the reactor business.

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Toward Criteria and Design Standards for Large (U-Pu)-Oxide Fuel Fabrication Plants

FREDERICK FORSCHER

INTRODUCTION

The continued progress of the nuclear industry depends on its performance, safety record, and public acceptance. We will achieve public acceptance if we show reliable performance and demonstrate safety in all phases of the industry.

Public attention and regulatory concern over the past years has concentrated on power reactors. As more reactors come on line, and their design, construction, licensing, and operation becomes a matter of increased standardization, it is clear that the emphasis of public concern and regulatory surveillance is going to shift toward the other facilities in the fuel cycle, such as reprocessing plants and fuel fabrication plants, as well as the associated waste disposal.

It should be noted that reprocessing plants are covered under 10CFR50 and by practically all other regulations that apply to reactors as well, including Price-Anderson coverage. On the other hand, fuel fabrication facilities are not so covered, and their performance, experience, and safety evaluations are not generally available. The most important of these facilities, from the public Health and Safety point of view, as well as because of its national security aspects, is the next generation of plutonium fuel manufacturing plants (PFMP's). By this is meant a facility with a production capability for power reactor fuel elements at the rate of, at least, 50 metric tons of mixed oxide per year. No such facility exists in this country today, but several are needed by the late 1970's. True, their number and cost will not approach those of power reactors. Yet, the absence of PFMP's effectively prevents the utilization of plutonium for recycle in LWR's, as well as its use in breeder reactors. Without such fuel fabrication plants, the era of breeders remains sterile.

Why has so little been done in such an important area? The answer lies in lack of leadership. The nuclear industry just did not provide the necessary technical and social/economic leadership that is called for. It is generally conceded that plutonium hazards are the most serious hazards to the public in the long run. Plutonium will be the battle-cry of the anti-nuclear forces for many years.

Segments of the nuclear industry that are, or should be, concerned with the PFMP design include the fuel manufacturers, the cognizant directorates, divisions and offices of the AEC, also Architect-Engineers, Insurance Pools, environmental protection agencies and consultants, and some people in the area of breeder technology. This diversity of interest has been pre-occupied with more serious problems, causing expensive delays in the power reactor area. There is also much uncertainty how NEPA will apply to the PFMP's and what the Environmental Impact Statements would contain. Furthermore, there is the confusion associated with the license requirements for material protection, safeguards, and national security, and also with the implementation of the Non-Proliferation Treaty that opens our domestic PFMP's to teams of international inspectors from the IAEA.

Because of all this diversity of interests that exist in the industry, it is not surprising that so little was done toward development of design standards and criteria. Early in 1972, a fresh start was made under the "neutral" auspices of the American National Standards Institute's Nuclear Technical Advisory Board. A group of concerned professionals, representing all special interests in this issue, volunteered to focus on the hard (numerical) and judgmental questions with a knowledgeable and impartial attitude for the benefit of the industry as a whole, rather than a parochial self-interest of its component parts.

OBJECTIVES

Perhaps the most significant aspect of the work connected with standards development is the need to come to grips with a variety of judgmental factors in numerical, or at least quantitative, form. Only quantitative and measurable standards can avoid interminable procedural disputes, which are the results of vague language, such as "as low

as practicable," or "as reasonably safe," or "as technically available and feasible," etc. Standards ought to be clear enough (and so should laws and regulations) to allow a competent designer to use it as his design objective. Not stating these factors explicitly in the first place, but then challenging the chosen limits in public hearings or in the courts, just does not make any sense.

The purpose of this paper is to present some of the judgmental and numerical factors to the nuclear industry, to the technical community, and to the public at large. These factors are not yet final nor are they complete. It is expected that, if and when they are finalized, they could be adopted as regulation by the regulatory agency. They must satisfy the current spirit of participatory technology, and they must meet the statutory requirements of the Act of 1954 in regard to public health and safety, and in regard to national security. The scope is defined as follows:

There are three primary considerations for the criteria for the siting, design, construction, and operation of plants for the manufacture of mixed oxide (U-Pu) fuels:

1 Protection of the general public and environment
2 Protection of site personnel
3 Control of nuclear materials

It is planned to follow, as much as possible, the criteria of 10CFR50 (and Appendices), and any applicable design standards, safety guides, specifications or codes, etc. There is no intent to duplicate any existing standards or any work in progress. Accordingly, we have drafted the three introductory paragraphs (Table 1), following closely the language of Appendix A, and which paragraphs further define the scope of our effort.

The first two paragraphs address themselves to the statutory requirements of the Act of 1954, while the last paragraph applies to the National Environmental Protection Act of 1969 (NEPA). It is worthwhile to point out, that only the first paragraph, in connection with the Health and Safety of the Public, is a citation from Appendix A. The second paragraph is a paraphrase of the same idea, but in connection with the equally important aspect of National Security. The second requirement assumes about equal importance in operating any PFMP, but appears of lesser significance in the case of a power reactor.

These introductory paragraphs seem to be suitable for any fuel fabrication facility. In the case of Pu-fuel, it could equally well apply to Pu-alloy, mixed carbide, or mixed oxide fuel. However, in order to be most responsive to present needs, to take advantage of the widest technical base, and to aim for a reasonably short completion date of the criteria to be developed, our committee decided to forego, at present, all considerations of the hazards associated with metallic or carbide fuel, and concentrate only on mixed oxide fuel. This type of fuel represents clearly the largest volume of Pu-fuel for plutonium-recycle in LWRs, as well as for the first generation of LFMBRs.

Table 1 Design Criteria Objectives

These criteria establish the necessary design, fabrication, construction, testing, and performance requirements for structures, systems, and components important to safety; i.e., they provide reasonable assurance that the facility can operate without undue risk to the health and safety of the public.

In addition, some criteria establish the necessary design, fabrication, construction, testing, and performance requirements for structures, systems, and components important to the physical security and accountability of special nuclear materials; i.e., they provide reasonable assurance that the facility can operate without undue risk to the national security.

In addition, some criteria establish the necessary design, fabrication, construction, testing, and performance requirements for structures, systems, and components important to the protection of the environment; i.e., they provide reasonable assurance that the facility can operate without undue risk to the quality of the environment.

DESIGN BASIS ACCIDENT

Every engineering design involves judgmental factors. The lack of public acceptability of these factors, and the lack of industry's credibility with the public have been a source of agony. Much could have been avoided had there been a body of voluntary consensus standards that could replace some or most of these judgmental factors in design. The best known of these factors are in the economic domain, because engineers are trained to produce a "safe design at lowest cost." But, how safe is safe enough? What is the numerical value of the safety factor and how is it arrived at? In addition, the designer must now also consider emission limits and exposure levels over the total life time of the facility, counter-sabotage protection, physical security, etc. They must be properly balanced and developed quantitatively by consensus of experts.

It may seem to some novice in standards' work that this multitude of requirements can never be met by general criteria and design standards without referencing a specific plant design. However, this dilemma arose before in reactor design, and it was resolved by the introduction of the concept of Design Basis Accident (DBA). For LWRs, the Loss of Coolant Accident (LOCA), as defined in Part 50, is the accepted DBA. For transportation of nuclear materials in approved containers, the DBA consists of a 30-ft drop test, followed by a specified fire, and finally ended by water immersion of the test container. In line with such precedents, and in accordance with the language to be modeled after 10CFR50, it was clear that designers need a clearly defined DBA for the mixed oxide plants. It is equally clear that an accident so defined will be strictly a design basis, and most likely will never happen in a real plant situation. (Table 2: Definitions).

There is general agreement that the protection of the integrity of the final containment — the one separating the inside of the containment system from the environment at large — must be the subject of utmost concern. For this reason, the facility must include structures, systems, and components which have specific safety functions.

The containment system is defined as that series of physical barriers which prevents the release of radioactive materials to the environment under normal and abnormal conditions. The containment system must be so designed as to maintain its intended safety function under abnormal conditions, both internal and external to the facility. This design objective can be reached if the abnormal conditions are clearly stated in quantitative terms.

External abnormal conditions may result from natural phenomena that are site dependent, such as tornadoes, earthquake, differential settlement, floods, loss of power, loss of other utilities, loss of access and communications, etc. External abnormal conditions could also be man made, such as riots and insurrection, impact by a falling airplane, fire or explosion in an auxiliary facility or nearby building, collision by derailed cars and engines, leaking chemicals, sewage explosion, and others.

However, we are primarily concerned here with the internal abnormal conditions which are more analogous to the LOCA, and consist of accidental criticality, fire, explosion, power failure, and uncontrolled water. The importance of defining these occurrences numerically and quantitatively cannot be overestimated. The numbers must be defendable, simple, and useful in design.

The DBA Criticality is a burst of 10^{17} fissions with an energy release of 200 Mev/fis. The type and quantity of fission products is process dependent.

Table 2 Definitions

1 Standard — The stated result of a particular standardization effort approved by a recognized organization, and which has been achieved by general consent, or common use: A standard usually establishes a definite level, degree, material, quality and the like, as that which is proper and adequate for a given purpose.

2 Criterion — A statement of principles, rules, or regulations which serves as basis for judgment, or decisions.

3 Design basis accident — A postulated event, or sequence of events, leading to an accident (e.g.: breach of containment system) which the design aims to prevent.

4 Containment system — A series of physical barriers which prevent the release of radioactive materials to the environment under normal and abnormal conditions.

The DBA Fire for each process area shall be that which generates as a minimum 1000 Btu/sq ft/min., plus that amount of heat potential in the primary containment and all contents therein, for a period of 30 min., except for processing areas using significant quantities of flammable hydrocarbons (solvent extraction area), where the DBA Fire generates 10,000 Btu/sq ft/min. for 30 min.

The primary containment is that physical barrier that is closest to the plutonium containing substance. The Process Area is the space between the primary containment and the next fire resistant physical barrier.

The DBA Explosion is a rupture of a primary containment at an internal pressure of 105 psi. Please note that this will result not only in a pressure wave, but also in missiles within the process area.

The DBA Power Failure is the loss of total electric power for more than 60 sec and the loss of normal electric power for more than 48 hr. Total electric power means all sources of electric energy, delivered, as well as auxiliary and standby. Normal electric power means the services usually supplied by a utility company.

The DBA Uncontrolled Water is a break inside the plant of the main pressurized water supply for 30 min. Please note that uncontrolled may imply "too much," or "too little" for safe operations.

The Design Basis Accident for the PFMP is defined as a breach of the containment system,

whether resulting from natural phenomena or the occurrence of a single event, including criticality, explosion, fire, power failure, and uncontrolled water; or a consequential combination thereof, initiated by a single event internal or external to the facility.

With the DBA firmly established, one can now proceed to use the designer's prerogative and ingenuity in the actual design of the PFMP. Naturally, many other established standards must be factored into the design. Here I have in mind criticality limits, personnel exposure limits, MPC's for air and water effluents, shielding data, and many others.

In this connection, it is well to point out that the designers must, of course, consider other accident conditions besides the DBA defined in the foregoing. It is suggested to follow the Annex to Appendix D of 10CFR50 titled, Discussion of Accidents in Applicants Environmental Reports. Several classes of accidents are defined, each class being characterized by an occurrence rate, and a set of consequences. It is not too difficult to come up with a similar series of classes of accidents for the PFMP, ranging from the trivial to the catastrophic.

ESTIMATED ECONOMIC EFFECTS

The rational for the proposed DBA was primarily to provide "reasonable assurance that the facility can operate without undue risk to the health and safety of the public." However, there are two other Design Criteria Objectives (Table 1) which will also "harden" the facility and thus increase the cost. Provisions must be made to satisfy the "reasonable assurance" clause, that the facility can operate without undue risk to: (a) the national security, and (b) the quality of the environment.

For the latter category, for example, it is quite reasonable to expect that no contaminated liquid waste is allowed to leave the plant through an effluent. This requirement would call for evaporators, solidifiers, storage, etc. Leachable waste could be decontaminated with liquids, and burnable waste may involve incineration and liquid processing of the residues. In any event, satisfying the environmental quality requirement will add to the capital cost and operating cost of the facility.

Regarding the "reasonable assurance" clause for national security, we should, for example, expect requirements that include counter-sabotage provisions and material security devices of quite sophisticated design, such as the new line of non-destructive instruments which can detect, by active or passive interrogation, the quantity, location, species and movement of special nuclear materials. Diversion of Plutonium is a threat that must be taken serious. The scenarios by which this material might be stolen are only limited by the imagination of the science fiction writers. One obvious scenario, however, would be a false evacuation alarm, i.e., a plant evacuation initiated by the diverters. All persons present inside the plant would scramble for the nearest exits; some would carry with them significant quantities of plutonium. An external and controlled access perimeter must be provided for such or similar eventualities.

Sabotage can be described in scenarios covering a whole range of threats. It is useful to classify these threats within a spectrum of severity, ranging from the trivial case of pilfering (say, plastic containers) to a full blown organized and mechanized attack of a para-military nature. Like the range of "classes of accidents" discussed in the foregoing (Annex to Appendix D of 10CFR50), we must define the central portion of the spectrum of threats, against which the design will offer the "reasonable assurance" against undue risk. All these examples point in the direction of "hardened" — which means more costly — facilities.

Let us assume that because of all these considerations, the necessary capital investment would actually double. What would be its effect on the fuel cycle cost? One simple way to fet a ball-park answer to this question is to look at the various components that make up the total generating cost. Without reference to a specific plant, type, size, or year of completion, I propose to use the following rough figures:

Plant cost - - - - - - - -	5.50
Fuel cost - - - - - - - -	1.60
Operation, maintenance - -	0.40
Total	7.50 mills/kwhr

We know that the design and fabrication of the fuel amounts to only about 25 percent of the fuel cost. (Most of it, nearly 70 percent, is the inherent fuel value of enriched uranium and plutonium.) Hence, the fabrication service cost is 0.40 mills/kwhr. Of this value, only about 5 percent can be charged to facility depreciation; i.e., 0.02 mills/kwhr represents the facility cost. If the hardening of the PFMP doubles this cost, we would be paying another 0.02 mills/kwhr for the safety and reliability of our fuel supply.

The same argument, of course, can be made in terms of dollars per kg of fuel, which is the preferred marketing method. Manufactured fuel may

cost $60/kg, plutonium (recycle) fuel may cost, perhaps, $100/kg, all exclusive of the intrinsic value of the U or Pu in the fuel. If the 5 percent doubles because of the hardening of the facility, it would cost $105/kg to buy plutonium fuel. No doubt, the plant capacity and, more importantly, its annual throughput will have a major effect on the unit cost.

We must remember that the foregoing assumption, of doubling the facility cost because of hardening, is very conservative and unlikely. A fuel plant that could normally be built for $12 million, will not likely require a $24 million investment under these hardened circumstances. But even with the assumption of doubled facility cost, we conclude that the effect on the "generating cost" would be much less than 1 percent (i.e., 0.02 mills/kwhr in 7.50 mills/kwhr). In any cost-benefit analysis, that would weigh heavily in favor of hardening the plants, particularly when plutonium is involved.

ACKNOWLEDGMENT

Parts of this paper are based on deliberations and discussions of ANSI's standards committee N101-4 (now N46-4) of which the author has the honor to be chairman. The contribution of the committee members are appreciated. The charter for this committee covers all nuclear fuel fabrication facilities. The parent committee N101 (now N46) is sponsored by the AIChE.

Dr. Mills: Thank you.

Are there any comments or questions from the panel?

Dr. Radford?

Dr. Radford: Dr. Forscher, you are an engineer, correct?

Dr. Forscher: Yes.

Dr. Radford: What are the professional backgrounds of the ANSI standard setting committee? This particular one.

Dr. Forscher: This particular committee was composed of members who had experience in plutonium work and are currently employed by organizations such as insurance pools, contractors, AEC (general managers side as well as from the standards group), EPA, health and safety group.

Dr. Radford: Basically, are they all engineers or are there any biomedical people on the Committee?

Dr. Forscher: There are no biomedical people on this committee. This is a group, N 46.4 which is chartered to develop standards for fuel fabrication facilities, in other words, consideration of design, operation and quality assurance of these structures.

These are the components, that we must maintain the safety.

Dr. Radford: Have you compared the emission rates that would apply to these accident conditions, I presume, in Table 2? Would you compare these with standard emissions that might occur from other facilities or even fuel fabricating facilities under the current regulations?

Dr. Forscher: Yes, we have. They are tighter, more conservative.

Dr. Radford: They require closer containment of plutonium than do the current standards?

Dr. Forscher: Yes but, as I mentioned in the objective, the numbers which appear in Tables 1 and 2, are achievable with present technology by consensus of many people in the AEC, EPA and contractors.

As I also mentioned, these people on the committee do not represent these organizations. They represent themselves and use their best judgment on this problem. We come up with a consensus.

Whether they are employed by EPA or AEC or insurance pools, et cetera, I do not think they express official views. As I said in the beginning, this standard has not been accepted by the AEC or EPA.

Dr. Radford: Can you give us a ballpark figure, how much more restrictive this kind of emission standard would be compared with the emission standard now permitted?

Dr. Forscher: I cannot really give you a number there because we have tried to translate, interpret, the MPC's which appear in Part 20 into dose commitment, and this translation of exposure to dose commitment is 50 years by itself.

Dr. Radford: So it is a reduction of about 50? These knowledgeable people who work for the industry feel that this is attainable and therefore, it comes under the as low as practicable aegis; that it is practicable and therefore it should be achieved. Would that be a fair statement of the committee's feeling?

Dr. Forscher: The committee feels that the standard as presented is practical. This committee does not speak for industry. Whether industry feels that it is practical is another thing.

Dr. Mills: Dr. Morgan?

Dr. Morgan: Dr. Forscher, I notice that in Condition Four, you gave the dose limits of 25 rem total, along with 150 rem to the bone, and 75 to lung. But these figures omitted the levels for the thyroid, which might receive the highest part of the dose from any type of accident.

Is that intentional?

Dr. Forscher: It is not intentional, Dr. Morgan.

Dr. Morgan: There might be reason.

Dr. Forscher: In the appendix table, we list dose commitments to the whole body, skin, bone and thyroids and other critical organs.

Dr. Morgan: I notice in your Table 2, that you use plutonium 239 equivalents, but there is not indication, for example, what the equivalence might be of plutonium 238.

Do you happen to know what was used as the equivalent per gram basis?

Dr. Forscher: No. I do not. You understand, this standard was written for a specific type facility, a manufacturing facility, manufacturing commercially available large scale mixed oxides of plutonium which makes uranium oxide.

There is very little plutonium 238 in there, so we have not concerned ourselves with plutonium 238.

Dr. Morgan: There is quite a bit of plutonium 238 in alloys, though, as well of course as plutonium 241.

Dr. Forscher: Yes, there is a whole range of isotopes. Understand, I do not have it with me. I will send it to you.

We have calculations of the equivalents. I am not sure if we included conventional points to 238.

Dr. Mills: Dr. First?

Dr. First: I would like to just clarify a point of the release limits. It is my understanding that the ANSI committee's objective is to develop engineering, construction, maintenance, et cetera, standards for achieving particular standards, and that it is not the part of the ANSI committee to establish the standards here, but only the method of achieving them.

Is this not correct? In other words, these are not standards which are recommended by the committee that differ in any way from those that have been published. Is that not correct?

Dr. Forscher: They should not contradict or be different from any of the others that have been published. We have, in our committee, attempted to be as quantitative as possible and stay away from generalities such as "as much as is practical" and "economically feasible," and also to help the designer to overcome this judgmental gap.

This is what the purpose of the ANSI committee is. To provide the limiting conditions, the criteria, so that the designer, within these limited conditions, can design facilities which are economical and at the same time safe. If you do not give him the numbers of the emission limits to shoot for, he would not know where to begin.

Dr. First: I think we can agree that criteria are needed, but I think we are talking about several different criteria here. This is the point I am trying to get to.

The objective of the committee is not to establish new criteria for uptake of radioactive materials. Is that correct?

Dr. Forscher: That is correct.

Dr. First: So you have worked on the criteria which are in existance, the existing ones. You are not suggesting that these should be changed in any way. Is that correct?

Dr. Forscher: That is correct, but in order to provide guidance to the designer on this, we had to start with some assumption of dose commitment. Working backwards from this dose commitment, including meteorological models which distribute --

Dr. First: I think we understand this, but the point I am trying to make is you have accepted the standard which now exists as being the one to which the ANSI standard is addressed.

You have not considered whether or not this standard, environmental standard, should be increased or decreased.

Is that correct?

Dr. Forscher: We have interpreted the current standard in terms of dose commitment, which I do not think is generally interpreted this way.

Dr. First: You have interpreted it, if I understand you correctly, in terms of emission standard. Is that correct?

In other words, you have taken the permissible dose to the population and you have extrapolated that to some distance from the plant, through a stack of a certain height. You have then concluded that based on the standard, you are permitted to emit certain quantities of

plutonium for a year.

Is that a correct interpretation?

Dr. Forscher: That is right.

Dr. First: You say this is attainable and your figures show this. Is a lower standard attainable as a practical matter?

Dr. Forscher: I do not think there is a generally applicable answer to this question. I can only report that our preparation advised itself of this for ours.

We came away with a consensus feeling that our emission limit is about as low as is practicably, attainable, with current technology.

Dr. First: So, from the standpoint of the committee, the present standard is as low as practicable. Is this a correct interpretation?

Dr. Forscher: Yes.

Dr. First: Thank you.

Dr. Mills: One question having to do with clarifying the status of the standard as you proposed. Knowing how most of the ANSI committees work, it is usually one man's effort to actually put the document together.

When you say it is up for formal balloting, are you saying that the members of the subcommittee have not voted on this as yet?

Dr. Forscher: In our committee at least, it is not a one man effort. It has gone through many internal reviews before we went out to have the working group comment on it.

Then, after these comments were accommodated in Draft Five, it was allowed to go for voting by the full committee; N 46 committee is a

subcommittee of ANSI. All standards for fuel cycle facilities are under N 46. This voting is a formal voting which is advertised in the ANSI Bulletin, which announces all such actions, not only for nuclear standards.

Consequently, we got considerable comments from societies, industry, regulatory agencies and so forth. These comments are being resolved.

After they are resolved, the standard with the resolution and the reason for the resolution is then submitted to the Board of Standards Review, BSR, for formal approval of the standard.

If they are satisfied with our resolution of the questions that came in with this formal voting, balloting, then they will agree that the standard should be issued as another voluntary type standard under ANSI auspices, based on voluntary, technical consensus.

Dr. Mills: To date, the subcommittee members have not voted or commented on it?

Dr. Forscher: We are in the process of resolving all the comments we have. We have formally balloted and got all the comments in, and we are in the process of resolving all comments which have come in.

We are one week away from finalizing it.

Dr. Mills: Thank you very much, Dr. Forscher.

We will adjourn until 1:30.

(Whereupon, the hearing in the above entitled matter recessed at 12:50, to reconvene at 1:30 that same day.)

AFTERNOON SESSION

Dr. Mills: We will get started this afternoon. For the remainder of the day, we have a very full schedule, so I hope everyone will make the effort to do what they can to help the schedule along.

We will start out this afternoon with Mr. Lester Rogers, from the U. S. Atomic Energy Commission speaking on the regulatory aspects of this problem.

Dr. Radford: Mr. Chairman, before we go on, could I ask what the schedule will be? We have four panelists who wanted to try to get away by four o'clock, as I recall.

When will they be put on the program?

Dr. Mills: I intend to try to get an opportunity to hear them. I hope they will stick around. I realize most have very tight plane schedules and it will be necessary that they leave some time before four o'clock.

We have Mr. Rogers; we have the representatives of the Westinghouse Electric Corporation; we have Dr. Tamplin. And we have Ms. Judith Johnsrud from the Environmental Coalition on Nuclear Power.

To the extent that we can get these in and questions and comments on each particular one, then the other panel members left over from the Biomedical will be around to answer questions.

I would suggest if they cannot remain, that the members of the panel put together their questions and we will submit these or have them submitted from the Environmental Protection Agency to the panel members

for response.

I realize that this is at the heart of the matter, but we will try to get out at some reasonable time tonight.

Dr. Radford: Mr. Chairman, can I suggest that, if it would be agreeable to Westinghouse people and Dr. Tamplin and the other people, that after Mr. Rogers presents his presentation that we bring back the AEC to finish that up?

I stress this because it seems to me, in my estimation, the information presented by the witnesses this morning was very crucial and very critical, and in no way would submission of questions to them subsequent to this event really get the issues thrashed out as thoroughly as I think we could do them now.

Dr. Mills: I can appreciate that, Dr. Radford. However, the representatives from Westinghouse also have a tight schedule. We had scheduled some time this morning for this group.

I believe I have no objection if Dr. Tamplin wishes to come on after Dr. Wright and Mr. Kramer of Westinghouse, but to allow the earlier panel to be around for questioning, I do not think I can hold up the Westinghouse people any longer.

Dr. Radford: Let me just say for the record, then, that the fact that we will probably not have an adequate opportunity to question much more extensively, particularly Dr. Bair and Dr. Richmond who presented such important information today, in effect vitiates a considerable amount of the input of the AEC to these hearings.

Dr. Mills: Well, their testimony will be put in the record.

As I have stated, I recognize the difficulty with trying to answer some of these questions. However, they have commitments to meet as well as the rest of us.

With that, I would like to proceed.

(Note: The panel was questioned at the end of the day and this is a part of the record placed directly after the previous AEC testimony.)

Mr. Rogers:

STATEMENT OF LESTER ROGERS

DIRECTOR OF REGULATORY STANDARDS

U. S. ATOMIC ENERGY COMMISSION

PRESENTED AT

EPA HEARING ON TRANSURANIUM ELEMENTS

DECEMBER 11, 1974

I am pleased to appear in this hearing to present a statement as a member of the Regulatory staff of the Atomic Energy Commission. We understand the purpose of the hearings is to gather information to assist the Environmental Protection Agency in evaluating the potential environmental impact of transuranium elements,and to consider whether additional EPA guidelines or standards are needed to assure adequate protection of the general ambient environment and the public health from potential contamination by radionuclides of the transuranium elements. We believe that it is appropriate and timely that EPA thoroughly examine this question.

In this brief statement I plan to summarize some of the principal considerations given to limiting exposures to the public by the AEC as the Federal regulatory agency responsible for implementing and enforcing radiation protection standards in the nuclear industry. We look forward to continued cooperation with EPA as they move forward in examining standards for transuranium elements,and will provide any information available to us that might be helpful. Attached as Appendix A to my testimony is a bibliography of recently issued environmental statements, regulations, and guides prepared by the AEC Regulatory staff and related to the subject of this hearing.

Regulatory Responsibilities of the AEC

The commercial use of atomic energy was the first technology to be subject to comprehensive Federal regulatory control from its inception. Under the Atomic Energy Act of 1954, as amended, no person may construct or operate a nuclear facility, such as a nuclear power plant or nuclear fuel reprocessing plant, or possess or use source, byproduct, or special nuclear materials except as authorized by an AEC permit or license (this includes all of the transuranium elements of interest in this hearing). In addition, the Atomic Energy Act authorized the AEC to promulgate regulations specifying design, siting, and operating requirements for nuclear facilities to protect against possible accidental radiation hazards. The Act requires the AEC to take measures to protect against accidental releases of radioactive materials, and to set limits on the amounts of radioactive material that may be released during normal operations of nuclear facilities and other activities involving nuclear materials.

Under the Atomic Energy Act the AEC has established a comprehensive Regulatory program involving licensing, standard setting, inspections, and enforcement. Detailed regulations concerning siting, design, and other aspects of regulation of nuclear facilities and activities have been published in 10 CFR Chapter 1. In addition, we have issued some 207 Regulatory Guides to provide guidance on methods acceptable to the Regulatory staff for implementing specific parts of the Commission's regulations, to delineate techniques used by the staff in evaluating specific problems

or postulated accidents, and to provide other guidance to applicants and licensees. The Regulatory program that I have just outlined is continued by the legislation that has created the new Nuclear Regulatory Commission.

Implementation of Radiation Protection Standards

Since its inception, the AEC has as a matter of policy used the recommendations of the International Commission on Radiological Protection (ICRP) and the National Council on Radiation Protection and Measurements (NCRP) as the bases for regulations and safety requirements in its Regulatory program. In 1959 the Atomic Energy Act was amended to establish the Federal Radiation Council (FRC), whose function was to advise the President on radiation matters affecting health, including guidance for all Federal agencies in the formulation of radiation standards.

All functions of the Federal Radiation Council were transferred to the Administrator of the Environmental Protection Agency (EPA) by Reorganization Plan No. 3 of 1970. Also transferred to EPA were "The functions of the Atomic Energy Commission under the Atomic Energy Act of 1954, as amended, administered through its Division of Radiation Protection Standards, to the extent that such functions of the Commission consist of establishing generally applicable environmental standards for the protection of the general environment from radioactive material. As used herein, standards mean limits on radiation exposures or levels, or concentrations or quantities of radioactive material, in the general environment outside the boundaries of locations under the control of persons possessing or using radioactive

material." The AEC retained the responsibility for implementation and enforcement of EPA standards.

In its first Memorandum for the President dated May 13, 1960, the FRC recommended adoption of Radiation Protection Guides for Federal use in normal peacetime operations. Subsequently, additional radiation protection guides were recommended and adopted in Reports No. 2 and 8. AEC regulations have been modified to conform to the FRC guidance to Federal agencies approved by the President. EPA has not altered the guidance issued by the Federal Radiation Council and the Commission's regulations remain consistent with FRC guidance to Federal agencies.

The FRC, ICRP and NCRP guidance includes, but is not restricted to, quantitative radiation protection guides and dose limits. Since any exposure may involve some degree of risk, these standards setting groups also have recommended that radiation doses be kept "as low as practicable" or, as stated by the ICRP, "as low as reasonably achievable, social and economic considerations being taken into account." Therefore, the AEC system of implementing FRC guidance is aimed at the following principal objectives:

1. To keep doses from all sources of exposure, other than natural background and medical procedures, well within the FRC numerical radiation protection guides.

2. To avoid unnecessary sources of exposure and to ensure that doses received are justifiable in terms of benefits that would not otherwise have been received.

3. To provide for design and operational control of specific facilities and uses of materials, both individually and in combination, so that the resulting doses are sufficiently low that any further reduction in risk would not be considered to justify the effort required to accomplish it; that is, the doses are "as low as practicable", or as some prefer to say, as low as reasonably achievable.

These objectives are achieved by:

1. Establishing and enforcing "regulatory upper limits" on doses and releases of radioactive material to the environment applicable to all licensed activities. These limits are not intended to be exceeded. They are set forth in the Commission's regulation, 10 CFR Part 20, "Standards for Protection Against Radiation."

2. Establishing and enforcing design objectives and limiting conditions of operation applicable to specific classes of nuclear facilities and uses of radioactive material to assure that persons engaged in activities licensed by the AEC make every reasonable effort to maintain radiation doses and releases of radioactive material in effluents to the environment as far below the regulatory upper limits as is reasonably achievable.

This approach to design objectives and limiting conditions of operation implies a cost-benefit methodology focused on the differential in

costs and benefits that might be involved in requiring the activity to be carried out at one level of exposure rather than another. The most definitive guidance, of which we are aware, on the application of this methodology as related to radiation protection is set forth in the Recommendations of the International Commission on Radiological Protection, ICRP Publication 22, "Implications of Commission Recommendations that Doses Be Kept As Low As Readily Achievable." I request that this document be incorporated into the record of this hearing, and we do have a copy to submit. (added oral testimony)

We believe that the application of this type of methodology in the regulatory process, with emphasis on design criteria and operating procedures, effectively controls releases of radioactive material and assures that the risk from exposure to radiation resulting from the nuclear industry is kept at an extremely low level.

We also believe that this approach to regulation is highly responsive to the recommendations of the Advisory Committee on the Biological Effects of Ionizing Radiation, National Academy of Sciences, as reflected in their November 1972 report on "The Effects on Populations of Exposure to Low Levels of Ionizing Radiation" (BEIR Report). Chapter II of the report, "Needs of the Times," emphasizes the need for quantifying risk and the use of cost-benefit analyses in decision-making. The report very wisely points out that this methodology brings into the decision-making process such important considerations as whether the public interests are better served by spending our limited resources on health gains from reducing contamination

or by spending for other societal needs. In discussing the difficulties and uncertainties in cost-benefit analyses, the report concludes, and I quote:

> "Despite these uncertainties, there are important advantages in attempting cost-benefit analyses. There is a focus on the biological and environmental cost from technological developments and the need for specific information becomes apparent. Thus, for example, we find relatively little data available on the health risks of effluents from the combustion of fossil fuels. Furthermore, it is becoming increasingly important that society not expend enormously large resources to reduce very small risks still further, at the expense of greater risks that go unattended; such imbalances may pass unnoticed unless a cost-benefit analysis is attempted. If these matters are not explored, the decision will still be made and the complex issues resolved either arbitrarily or by default since the setting and implementation of standards represent such a resolution."

I would like to observe that, based on our experience to date, perhaps the most urgently needed guidance is in those areas identified by the BEIR Committee regarding how we should properly take into account the comparative benefits to society from the expenditure of resources to reduce risk from radiation exposures relative to the benefits to be gained by the expenditure of resources on reducing other health risks. We believe a balanced approach is a necessity and that this would be a productive area for EPA's attention.

Experience in Implementing the "As Low As Reasonably Achievable" Concept

The effectiveness of the implementation of the "as low as reasonably achievable" concept in the regulatory process is confirmed by experience in the nuclear industry. This experience shows that licensees have generally kept releases of radioactive material in effluents at such low levels that resultant exposures to persons living in the immediate vicinity of nuclear facilities have been less than about 5 percent of the FRC radiation protection guides for individual members of the public. The Atomic Energy Commission has published numerical guidance on design objectives and limiting conditions of operation for light-water-cooled nuclear power reactors in a proposed Appendix I to its Part 50 regulations. This proposed regulation has been the subject of extensive public rule making hearings, including a detailed environmental statement with extensive cost-benefit analysis. The matter is now pending before the Commission for decision. However, as a practical matter all existing operating power reactors, as well as those under construction, either meet or are being modified to meet the design objectives and limiting conditions of operation in the range of the revised Appendix I recommended by the staff in its Concluding Statement of Position filed on February 20, 1974.* It is expected that conformance with the guides on design objectives and limiting conditions of operation will continue to provide reasonable assurance that annual total body doses to individuals living near the boundary of a site, from radioactive

*Regulatory Staff Concluding Statement of Position, Docket RM-50-2 February 20, 1974.

material released in either liquid or gaseous effluent from all reactors at the site, will generally be less than 5 percent of average doses from natural background radiation.[1/] The level of doses to the total body or any organ is expected to be generally less than 1 percent of Federal radiation protection guides for individual members of the public. Furthermore, annual average total body doses to the U.S. population from radioactive material released in either liquid or gaseous effluents from all light-water-cooled nuclear power reactors on all sites in the United States for the foreseeable future will be less than 1 percent of doses from natural background radiation.

Parallel to this, we have been working on comprehensive engineering and environmental studies to form the basis for numerical guidance on as low as practicable effluent releases for fuel cycle facilities other than reactors. Included are nuclear fuel reprocessing plants, plutonium processing and fuel fabrication plants, and uranium mills.

I would now like to turn to specific considerations related to the transuranium elements.

Implications of Existing FRC Guidance for Transuranium Elements

The FRC numerical radiation protection guides pertinent to the transuranium elements (transuranics) have been implemented by the AEC in 10 CFR Part 20, "Standards for Protection Against Radiation," as upper limits on occupational exposures and concentrations in effluents released to the environment. Consistent with FRC guidance, we have used the "maximum permissible body burden" and "maximum permissible concentrations of radionuclides

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[1/] Average total body doses due to natural background radiation in the United States are in the range of 100-125 millirems per year.

in air and water" derived from the radiation protection guides recommended by the ICRP and NCRP. These values are used as regulatory upper limits of individual exposure for normal operations and as indices of relative risk. Research and studies on the relation between intake of the transuranics and biological effect should continue, and we will keep the standards under review to assure that they reflect the best available knowledge.

However, it is not appropriate to arbitrarily project estimates of possible releases of transuranics to the environment, or possible health effects to the public, from commercial nuclear operations on the assumption that significant numbers of people are going to be permitted to be exposed to these upper limits of radiation exposure. Regulatory implementation of the "as low as reasonably achievable" concept through close attention to plant design requirements and operational controls will prevent this from happening. Based on information now being submitted in license applications, on operational data obtained from existing plants, and on evidence developed in studies now underway on available technology and cost-benefit considerations for fuel fabrication and reprocessing plants, it appears that normal operational releases of the transuranics to the environment will keep radiation exposures to individual members of the public on the order of 1000 times lower than would exposures at Part 20 concentration limits. In this regard we agree with EPA's findings in their February 1974 report, "Environmental Radiation Dose Commitment: An Application to the Nuclear Power Industry," that "current control practices for actinide releases at a single

operation, such as nuclear fuel chemical reprocessing, are expected to restrict releases to the order of 10^{-8} to 10^{-9} of the total amount processed, and future experience may justify the assumption of even smaller release fractions." Even so, EPA conservatively assumed that 10^{-7} of the total amount handled in any given year would be released for purposes of projecting cumulative potential health effects tothe Year 2020. The EPA estimates as reflected in the report show that the cumulative future potential health effects (i.e., number of lung cancers) from all assumed transuranic releases through the Year 2020 from the entire nuclear fuel cycle would not exceed (That's assuming a linear dose-effect relationship.) [added oral testimony]

21. The current normal incidence of lung cancer in the U.S. population when extrapolated over a 50 year period would indicate several million cases from all causes.

Protection Against Accidents

Protection against releases of radioactive materials that could result from accidents is a principal objective of the AEC regulatory program. Applicants and licensees are obligated to assure the AEC that safety considerations are a part of every step in the design, construction, and operation of each nuclear facility or plant.

The AEC has the responsibility to see that safety requirements are met by the plant operator. Licenses are issued only for those activities which, on careful and detailed review, can meet prescribed safety standards and criteria within the bounds of conservative engineering practices. AEC regulations require that nuclear facilities and plants be soundly and conservatively

designed with ample safety margins and redundancy of components and systems to compensate for the fact that no body of knowledge can ever be complete enough to reduce uncertainties and risks to zero.

Many requirements are imposed to achieve these safety objectives. Prominent among them is the defense-in-depth concept employed in the design of all nuclear facilities. The implementation of this concept includes the requirement of a comprehensive quality assurance program for the design, construction, and operation of the facility; the provision of multiple safety systems and physical barriers to prevent the uncontrolled release of radioactive material; and the requirements for extensive testing and inspection of plant equipment and systems, both before and during operation.

Although the operation of nuclear facilities is not completely risk-free, it is the safety objective of the AEC, through the licensing process, to require applicants and licensees to take those actions necessary to assure that the risks from design basis accidents are reduced to acceptable levels and to assure that the likelihood of accidents more severe than design basis accidents is extremely small.

In addition the licensee is required to develop a comprehensive emergency plan to take appropriate protective action to minimize the risk to public health and safety in the highly unlikely event that there is a significant release of radioactive material offsite. In this regard, we believe that EPA should give consideration to developing protective action guides for

the transuranic elements similar to those issued by the FRC in Reports Numbers 5 and 7 for iodine-131, cesium-137, strontium-90, and strontium-89. In addition to requiring licensee emergency plans, the AEC, in exercising its "Lead Operating Agency" role among Federal agencies having assigned responsibilities for nuclear incident emergency planning, is actively pursuing a program to assist State and local governments in developing and improving their Radiological Emergency Response Plans.

Summary

In summary, we are pleased that EPA is examining whether there is a need for additional guidelines on standards to further assure adequate protection of the ambient environment and public health and safety from potential releases of transuranium elements to the environment. We are confident that AEC regulatory requirements on the design and operation of nuclear fuel cycle facilities and the state of development of waste treatment technology will assure that the risk to public health and safety from the release of transuranium elements is kept at an extremely low level. Research to better define potential pathways of exposure and the relationship between intake of transuranics and biological risk should continue to be supported. Existing standards should be critically reviewed as additional information is developed on the dose-risk relationship. Guidance is needed on how to account properly, in cost-benefit analyses, for the comparative benefits to society from the expenditures of resources to reduce risk from radiation exposures relative to the benefits to be gained by the expenditure

of resources on reducing other health risks. Further guidance is also needed in the form of protective action guides for the transuranium elements similar to the guides for strontium-89, strontium-90, cesium-137, and iodine-131, as set forth in Reports Numbers 5 and 7 of the FRC. This concludes my statement and I will be pleased to respond to any questions you may have. In addition I have attached to my testimony an Appendix B which provides more of the detailed information requested in the Notice of Hearing. (Added oral testimony) Dr. Mills, I think you are aware that there are many documents in the public domain that are related to this subject, all of which are available for your use.

APPENDIX A

Bibliography of Recent AEC - Regulatory Issuances Pertaining to Plutonium and Transuranium Elements

1. Generic Environmental Statement Mixed Oxide Fuel, WASH-1327, August 1974.

2. Staff Testimony and Record of Barnwell Operating License Hearing, Docket 50-332, 1974.

3. Proposed amendment to 10 CFR Part 50, General Design Criteria for Fuel Reprocessing Plants, 39 FR 26293, August 18, 1974.

4. Proposed Amendment to 10 CFR Part 50, Technical Specifications for Fuel Reprocessing Plants, 39 FR 24626, July 5, 1974.

5. Proposed Amendments to 10 CFR Parts 40 and 70, Effluent Monitoring and Reporting (for fuel cycle facilities), 39 FR 38392, October 31, 1974.

6. Proposed Amendment to 10 CFR Part 20, Transuranic Waste Disposal, 39 FR 32921, September 12, 1974.

Bibliography Cont'd

7. Division 3 Regulatory Guides as follows:

3.1 Use of Borosilicate-Glass Raschig Rings as a Neutron Absorber in Solutions of Fissile Material

3.2 Efficiency Testing of Air-Cleaning Systems Containing Devices for Removal of Particles

3.3 Quality Assurance Program Requirements for Fuel Reprocessing Plants and for Plutonium Processing and Fuel Fabrication Plants (Rev. 1)

3.4 Nuclear Criticality Safety in Operations with Fissionable Materials Outside Reactors

3.6 Content of Technical Specifications for Fuel Reprocessing Plants

3.7 Monitoring of Combustible Gases and Vapors in Plutonium Processing and Fuel Fabrication Plants

3.10 Liquid Waste Treatment System Design Guide for Plutonium Processing and Fuel Fabrication Plants

3.12 General Design Guide for Ventilation Systems of Plutonium Processing and Fuel Fabrication Plants

3.14 Seismic Design Classification for Plutonium Processing and Fuel Fabrication Plants

3.16 General Fire Protection Guide for Plutonium Processing and Fuel Fabrication Plants

3.17 Earthquake Instrumentation for Fuel Reprocessing Plants

3.18 Confinement Barriers and Systems for Fuel Reprocessing Plants

3.19 Reporting of Operating Information for Fuel Reprocessing Plants

3.20 Process Offgas Systems for Fuel Reprocessing Plants

3.21 Quality Assurance Requirements for Protective Coatings Applied to Fuel Reprocessing and to Plutonium Processing and Fuel Fabrication Plants

3.22 Periodic Testing of Fuel Reprocessing Plant Protection System Actuation Functions

APPENDIX B

SUPPORTING INFORMATION TO THE STATEMENT OF LESTER ROGERS CONCERNING AEC REGULATION OF TRANSURANIUM ELEMENTS IN THE NUCLEAR FUEL CYCLE

The purpose of this Appendix is to describe where plutonium and other transuranium elements appear in the light-water-reactor fuel cycle, with and without plutonium recycle; to characterize the plants which process significant quantities of transuranics; to illustrate how the AEC Regulatory process is being applied to these plants; and to estimate the potential source terms.

1. The Light-Water-Reactor Fuel Cycle

The uranium fuel cycle is illustrated in Figure 1. It begins with the mining and milling of uranium. The uranium is then converted to UF_6, enriched in U-235, converted to UO_2, and fabricated into reactor fuel. The uranium oxide fuel is irradiated in reactors and, after several months, is reprocessed. In the reactors, some uranium is converted into plutonium and other transuranics and fission products. The reprocessing plants separate plutonium, other transuranics, and uranium from the spent fuel. The transuranics, other than plutonium, are normally disposed of as high-level radioactive waste along with the fission products. The recovered uranium is normally returned to the enrichment plants for recycling, and the plutonium is placed in storage.

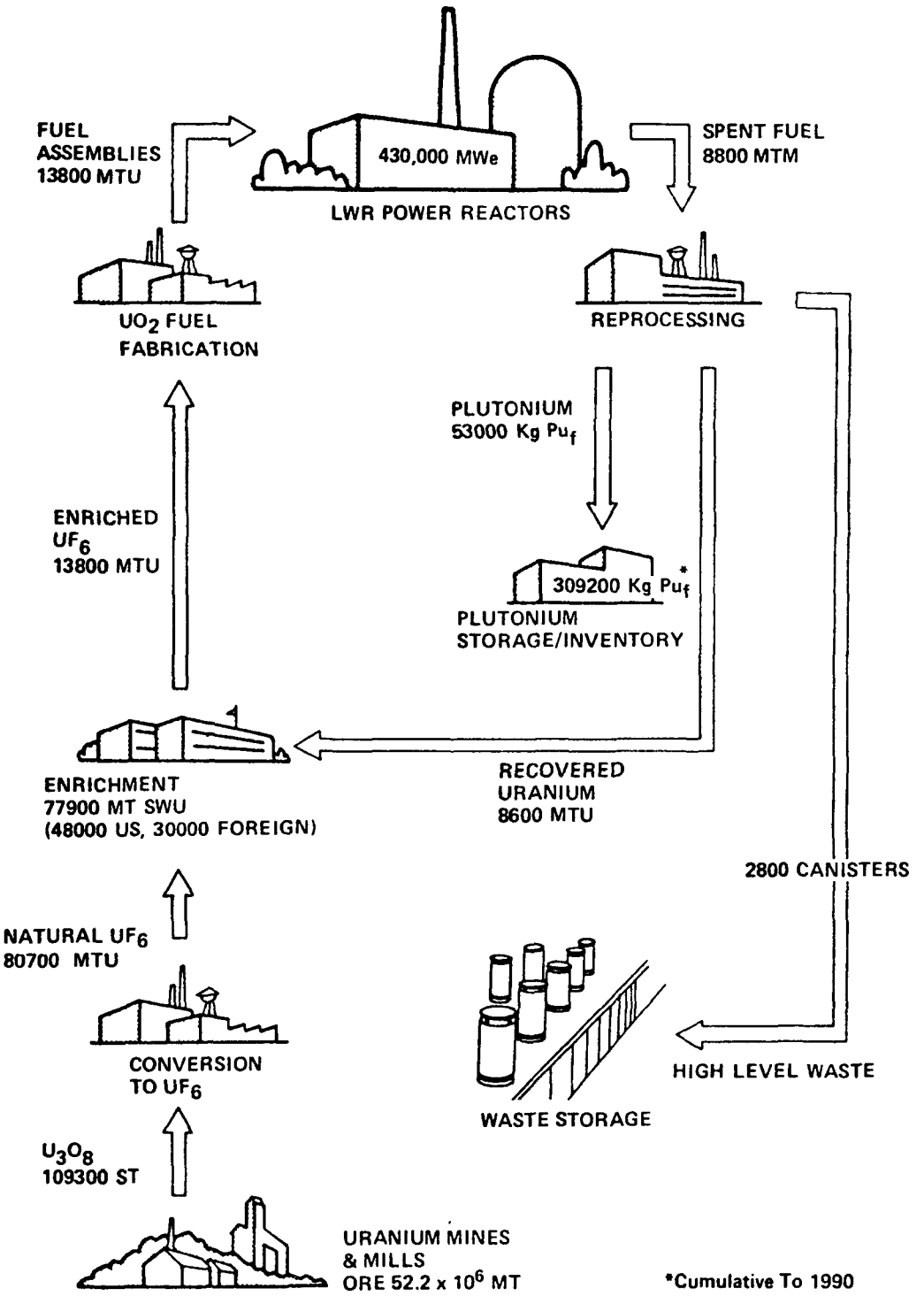

Figure 1. Annual Industry-wide Fuel Cycle Requirements for Light Water Reactors for about 1990 Without Plutonium Recycle (AEC-OPA 1974 Projection)

In the event that the use of recycle plutonium is approved, the LWR fuel cycle with the use of recycled plutonium is illustrated in Figure 2. Plutonium and other transuranics may be present in five phases of the LWR fuel cycle: (1) the reactor, (2) the fuel reprocessing plant, (3) plutonium storage, (4) high-level radioactive waste storage, and (5) the mixed oxide fuel fabrication plant.

In the reactor and in the storage facilities, the plutonium and other transuranics are contained by passive devices and not subjected to mechanical processing. It is expected that there will be a neglible discharge of plutonium and other transuranics to the environment in these phases of the fuel cycle.

The two phases of the fuel cycle which include processing of large quantities of plutonium and other transuranics are the fuel reprocessing plants (FRPs) and the mixed oxide fuel fabrication plants (MOFFPs). These plants are the most likely to discharge measurable quantities of plutonium and other transuranium elements to the environment and are described in more detail below.

a. Fuel Reprocessing Plants (FRPs)

The functions of a fuel reprocessing plant are to recover the residual fuel materials, uranium and plutonium, in a form suitable for re-use and to isolate radioactive wastes for storage and ultimate disposal. Spent fuel is transported from the reactor to the reprocessing plant in heavily shielded casks after a normal period

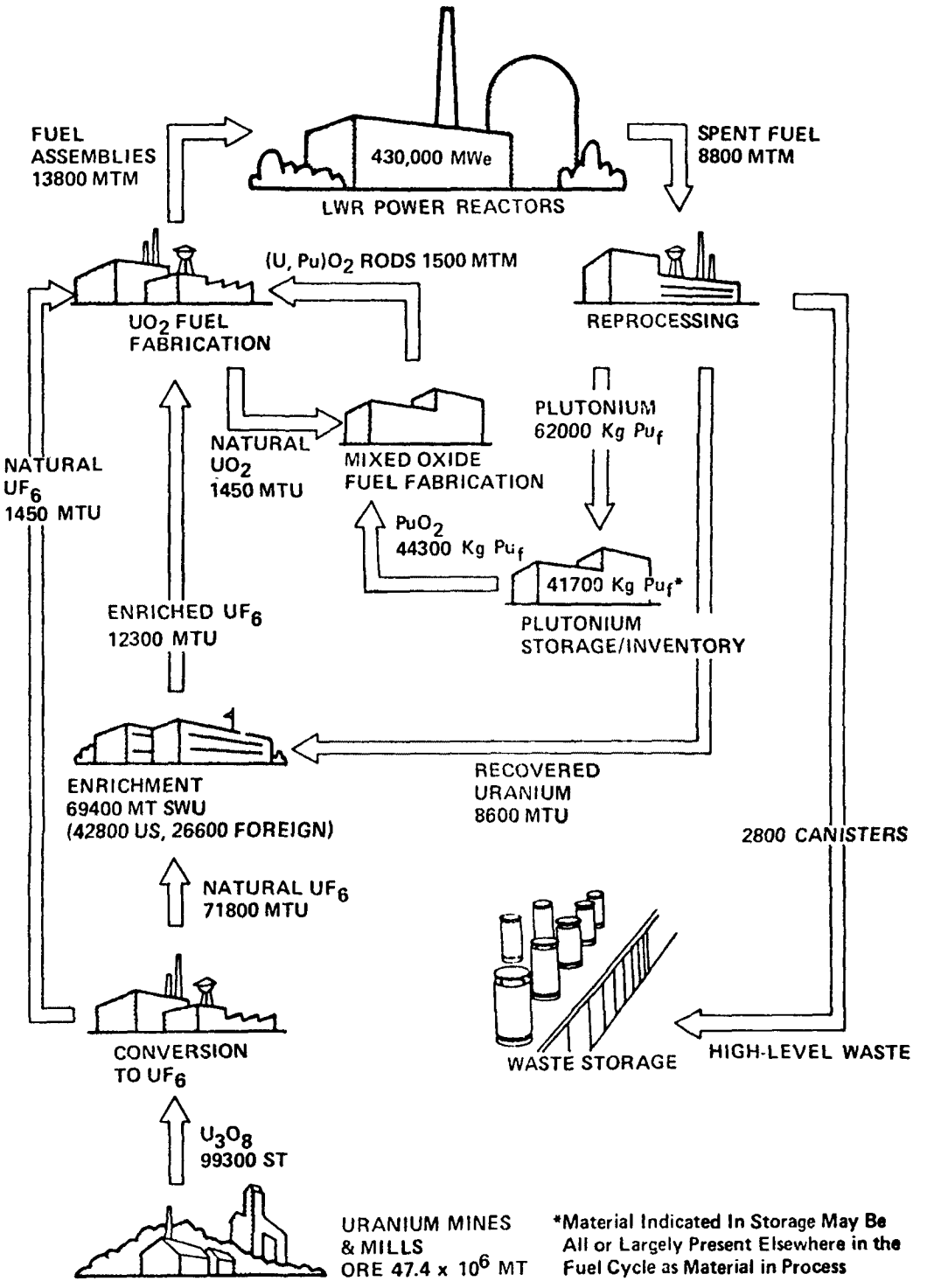

Figure 2. Annual Industry-wide Fuel Cycle Requirements for Light Water Reactors for About 1990 With Plutonium Recycle (AEC-OPA 1974 Projection)

of storage at the reactor of about 150 - 160 days. Commercial fuel reprocessing plants will use processes that are variations of the process that has been used in USAEC facilities for many years. After removal of the process tube and end-hardware of the fuel assembly, the next step in reprocessing irradiated nuclear fuels is to shear the long fuel assemblies into approximately 1-in. pieces to expose the fuel material for subsequent dissolution in nitric acid.

In the dissolver, the fuel material is dissolved in nitric acid, leaving the cladding hulls as a residue. The dissolver solution containing uranium, plutonium, other actinides, and fission products is assayed and transferred to a feed tank for the separation process. The residual hulls are examined to assure that fuel dissolution is complete and then are transferred to a solid waste storage area.

Uranium and plutonium are recovered and purified by a solvent extraction process in which uranium and plutonium preferentially transfer into the organic solvent, and the other transuranics and fission products remain in the acidic waste. The co-extracted uranium and plutonium then are separated from one another in a second solvent extraction operation. After similar purification steps, the purified uranium and plutonium products are packaged for future use. The highly radioactive acidic wastes from the solvent extraction system are concentrated by evaporation and stored in stainless steel tanks. Present AEC regulations (Appendix F, 10 CFR Part 50) require that

these liquid wastes be converted to a dry solid and transferred to a Federal repository no later than 10 years following separation of fission products from the irradiated fuel.

Gaseous waste streams from fuel reprocessing plants entrain small quantities of particulate plutonium and other transuranium elements. These waste streams are treated by gaseous radwaste systems prior to release to the atmosphere through tall stacks (typically 100 meters). The particulate removal efficiency of these systems, on the basis of current technology, is estimated to yield a system decontamination factor of 1×10^5 for 2 HEPAs in series.

A commercial scale FRP is expected to process about 1,500 metric tons per year of fuel irradiated to 33,000 MWD/metric ton at 30 kW/kg. After 160 days of radioactive decay, the calculated amounts of plutonium and other significant transuranics entering the facility per year would be as follows:

Nuclide	Expected FRP Throughput (Ci/yr)
Pu-238	4.2×10^6
Pu-239	4.9×10^5
Pu-240	7.1×10^5
Pu-241 (beta)	1.5×10^8
Pu-242	2.0×10^3
Am-241	2.4×10^5
Am-243	2.7×10^4
Cm-242	2.5×10^7
Cm-244	3.6×10^6
Alpha curie total:	3.4×10^7
Beta curie total:	1.5×10^8
Total:	1.8×10^8

b. Plutonium Fuel Fabrication Plants

The function of a plutonium fuel fabrication plant is to manufacture plutonium bearing fuel assemblies for nuclear reactors from plutonium oxide and uranium oxide feed materials. The fuel is often referred to as "mixed oxide" fuel, and the plant a mixed oxide fuel fabrication plant (MOFFP). The transuranium nuclide Am-241 entering a fabrication plant is that from the decay of Pu-241 following an aging time of about two years after plutonium separation in a fuel reprocessing plant.

Fuel pellets are fabricated from uranium and plutonium oxide powders. The pellets are inserted into zirconium alloy tubes and shipped to an enriched uranium fuel fabrication plant for placement in assemblies prior to shipment to LWR power plants.

All processing steps which involve radioactive materials are performed in process vessels, process cells, or alpha enclosures (such as glove boxes). The gaseous waste streams from the processing steps each receive a separate pretreatment. The treated process gases and alpha enclosure ventilation air are combined with ventilation air from personnel operating areas for final treatment with high efficiency filters prior to release to the atmosphere through a short stack (typically $^{4-6}$ meters). The particulate removal efficiency of this treatment system, on the basis of current technology, is estimated to yield a system decontamination factor of 3×10^7 for 3 HEPA filter banks in series.

Liquid effluent treatment systems are used to recover uranium, plutonium, and nonradioactive materials, such as nitric acid and water, and to recycle these materials to the processing operations. No radioactive process liquids are expected to be released from the plant. Residues from the treatment of liquid radwastes are already being solidified and shipped offsite for disposal.

Commercial scale plants expected to be built in the near future will typically have a throughput of one metric ton per day of mixed oxide fuel. The amounts of plutonium and transuranium nuclides entering a MOFFP per year are calculated to be as follows:

Nuclide	Expected MOFFP Throughput (Curies/Year)
Pu-238	6.6×10^{6}
Pu-239	3.5×10^{5}
Pu-240	7.7×10^{5}
Pu-241	1.7×10^{8}
Pu-242	4.9×10^{3}
Am-241	5.7×10^{5}
Alpha curie total:	8.3×10^{6}
Beta curie total:	1.7×10^{8}
Total:	1.8×10^{8}

2. The AEC Regulatory Process

a. General Design Criteria

The Atomic Energy Commission establishes regulations which set general requirements for the primary safety related features of nuclear facilities. These regulations are called General

Design Criteria. License applicants are required to show, by engineering analyses and tests, that individual facilities meet the general design criteria. The general design criteria specifically treat the design, inspection, and testing of components and systems which confine radionuclides including transuranium elements.

In 1972, the Atomic Energy Commission began to develop amendments to its regulations to provide general design criteria for fuel reprocessing plants and for plutonium processing and fuel fabrication plants. Proposed General Design Criteria for Fuel Reprocessing plants were published in August 1974. General Design Criteria for Plutonium Processing and Fuel Fabrication Plants are being developed. These criteria will assist license applicants in developing a description and safety assessment of the design bases for the principal structures, systems, and components of the plant, including provisions for protection against natural phenomena, and a description of the quality assurance program. Specific criteria which affect normal operational releases include those which refer to testing and maintenance of equipment, design of confinement barriers, ventilation and off-gas systems, protection systems, instrumentation and control systems, effluent systems, and effluent monitoring.

b. Siting Criteria

Revisions of AEC regulations giving siting criteria for fuel cycle facilities are being developed. The purpose of siting criteria is to control the risk to the general population by restricting the location of the sites.

In developing siting criteria, consideration is given to the potential releases of plutonium and other transuranics and to the pathways by which these nuclides can reach man. The criteria will be used in a screening process to identify suitable candidate sites for these facilities. The decision to build a plant on a specific site will be based on a detailed evaluation of the proposed site-plant combination, and a cost-benefit analysis comparing that combination with alternative site-plant combinations.

In 1972, the AEC began studies to provide the technical bases for developing generic siting criteria for fuel cycle facilities handling large quantities of plutonium and other transuranics. This work is still in progress.

c. The Policy of "As Low As Practicable"

In 1973 the Commission initiated comprehensive engineering and environmental studies to form the basis for numerical guidance for as-low-as-practicable effluent releases for fuel cycle facilities other than reactors. These studies included nuclear fuel reprocessing plants and plutonium processing and fuel fabrication plants.

The studies began with the development of conceptual designs of model plants. Calculations were then made of the quantity of radioactive material that would be released to the envionment (in liquid and gaseous effluents) and the resulting dose commitments

to individuals and the population. The model plants included sufficient radwaste treatment equipment to limit radioactive materials in liquid and gaseous effluents at or below the levels in 10 CFR Part 20.

The next phase of the studies consisted of adding to the conceptual model plant successive stages of radwaste treatment equipment to limit radioactive materials in effluents to successively lower levels. The cost was estimated for each increment of added radwaste treatment. The quantity of radioactive material released to the environment and the resultant dose commitment to individuals and the population were also calculated for each increment.

The third phase of the studies was to determine the cost effectiveness of each increment of radwaste equipment that was added to the model plant. This was done by dividing the cost of each increment of treatment by the reduction in dose commitment to the population that the equipment achieved. The cost effectiveness was thus determined in units of dollars per person-rem of reduction in population dose commitment.

The final phase of the studies is to select for each fuel cycle facility numerical guidelines for as-low-as-practicable releases. This includes limits on the quantities of radioactive material released to the environment and the maximum annual dose commitment that an individual can receive at the site boundary.

The numerical values will be chosen so that doses are at a very low level where further reduction in risk would not be justified by the effort required to accomplish it; i.e. the doses are as low as reasonably achievable.

The proposed rule changes and draft environmental statements relating to ALAP for fuel reprocessing plants and mixed oxide fuel fabrication plants are being developed.

d. The Use of Technical Specifications, Monitoring, and Inspections

In licensing individual nuclear plants such as FRPs and MOFFPs, certain factors quantified in the analysis of the plant may be specified in the technical specifications or license conditions which become part of license to operate the plant. These requirements provide assurance that the plant is operated so that normal releases do not exceed those evaluated in the licensing process.

Further assurance that actual releases do not exceed those specified in the technical specifications is provided by monitoring gaseous and liquid effluents from the facilities. For fuel reprocessing and plutonium fuel fabrication plants, emphasis is placed on sampling of gaseous effluents from the exhaust stack, since evidence indicates that inhalation (both during plume passage and from resuspension of deposited particles) is the critical pathway for dose commitments from plutonium and other transuranics. As a result, the major monitoring effort in such plants is directed toward measurement

of the small quantities of plutonium and other transuranium elements which penetrate the final confinement barrier (the final filter bank) and are released to the atmosphere. In addition, environmental monitoring is performed for plutonium and other transuranics, and is generally done to (1) establish baseline data (e.g., fallout plutonium from weapons tests or burnup of systems nuclear auxiliary power (SNAP) generators returning to the earth from space applications), (2) provide confirmation that plutonium is not accumulating in the environment, or (3) provide environmental contamination data following an accidental release of plutonium. Effluent monitoring guides are now being developed for FRPs and MOFFPs and are expected to be issued for comment in 1975.

In addition to the monitoring efforts required of licensees, periodic and extensive on-site inspections of each plant are carried out by the Regulatory staff. The purpose is to provide further assurance that the requirements of Regulatory standards and the technical specifications at each plant are being complied with. In the event of violations by licensees, Regulatory response may range from written admonitions to correct unsatisfactory conditions, to monetary fines or plant enclosure in the event of serious violations.

e. The AEC Policy for Radioactive Waste

The Atomic Energy Commission is considering the amendment of its regulations to prohibit the disposal by burial in soil of

plutonium and other transuranics (39 FR 32921, 9/12/74). Wastes containing plutonium and other transuranium elements generally consist of (a) expendable material such as absorbent tissues, clothing, gloves, and equipment; (b) solids such as filters from effluent treatment systems; (c) liquid and solidified liquid wastes; (d) fuel hulls which remain after fuel reprocessing operations; and (e) wastes which contain or are contaminated with transuranics resulting from reprocessing operations, but which are not classified as high-level waste.

Presently, the AEC regulations permit the disposal of specified small quantities of transuranics by burial without the specific approval of the Commission. The proposed amendment would require waste containing transuranium elements to be solidified (if necessary), packaged, and transferred to the AEC for storage as soon as practicable but within five years after its generation.

3. Source Terms of Plutonium and Other Transuranium Elements

With the implementation of the Regulatory process which has been outlined above to include general design criteria, siting criteria, ALAP numerical guidelines, monitoring and inspections, and waste disposal policy, it is possible to make projections of the releases of plutonium and other transuranics from the commercial scale FRPs and MOFFPs of the near future. Such estimates are largely theoretical in nature, based on limited experience with

much smaller facilities. Until larger facilities have been licensed and operating it will be difficult to precisely define such releases.

Based on current projections, there will be several commercial scale FRPs in operation by 1990, reprocessing on the order of 8,800 metric tons of LWR fuel per year. For each typical, commercial scale FRP, the Regulatory staff estimates that less than 0.1 curie (alpha) of plutonium and other transuranics will be released in gaseous effluents per plant-year. In addition, less than one curie (beta) of plutonium-241 would be released in gaseous effluents per plant-year. No liquid releases are anticipated. The maximum annual organ dose (bone) to an individual living near the site boundary has been estimated to be less than 1.0 mrem from plutonium and other transuranics. The annual dose to the whole body is much lower than the maximum organ dose to the bone. These estimates include dose contributions from inhalation and ingestion.

The decision regarding the use of recycle plutonium for LWR fuel has not yet been made. Current projections indicate that if plutonium recycle is initiated, there will be several commercial scale MOFFPs in operation by 1990, fabricating about 1,500 metric tons of mixed oxide fuel per year. The Regulatory staff estimates that less than 0.0001 curie (alpha) of plutonium and other transuranium elements would be released in gaseous effluents per plant-year for a MOFFP of commercial scale. About 0.001 curie of

plutonium-241 (beta) would be released in gaseous effluents per plant-year. The maximum annual organ dose (bone) to an individual living near the site boundary has been estimated to be less than one millirem. The annual whole body dose would be much lower than the maximum annual organ dose. These estimates include dose contributions from inhalations and ingestion.

Thus, for the uranium fuel cycle, with or without plutonium recycle, the maximum dose to any organ or to the whole body of an individual from plutonium and other transuranium elements would amount to no more than one percent of the natural background radiation dose.

ICRP PUBLICATION 22

Implications of Commission Recommendations that Doses be kept as Low as Readily Achievable

A Report by Committee 4 of the
International Commission on
Radiological Protection

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Dr. Mills: Thank you very much, Mr. Rogers.

Dr. Morgan, do you have any questions?

Dr. Morgan: I have just one question, Mr. Rogers.

You indicated that for the foreseeable future, it was not anticipated that the doses to the population from the operation of the light-water-cooled reactors would exceed more than about one percent of the natural background radiation.

Perhaps I could break this into two questions.

Does this include the occupational dose and the accident dose?

The other question, then, would be what about the LMFBR and the fuel fabrication and the rest of the fuel cycle?

I think it would be much more meaningful if you could give us the percent in reference to the whole fuel cycle.

Mr. Rogers: This does not include occupational exposure inside the facility. It relates only to the population exposure received off-site.

Dr. Morgan: It does not include accidents?

Mr. Rogers: It does not include accidents.

Dr. Morgan: What about LMFBR?

Mr. Rogers: It does not include the LMFBR. The information that is presently available on technology would lead us to believe that the levels of release from any LMFBR would be at least as low as those from the light- water reactor and should not be significantly different.

With respect to the remainder of the fuel cycle as related to

population dose, we would expect again that the average population dose would not exceed the order of one percent of the natural background.

Mr. Morgan: The two percent total would be --

Mr. Rogers: In that range somewhere. As you know, these are estimates and projections, so I would not want to refine those numbers any further.

One or two percent, somewhere around that figure.

Dr. Mills: Dr. Garner?

Dr. Garner: As a follow up to what Dr. Morgan was saying, you say you think approximately the same amount of transuranics will be released from the recovery operation, or do you mean to say that percentage of the total inventory will be released?

Mr. Rogers: With the LMFBR, I was really referring to the relative dose offsite from the LMFBR.

Dr. Garner: That does not mean, does it, that since you are going to have a total greater throughput of transuranics, that you must be cutting down the releases to the environment, the percentage of the total handled that is released to the environment will be cut down?

Mr. Rogers: I think that is correct.

Dr. Garner: So you are going to improve the hold-up. I do not know what percentage you normally take of material in the processing plant, what percentage you take as released, escaping to the environment. Could you give me a figure on that, a working figure?

Mr. Rogers: We are doing detailed studies on that at the moment. I do not think I have specific figures as to percentage other than the decontamination factors that we get, on the order of 10^8 or 10^9 with respect to fuel reprocessing and 10^9 or 10^{10} for mixed oxide fuel fabrication plants.

Dr. Garner: I think that is all I have to say.

Dr. Mills: Dr. Radford?

Dr. Radford: Mr. Rogers, you referred to these estimates of the dose commitment that EPA has made in a publication. Are you familiar with the model on which they based these estimates, the exposure conditions that they assume, and so on?

Mr. Rogers: I am generally familiar with it. It is in the published report.

Dr. Radford: On page 6 of your appendix B, you give the throughput for a 1500 metric ton per year fuel reprocessing plant?

Mr. Rogers: That is correct.

Dr. Radford: In curie amounts, curium 242 and 244 constitute far and away the most important throughput of alpha activity. Now, I am only talking about alpha activity.

Mr. Rogers: I am not sure I would characterize it as the most important. It is the largest number.

Dr. Radford: Well, OK. It is far and away the largest fraction. If my quick arithmetic is right, something on the order of 95 percent of all the alpha activity through fuel reprocessing plants is curium isotopes.

Now, I am not quite sure, this is entering a facility, but the plutonium will be recycled out, so the plutonium becomes an even smaller fraction once it is recycled out. Is that correct, if you assume a recycle?

Mr. Rogers: A smaller fraction of --

Dr. Radford: You have a certain amount of activity of plutonium isotopes coming in, right?

Mr. Rogers: Yes.

Dr. Radford: Now the waste stream will not contain much of that plutonium. You hope it will only be, as we said yesterday, something like a half percent.

Therefore, the amount released in the waste and potentially capable of reaching the environment, plutonium isotopes on a curie basis now, would be very small indeed, proportionate to the americium even?

Mr. Rogers: But the curium that is retained in the process, of course, goes into solidified waste. It is not released to the environment.

Dr. Radford: The point I am making is, it is not recovered. It is simply put aside or maybe lost in the process.

Now, the question I would ask pertinent to this dose commitment, what assumptions were made about releases from the waste system, from the throughput system, and so on as far as the activities of these alpha emitters are concerned?

Mr. Rogers: Again, I believe the same assumptions that decontami-

nation factors of 10^8 and 10^9 were used.

Dr. Radford: So that would apply to curium isotopes also?

Mr. Rogers: That is right.

Dr. Radford: We could then use these across the board as the estimates of what would escape?

Mr. Rogers: Right.

Dr. Radford: OK. Now, in view of the fact that the curium isotopes are in far greater alpha activity concentration, do you know if the dose estimates were based on curium uptake?

Mr. Rogers: I believe the dose estimates did include curium.

Dr. Radford: We would have to include mostly curium, since on an activity basis, it is mostly curium. I think I heard today and we have the people in the audience who can correct this, that some recent experiments have indicated that curium was unusually hazardous, as least as far as per rad dose base was concerned; the assumption being that it was uniformly distributed rather than perhaps aggregating in a lymph node, such as some of the plutonium.

Therefore, the question would be has an adequate evaluation of this new information changed the picture as far ar perhaps the curium toxicity might be?

Mr. Rogers: I do not think I would want to comment on that with respect to the curium toxicity, Dr. Radford. But, I do not think it changes the picture of our basic approach to isolate this material through good design objectives and conditions of operation, to simply

avoid letting any significant quantity enter the environment, thereby avoiding the risk fostered by unwarrented exposure.

Dr. Radford: That might influence whether the number of lung cancers was 21, 21,000, 20 million or something.

Mr. Rogers: I really would not argue about the risk; if the estimate is 21, 30 or 40, from that standpoint. I think the basic message that I would like to get across is that from a regulatory standpoint, our emphasis is on design objectives and limiting conditions of operation, using technology on a reasonable cost-benefit basis to keep the material out of the environment and to isolate.

Our best estimates, I think, both with respect to EPA and the AEC and all the estimates that have been made in the environmental statement on the breeder and the details of the envioronmental statement on plutonium recycling, shows that it is technically feasible to keep these levels down to extremely low levels as far as exposure is concerned.

So I think that is the basic message. Surely, we should continue to carefully study our dose risk relationship, so that we will be acting on the best available information. But from the standpoint of the end result of reducing exposures, I do not think that we are waiting on that kind of information to go ahead and apply technology to keep these releases at extremely low levels.

Dr. Radford: We heard from Mr. Forscher of ANSI earlier. I believe you were here. He indicated that the ANSI standard, in effect, led to a 50-fold reduction in the calculated emission limit.

These were fuel fabrication facilities only. Do you think that 50-fold reduction is a relatively easy thing to achieve?

Mr. Rogers: I would like to make two comments. First, I would not want any misunderstanding with respect to the status of the draft standard that Dr. Forscher talked about this morning. That is still in committee work.

We do not subscribe to the specific numbers that are in the standard. We really think the question of effluent limitation, numerical effluent limitation, is really a prerogative of the regulatory agencies to establish.

Having said that, I would not want to be associated with that standard as being any type of official document. But having said that, I think I have just indicated in my testimony, that as a practical matter we feel by applying the "as low as reasonably achievable" concept on a cost-benefit basis, that in normal operations and most of the time, we can achieve levels of exposure from the transuranics which are perhaps less than one percent of the existing basic radiation protection standards. So that would indicate a reduction in terms of exposure of a factor of 100. We are doing that as you well know in the light-water-cooled reactors.

We feel that the exposures can be kept generally down to this range of one percent of existing radiation protection basic standards from these individual sources.

Dr. Radford: A final question: There has been some concern expressed, including by myself, that if you set, let us say, environ-

mental limits either by emission limitations or by ambient measurements, however they are specified, below the detection limit, below the practical detection limit, that in effect you have really an unregulated situation.

Mr. Rogers: Well, I understand what you are saying. Let me say I think the feasibility of detection depends on the point of measurement.

If you wait until the radioactive material is dispersed in the environment, and you go out and try to measure environmental levels, it becomes extremely difficult at these low levels. Although with research instrumentation, as you well know, you can get extremely low. But, if you do put your emphasis on the point of control, on the source, and do your measurement there, just behind the HEPA filters, to measure materials while you have it in a small volume, then you can detect extremely low levels.

Dr. Radford: Does not that pose certain special problems when you are talking about particulates coming out?

Mr. Rogers: No question. There is no question that it does pose problems and it takes a very substantial technology and very substantial effort to contain the material and then to do the right kind of monitoring programs to show what you are doing.

But we feel we should go ahead and take those kinds of measures. Let me emphasize one thing. I think there is a good deal of misunderstanding as to what the AEC is doing in trying to define design objectives and limiting conditions of operations for individual kinds of

facilities. Those are derived working limits, working levels for the purpose of design objectives. Many people are confusing that with the basic standards and saying we have reduced the basic standards. That is not true.

The basic standards apply with all sources of exposure, except natural background and medical exposures. When an engineer goes to design a reactor or reprocessing plant, he has to define system performance requirements. Therefore, there have to be numbers to design against. It is these design objectives which we are defining, which is based strictly on the basis of technology.

It so happens that with technology, you can get down to a level of risk which we consider to be approaching the trivial level, extremely low levels. Having reached those levels, we feel that the problem then is solved, that those are design objectives for limiting conditions of operation, not lowering the basic standard, nor are they considered as limits as such.

Dr. Radford: I understand.

Dr. Mills: Dr. First?

Dr. First: In all of your statement, you qualified your environmental limit as for normal operations. What would be a practical number considering perturbations and upset conditions and so on? Would this change in any way?

Mr. Rogers: What I use in normal operations takes into account perturbations and unusual kinds of operation. What I am trying to do is differentiate between accidents and normal operations.

Dr. First: I take it, accidents then, are those in which some considerable amount of activity escapes the containment, et cetera?

Mr. Rogers: Our basic approach to accidents is to require the design and safety system to make the probability of the accidents extremely low.

Dr. First: Just one other minor point I would like to ask about. In Appendix B, where you discuss how you arrived at the least reasonably achievable levels, you state that you keep looking at the problem go lower and lower in emissions. I am on page 11.

You say the cost effectiveness is determined at a point where further reduction of risk would not be justified by the effort to accomplish it, as you get less and less risk reduction per unit cost.

What is the other end of that equation? How do you make this determination, when the dollars are no longer worthwhile?

Mr. Rogers: Of course, this is one of the most difficult and, perhaps, one of the most controversial areas. It is in this area that I suggest that the EPA might help us in providing some guidance.

If you look in the light-water reactor area, let me say first, we feel that you have to consider both the population dose as well as the dose for the individual. These both have to be considered, both the individual as well as population dose.

There are going to be times when the dose to the individual will be controlling over the population dose. It is a very difficult, subjective kind of decision to make, but in the light water reactor

area, the design objectives and limiting conditions of operation are recommended by the staff in their final concluding statement.

I think for whole body doses, it turns out the range is on the order of 200, 250, 300 dollars, perhaps, per man-rem; some lower than that.

In the literature, suggestion has been made of dollars per man-rem from a few pounds sterling, I believe, up to ranges, perhaps, to $1,000 or less than $1,000 per man-rem. There are estimates all within that range.

I do not know how valid these numbers are, and this is where judgment is very difficult. I think this is where we really need guidance.

Dr. Mills: Dr. First asked my question about the selected number. As you know, we have been battling about this number for some time as to where it should be.

I think you are right. It is very complex, a complex decision to make.

The only minor question I have has to do with this question of background. Are you proposing that the process for establishing the standard for the nuclear industry as a whole should be related to natural background, or should we use natural background to put the inner risk that we might assign in the proper perspective?

From time to time, I have heard people say there should be some percentage of background.

Mr. Rogers: No. I think our basic approach to controlling the releases that I have outlined here is with emphasis on developing of sound technology with the basic philosophy of trying to contain the materials.

You know, it turns out that with technology, it is feasible to get down to levels which are on the order of just a few percent of natural background.

It is my own judgment, and this is my personal feeling, that you reach a level where the residual risk is so small, and it is in this range of percent or so of natural background radiation, that you reach a level of risk where the risk is so small it is simply not worth the effort to try to eliminate that residual risk.

I think our cost-benefit analysis generally supports that when you get down into that range, your costs start going up rather rapidly.

Certainly, natural background radiation is probably the most valid indicator that we have as to the relative risk of radiation as a comparison.

Dr. Mills: No more questions.

Thank you very much.

I have been asked to make an announcement. EPA will have a copy of all the written material submitted available for inspection on Monday, December 16, in the EPA Freedom of Information Office.

As was announced earlier, the transcript will be available within 30 days.

Next we have the representatives of the Westinghouse Electric

Corporation, Power Systems Division, Mr. Kramer and Dr. Wright.

Dr. Kramer: Good afternoon, gentlemen.

Before I begin, may I ask if it will be possible for Dr. Wright's talk and mine to be consecutive and then have the questions afterwards?

Dr. Mills: Fine.

STATEMENT BY

FREDERICK W. KRAMER

ENGINEERING MANAGER, NUCLEAR FUEL DIVISION

WESTINGHOUSE ELECTRIC CORPORATION

BEFORE THE

ENVIRONMENTAL PROTECTION AGENCY

DECEMBER 10, 1974

My name is Frederick W. Kramer. I am the Engineering Manager of the Nuclear Fuel Division of the Westinghouse Electric Corporation. I am accompanied by Dr. James H. Wright, Director of the Environmental Systems Department, who will also speak, and Roger E. Wills of the Westinghouse Law Department.

I am pleased to have this opportunity to appear before you on behalf of Westinghouse and to participate in the Environmental Protection Agency's effort to ascertain whether there is a need to establish new environmental guidelines or standards at this time. I will direct my remarks to categories 1, 4 and 5 of the Federal Register announcement. Dr. Wright will address his remarks to categories 2 and 3.

We believe that the most complete information on the social and economic implications of using plutonium as applied to our environment and to the national economy is available in the AEC draft publications, WASH-1535 (March 1974), "Environmental Impact Statement for LMFBR Industry," and WASH-1327 (August 1974), "Generic Environmental Impact Statement for Mixed-Oxide Fuels." The statements represent two uses of plutonium in generating nuclear power. As explained later, these applications are expected to utilize virtually all of the plutonium made available commercially for several decades. Basically, WASH-1327 describes the near-term

situation where plutonium will be recycled in LWRs, while WASH-1535 covers the transition from this usage to application in a breeder industry through the year 2000 and beyond.

Both reports provide extensive reviews of the benefits of plutonium utilization in power generation, and both include relevant information on potential environmental and public health impacts. Additionally, the AEC is currently reviewing various aspects of the entire fuel cycle. These activities should provide an important base for any reviews of plutonium and transuranic guidelines or standards, and we anticipate that the EPA will work closely with the AEC to develop coordinated and integrated radiation protection guidelines in a systematic manner.

We recognize the benefits and risks of plutonium are a subject area which commands a great deal of attention, and we welcome the EPA's public airing of this subject. While this public hearing and related AEC efforts can go far toward placing the use of plutonium in perspective, it is important in considering possible new standards for plutonium that such efforts eliminate any alternatives which on balance offer little or no benefit at a significant cost.

For example, if a standard were to be adopted which permitted, as a limit, releases from nuclear facilities of only a small fraction of fall-out levels, environmental measurements and effluent control systems required to prove that such limits were not approached or exceeded could be very extensive. To adopt standards without carefully considering the total risks and benefits associated with nuclear and non-nuclear options (and in the context of effects from widespread fallout versus localized effects from a few facilities) would be unwise.

As part of any facility environmental report, a description of various control alternatives is presented in the context of a cost-benefit analysis. This cost-benefit approach would be continued and, as required, extended to include entire fuel cycle or plutonium usage activities, such as were included in the AEC's Generic Environmental Impact Statements. In this regard, we would suggest that the EPA consider the value of preparing an environmental impact statement for any contemplated new standards -- one which includes a detailed cost-benefit analysis -- in view of the desirable social results of such preparation.

For instance, preparation of the impact statement would provide for improved planning and coordination, a greater likelihood that decisions to further one environmental goal will be taken with the awareness of

possible impacts on other environmental concerns, fuller use of available expertise through the extensive review process, substantial benefits of public participation, and careful decision making through weighing of costs and benefits. A complete discussion of alternatives would allow for stimulated and factual debate with constructive results.

The implementation of general ambient environmental guidelines or standards for plutonium and the transuranium elements will eventually require a determination of an emission standard for each source of contamination. The validity of the ambient environmental standard as well as the method for establishing the emission standard could greatly affect the direct costs of facilities and indirectly affect the cost of energy to the American consumer. This latter issue has been raised in AEC hearings, and it is appropriate that the extrapolation of the costs to the American consumer should be addressed.

In our detailed statement being submitted for the record, Westinghouse identifies the general factors to be considered in the cost-benefit analysis.

Westinghouse has long held a position of leadership in the nuclear industry, and we have accumulated substantial experience and knowledge to demonstrate that plutonium can be handled and utilized safely. The Westinghouse Plutonium Fuels Development Laboratory has been on-line for

five years. The Fast Flux Test Facility is approaching completion. The Liquid Metal Fast Breeder Reactor represents a new generation in reactor development. The Westinghouse Recycle Fuels Plant is in the licensing process today and is destined to be the industry's first full-scale plutonium fuel fabrication facility.

In recent months, Westinghouse has been engaged in detailed evaluations of the impact of plutonium on the environment for each of the programs mentioned above. These environmental reports are in the public domain, and I would encourage interested citizens to inspect them. Only in this manner can the depth of study involved be fully appreciated.

Our actual operating experience with plutonium handling and processing has been achieved at the Plutonium Fuels Development Laboratory (PFDL) located at Cheswick, Pennsylvania. This laboratory has provided extensive, practical experience in the fabrication of plutonium fuels and is the source of mixed-oxide (PuO_2 - UO_2) fuel elements which have already been successfully demonstrated in operating reactors.

Since 1969, Westinghouse has conducted a program of monitoring, measuring and controlling both gaseous and liquid effluents at PFDL. Detailed data are presented in our written submission but a few summary notes are significant:

1. Monitored airborne releases from PFDL have been found to be less than detectable levels, even while minimum detectable levels have been reduced through the increased sophistication of measurement methods.

2. Liquid releases at the point of discharge are less than four percent of the maximum permissible concentration.

3. Activity levels in the plant sanitary sewer are approximately three orders of magnitude lower than the maximum permissible concentration, and those levels measured in the Allegheny River are approximately seven orders of magnitude lower than MPC, which is indistinguishable from the plutonium present in the environment due to fallout background.

It should be stressed that these are normal, anticipated levels expected as a function of plant design and operational control as well as environmental background. This is pertinent experience and should be carefully considered in judging the adequacy of existing standards.

Of further interest is our study to identify and to quantify potential radiation exposure pathways for humans and other biota living within the sphere of influence of the several facilities. These are necessary to establish an environmental monitoring program which will effectively quantify unusual conditions as well as monitor normal conditions anticipated. My written statement discusses the exposure pathways related to PFDL and compares their maximum impact with natural background levels. In each instance, the maximum potential exposure is a small fraction of the natural background. It is important that a continuing study be conducted to refine models as knowledge is gained and to evaluate operating data as it is generated, and Westinghouse is doing this.

Several reliable predictions are available projecting uses of plutonium, both in light-water and breeder reactors for commercial power generation. The Westinghouse forecast is presented in the written statement for the period 1975-1990, and the data are consistent with those estimated by the AEC. It shows a cumulative usage of less than 200 metric tons of plutonium by 1985 and approximately 1400 metric tons by the year 2000. The curve shows slow initial growth in usage, relatively large increases after 1985, and ultimately the changeover in application from recycle in LWR plants to use by the breeder industry. The gradual start means another decade is available for resolution of ultimate waste disposal and for refinement of safeguards.

The Westinghouse Recycle Fuels Plant (RFP) will be the first fuel fabrication facility sized to process large quantities of plutonium. Environmental and safety analysis reports for this facility are detailed in Docket No. 70-1432, wherein the plutonium confinement practices are evaluated in depth. Briefly, the manufacturing building will be designed to withstand earthquake and tornado conditions and, within this structure, a second specially shielded "canyon" will house all the equipment required to fabricate plutonium fuel. This canyon serves the dual purpose of positively confining the plutonium to a restricted area together with providing protection for all personnel. Of particular interest is the ventilation system which is designed to remain functional under design basis accident conditions including a tornado or earthquake. The high efficiency filtering system is also protected with a fire suppression system and, of course, all exhausts will be continuously monitored.

Current regulations require that the facility must have the capability of being decontaminated and decommissioned. Since the design of the canyon must necessarily provide for equipment maintenance and replacement, many features required for decommissioning are inherent in the design. The systems and barriers can all be removed and packaged for ultimate disposal.

Conclusion

At present, the number of commercial facilities handling plutonium is small. The environmental and safety requirements for such facilities are already rigorous and demanding. These requirements reflect the cumulative experience of a variety of operations under AEC control and the newer demands of NEPA. Benefits are also resulting from the continuing and extensive AEC-supported R&D programs related to environmental transport and health effects.

Much of this information is new, and its application will be factored into the new or planned commercial facilities. Consequently, it may be a few years before extensive experience and data are obtained on the actual releases from such facilities and their environmental pathways. While we are confident that the results will confirm what we are finding at the PFDL -- that plant operation has a negligible effect on the environment -- it is appropriate to obtain further data before modifying the existing standards. We believe that the current regulations and procedures for controlling releases of plutonium and the other transuranium elements are adequate, and there is merit in obtaining further operational experience and R&D results before developing revised or additional standards.

The slow increase in plutonium utilization during the next decade affords an opportunity to institute a well planned program of data acquisition and environmental impact confirmation. Environmental standards for plutonium can then be rationally modified, if necessary, based on experience and need. Westinghouse endorses an effort of this type and pledges its cooperation with the cognizant regulatory agencies. In the interim, it would be appropriate to continue to utilize the currently conservative regulations and guidelines for plutonium.

ATTACHMENT

DETAILED COMMENTS

General

The general factors to be considered in the cost-benefit analysis include the following:

a. present environmental standards:
   (i) costs of equipment and energy
   (ii) risks

b. present operational standards
   (i) costs of equipment and energy
   (ii) risks

c. reliability of extrapolation from operational limits to ambient environmental standards

d. incremental costs and risks from the sources within the fuel cycle

e. differences between known potential adverse consequences and estimates of upper limits of potential adverse consequences

f. existing or presently planned facilities
   (i) equipment costs
   (ii) energy costs by requiring modifications
   (iii) risks if retrofitting is not applied.

Applications Using Plutonium

The principal use of plutonium will be as a fuel in the generation of commercial nuclear power. Westinghouse, as a supplier to the nuclear industry, is involved and concerned with that application both in Light Water Reactors (LWRs) and Liquid Metal Fast Breeder Reactors (LMFBRs).

The actual amounts of plutonium available for fabrication as fuel at any point in time will be dependent primarily on the prior size of the nuclear power industry, and many forecasts are available in the literature. Two of these predictions considered to be most reliable are those published by the AEC in the draft environmental impact statements for the breeder industry (WASH-1535)[1], and for plutonium recycle

(WASH-1327)[2]. Values for plutonium production and usage over a 50-year period trace the development of the breeder industry in the earlier of these documents, and the shorter-range recycle within LWR plants is covered in the other. The Westinghouse forecast for plutonium usage during the period through 1990 is shown in Figure 1, and agreement within the range of AEC sensitivity studies is reasonable.

Some significant points in this prediction are the slow initial growth in plutonium usage, the relatively large increases after about 1985, and the changeover in application from recycle in LWR plants to use by the breeder industry. The slow start provides another decade for full development of solutions to safeguards and waste disposal situations currently under continuing evaluations. During the period of fast growth in plutonium supply through the 1990's, a commercial breeder industry is also expected to expand rapidly. At some point around year 2000, plutonium recycle will no longer be able to compete economically, and the breeder industry should utilize essentially all plutonium supplies. Pinpointing that date is relatively unimportant in respect to environmental factors, since adequate safeguards and safety measures will be provided to protect both the public and the environment regardless of the specific application. Westinghouse also expects to be involved in fabrication of both fuel types well in advance of that date.

In respect to the inquiry concerning possible releases to the environment, Westinghouse has accumulated release data from five years of operation of the Plutonium Fuels Development Laboratory (PFDL) at Cheswick, Pennsylvania, and this information is detailed in the site environmental report Docket Number 70-1142. Based on this operational experience of PFDL and in compliance with criteria set forth in 10CFR20, 70, 73 and other federal, state and local requirements, the Westinghouse Recycle Fuels Plant (RFP) is being designed for operation in about 1979. An environmental report for this site and facility is detailed in Docket Number 70-1432.

Although the recycle of plutonium as a fuel in nuclear reactors increases the quantity of in-core plutonium, this material is not a significant component of the radioactivity in the waste and effluents, nor will it increase the volume of waste and effluents. Also, no significant contribution is expected from the LMFBR system where the in-core plutonium content will be higher than in LWRs.

The overall environmental effects of reactor utilization of plutonium are discussed in detail in the AEC environmental reports[1, 2]. Westinghouse concurs with the conclusions in these documents, that plutonium can be and

should be utilized for economic power generation with adequate protection to the environment. These documents stress the fact that existing environmental design requirements and features are constantly being evaluated and improved. A principal concern in the utilization of plutonium has been application of proper security and safeguards measures, and continuing efforts on the part of both the AEC and industry are improving these aspects of plutonium utilization.

Control and Cleanup Technology

Plutonium fuel fabrication operations are performed in facilities with engineered physical barriers and ventilation systems designed to confine plutonium. In general, existing facilities utilize glove boxes as physical barriers, and directional air flow to protect and isolate the workers from plutonium and also to eliminate release to the environment.

The air and gaseous effluents pass through at least two high efficiency particulate air (HEPA) filters in series. These filters are tested individually and in place using DOP (diocty phthalate) to assure a minimum efficiency of 99.97%. In addition, the exhaust is continuously monitored and shut down in the unlikely event that plutonium is detected

in the exhaust air. The air is also sampled and sensitive analysis of the samples made in order to monitor the operations at very low concentrations.

Liquid waste from operations within the confinement system is solidified or evaporated and packaged for transport to a transuranium solid waste disposal site. Liquid effluents from areas outside of the confinement systems are quarantined and analyzed to verify that the plutonium concentration is acceptable prior to release. If plutonium is found, techniques such as precipitation, filtration, evaporation and ion exchange are employed to remove the plutonium, and the effluent is again quarantined and analyzed to verify the removal prior to release.

Westinghouse is convinced that technology to control and restrict the release of plutonium to the environment from fuel fabrication operations is feasible and has been demonstrated at the Westinghouse PFDL and further extended into the design for the RFP.

Another inquiry was made concerning availability of technology to restore fuel fabrication facilities which become obsolete or are shutdown for other reasons to general use. With the exception of the

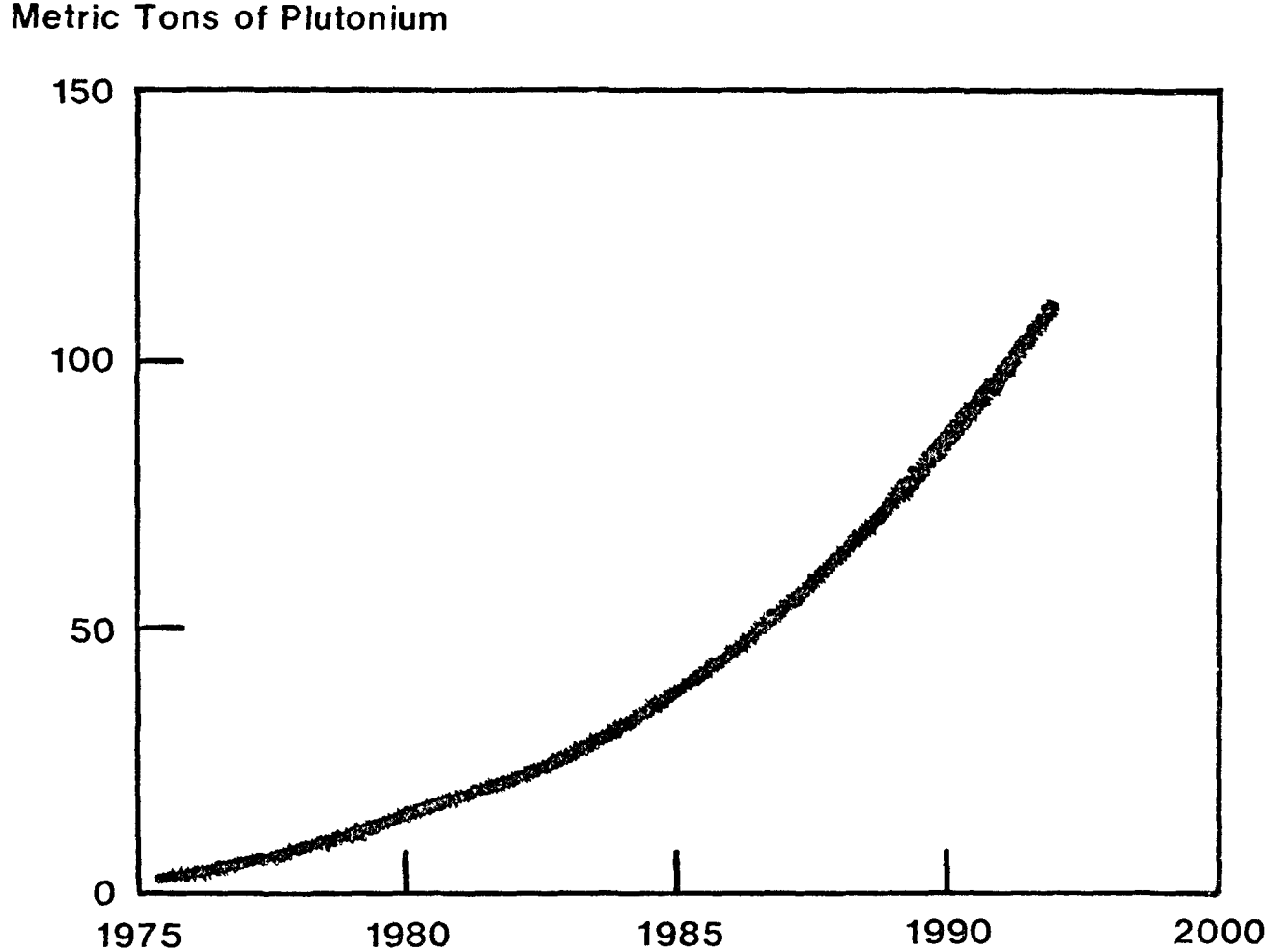
confinement system, these facilities will be maintained free of plutonium contamination during the operational period. These confinement systems must then be decontaminated to levels required for disposal and the remaining contamination must be fixed in place to aid in contamination control during removal and transportation. These systems or barriers can then be removed and packaged for disposal at a designated transuranium waste disposal facility. Final cleanup of the basic structures can then be completed. Features to facilitate decontamination and decommissioning will be included in the facility design. Thus, current cleanup and control technologies are adequate for fuel fabrication facility decommissioning. The plutonium fabrication facility owned by Gulf-United Nuclear and located in Pawling, New York, is illustrative of a plant being returned to general use. According to a former Gulf-United Nuclear official, the facility has been decontaminated and a request is being made to the AEC to release the facility. The decommissioning of the Elk River Reactor Plant is another example that available technology is suitable. This decontamination program is reported in a series identified as Docket Number 70-1151.

A document entitled "Program Plan for Decontamination and Decommissioning the EBR-1 Complex at NRTS" (CONF-740406-21, 1974) has also been

submitted to the AEC by Aerojet Nuclear Company. This program provides for the removal and processing of the EBR alkali metal coolant (the eutectic alloy of sodium and potassium), the decontamination of all radioactive contaminated portions of the complex, the demolition and removal of those portions which could not be made safe and/or detract from general appearance of the area, and rendering of EBR-1 safe for the public use and enjoyment as a registered national historic monument.

These examples cited demonstrate that the necessary technology and expertise is available to restore nuclear facilities to conditions acceptable for general use by the public.

ESTIMATED PLUTONIUM IN INVENTORY
(ASSUMING PU RECYCLE IN LWR'S)



PLUTONIUM AND THE TRANSURANIUM ELEMENTS

Testimony of

Dr. James H. Wright, Director

Westinghouse Environmental Systems Department

Before the

Hearing Panel of the Office of Radiation Programs

Environmental Protection Agency

December 11, 1974

Washington, D.C.

I am James H. Wright. I reside at 1195 Colgate Drive, Monroeville, Pennsylvania. I am director of the Westinghouse Environmental Systems Department. My educational background, including a Ph.D. in Chemical Engineering, and 30 years of professional experience in the field of energy systems and related environmental effects are detailed in the attached biographical information.

The following comments relate to your questions on environmental effects and on environmental levels and pathways.

It seems to me that any discussion regarding these factors as related to plutonium and transuranic elements must be continuously reviewed in the light of general ambient environmental levels of plutonium from bomb fallout.

In the time period 1951 to 1962 approximately 300,000 Curies of plutonium were dispersed in the world atmosphere with approximately 10 to 25,000 Curies over the United States. It would seem clear that a study of the dispersion and ultimate distribution of this high quantity of plutonium would provide profoundly significant results regarding overall plutonium migration and pathways to man. We have made only a cursory appraisal of this situation, using data reported in the literature, and are convinced that much important information bearing on your deliberations here can be obtained.

In our simple study we attempted to develop a material balance based on reported plutonium concentrations in the environment. Starting with the atmospheric source terms just mentioned, we find that most of the plutonium is in soil and sediment and water with only a few Curies remaining in the atmosphere. From other data we have estimated that the total human population of the world has a burden of plutonium, at the present time, of probably less than 1/10 of a Curie. This point suggests that gross effects of all pathways to man from atmospheric plutonium releases has an attenuation factor through the environment of 3,000,000 to 30,000,000: for each million units of plutonium released to the atmosphere less than one unit of plutonium vectors to and is retained by the world population. (Bair, W. J., Richmond, C. R., and Wachholz, B. W., A Radiological Assessment of the Spatial Distribution of Radiation Dose from Inhaled Plutonium, U.S.A.E.C., September 1974, p. 29, WASH-1320.) (UNSCEAR, Ionizing Radiation Levels and Effects, Volume I: Levels, United Nations, 1972, p. 54.)

This preliminary study poses some interesting considerations with regard to the regulation of plutonium in the environment:

1. The world's population may have had a higher burden in the lungs in the recent past when atmospheric contamination from plutonium was much higher, and the pathway from lungs through the blood to bone,

kidneys, liver, and lymph nodes could account for most of the current body burden.

2. The soil seems to be the principal repository for environmental plutonium. This repository seemingly provides a highly limited mechanism for a pathway to man. This suggests the possible concept of "environmentally inactive" plutonium.

3. Leafy plants consumed by man may be significant pathways to man--particularly smokers.

4. The data provided by Bair, et al., also suggests that the body burdens of the non-occupationally exposed man near facilities handling plutonium do not vary greatly from the general population. This could mean that the dominant pathway is not associated with distance, but is related to some common transport system, such as smoking, that is essentially independent of distance.

5. The consideration of fallout plutonium seems to establish considerable doubt on the pathway and dose modeling used by EPA (EPA 520/4-73-002) studies on environmental dose commitment as applied to nuclear power. Specifically, we have several problems with this study:

(1) The source terms for a given plutonium handling facility were suggested to have an atmospheric release of 10^{-8} or 10^{-9} of the plutonium throughput. It is also suggested in this report that future operations may even be lower than this. Our experience verifies the latter statement. But, the report then proceeds to integrate over several facilities and erroneously concludes that the summation or fraction released for the total industry is 100 times greater than the fraction released from a single operation. This is patently absurd. The fraction is, after all, a fraction of the total throughput or inventory. This EPA estimate of source term is high by a factor of at least 100.

(2) The pathway model to man contains an apparent gross error (overestimate) in that the plutonium concentration was obtained from a χ/Q dispersion of atmospheric releases at 3 km from the plant and, then, this concentration was uniformly applied to 1,500,000 to 15,000,000 people assumed to be living within 80 km of the plant. At the Recycle Fuels Plant and the Clinch River Breeder Reactor Plant, a population density of less than 10,000 people within 3 km is a more typical population density. For fifty such facilities sometime in the next century, the population dose actually expected would be 100 to 1000 times less than the exposure model apparently incorporated in this EPA report.

(3) The effective pathway beyond the 3 km dispersion zone would be best approximated using the dispersal, pathway and uptake information which can be inferred and derived from plutonium fallout. These data infer that only one part per 30,000,000 of the plutonium released found its way to man. The EPA vectors more than 1000 times as much to man. The concept of resuspension of plutonium from the soil was incorporated by EPA but is clearly not demonstrated in the behavior of the fallout plutonium.

(4) We certainly agree that standards for protecting the public health of our citizens should be established from a reasonable consideration of probable source terms, pathways through the environment and reconcentration in the ecosystem, and dose effects. We take no issue with the increased dose conversion factor which EPA incorporated but we feel that a study containing accumulative errors (overestimates) of more than 10,000,000 from source to man in predicting health effects serves no useful value whatsoever but it does alarm, unnecessarily, government regulators, industry and the general public.

We would strongly urge EPA to intensively investigate the environmental fate of prior weapons plutonium fallout in hope of developing and testing pathway models in the total environment and, hence, provide much better interpretation of the significance of general ambient environmental plutonium.

Residual plutonium from bomb fallout also has a significant effect on the relative impact of plutonium released from the fuel cycle operation and on our ability to discriminate plutonium from fuel cycle operations in the environment.

We are conducting environmental studies of the Westinghouse Plutonium Fuel Development Laboratory (PFDL) located at Cheswick, Pennsylvania. Liquid and gaseous effluents have been measured during the five years of operation of this plant in order to determine compliance with 10 CFR 20. The effluent releases of plutonium and transuranic elements from this facility have been held to a very low level -- within a small fraction of 10 CFR 20. From our experience it would appear that plutonium fabrication plants will not be a significant source of environmental plutonium.

Environmental monitoring has been conducted at this plant over the past year and many samples reflect less than detectable concentrations of plutonium. At these very low environmental levels resulting from plant operations, the problem of discriminating background plutonium from

plant released plutonium is a most difficult problem. Furthermore, the plutonium background fluctuates widely (a factor of 8 or 10 in air, for example) further compounding the problem of discrimination. These data are contained in our environmental report on that facility recently submitted to the AEC. (Note: environmental reports in four large volumes were submitted for the record. They are available for review in the Office of Radiation Programs, EPA, Washington, D.C.)

Additional studies have been conducted by WESD at proposed sites for new plutonium handling facilities -- the Recycle Fuels Plant -- a facility for the fabrication of plutonium recycle fuel to light water reactors, and the Clinch River Breeder Demonstration Plant. In these cases we felt that is was particularly important to make an accurate determination of plutonium background long before any plutonium was brought on the site. We have encountered continued difficulties in satisfactorily determining background levels to the precision required to allow us to discriminate the small additional plutonium burden anticipated from the operation of these facilities. Particular difficulty has been encountered in obtaining reliable sampling and analysis of the biota.

In all of these cases, we have attempted to determine, by calculation, the dose through pathways to man (See Figure 1) as well as the resulting effects on the general ambient environment including biota. We have encountered particular difficulty with regard to monitoring animals -- fish and mice. Using duplicate samples and, eventually, spiked samples, we found that the problems involved in sampling and analyzing low level plutonium gave a wide variation in results. Retrospectively, it would appear that the

costs of these low level determinations are not justified by the benefits of the results to ourselves, our clients or to our society.

We believe that low level releases (one hundredth or less of MPC) can be monitored at the plant with reasonable accuracy but that the probable error in environmental sampling and analysis at or below general background in an environment having wide fluctuations in that background can be expected to be very large. In the case of animal sampling, the error, generally an overestimate, can be as high as a factor of 10 or even 100.

Our conclusions are that calculated concentrations and doses through the various pathways are more meaningful than environmental sampling at the low concentrations found in the operation of PFDL.

The dispersion of plutonium releases to water have been both calculated and measured at PFDL. The results indicate that the calculated dispersion pathway was in reasonable agreement with the environmental monitoring. At PFDL, the principal pathway of plutonium to man was calculated to be through fish feeding in the creek receiving the storm sewer outfall from the plant. A human's diet of 50 grams per day of fish from that creek could produce a plutonium bone dose of less than 1 mrem/yr. In the fish survey conducted, no edible fish were found in that creek. A few hundred feet downstream from the plant, the creek flows into the

Allegheny River. The dilution occurring here greatly reduces the plutonium content in the water and in biota growing there.

Air dispersion of plutonium from the plant stacks to the ambient air have been both calculated and measured. Calculated dispersion concentrations yield results that are less than 1% of background plutonium at our on-site monitors and, hence, have not provided a quantitative basis for comparison of calculated and measured dispersed concentrations.

During the five years of PFDL operations, gross α has been monitored in the stack effluent. For conservatism, the gross α has been assumed to be due to plutonium 238, 239 and 240. During the past year, isotopic analysis measurements of α emitters in the stack effluent have indicated that the plutonium represents less than 10% of the gross α activity. Subsequent analysis has identified that most of the remaining α activity is from uranium. In the identification of the plutonium isotopes, we have used the α energy to discriminate between Pu 238 and Pu 239. Americium 241 is included with the Pu 238 because the energies are so similiar we have not been able to discriminate at this time. The dose calculations have been based on the assumption that all of the α activity including uranium and americium is soluble plutonium.

In the present fuel used at the PFDL the specific activity of plutonium 241 is 34 times greater than the specific activity of all the α emitting plutonium isotopes. Therefore, in dose calculations,

we assume that there is 34 times as much Pu 241 beta activity as measured or calculated α activity. Attempts to check this assumption suggest that a β to α specific activity ratio of 20 to 1 is indicated. Because of higher volatility americium should conform to our estimated atmospheric dispersion models as well as or better than Pu.

Recommendations

From our experience in environmental studies of transuranic elements it would most certainly appear that the general ambient environment has a (variable) plutonium content generally much higher than the increment of plutonium from fuel fabrication. I recommend these actions for EPA with regard to this problem:

1. EPA should establish standard sampling and analytical procedures for environmental plutonium.

2. EPA should consider qualifying vendors for plutonium analysis.

3. EPA should prepare environmental monitoring guidelines for plutonium and transuranics with specific considerations for tracing low level plutonium; e.g. when environmental concentration of plant plutonium is calculated to be a small fraction of ambient plutonium background, infrequent environmental monitoring is required just to verify the general low level. With regard to other transuranic elements I recommend that EPA suggest guidelines for routine industrial isotopic analysis in order to be certain emission monitoring is conducted and reported on a consistent basis.

I recommend that EPA conduct such research on the chemical fate of plutonium and other transuranics such that dispersion in air and water can be treated on a more realistic basis (particularly resolving the solubility question).

I strongly urge that EPA conduct extensive analyses of the fate of bomb fallout plutonium in the environment with the specific objective of determining demonstrated paths to man and, then, to use these results in future pathway and dose models used evaluating or setting future standards.

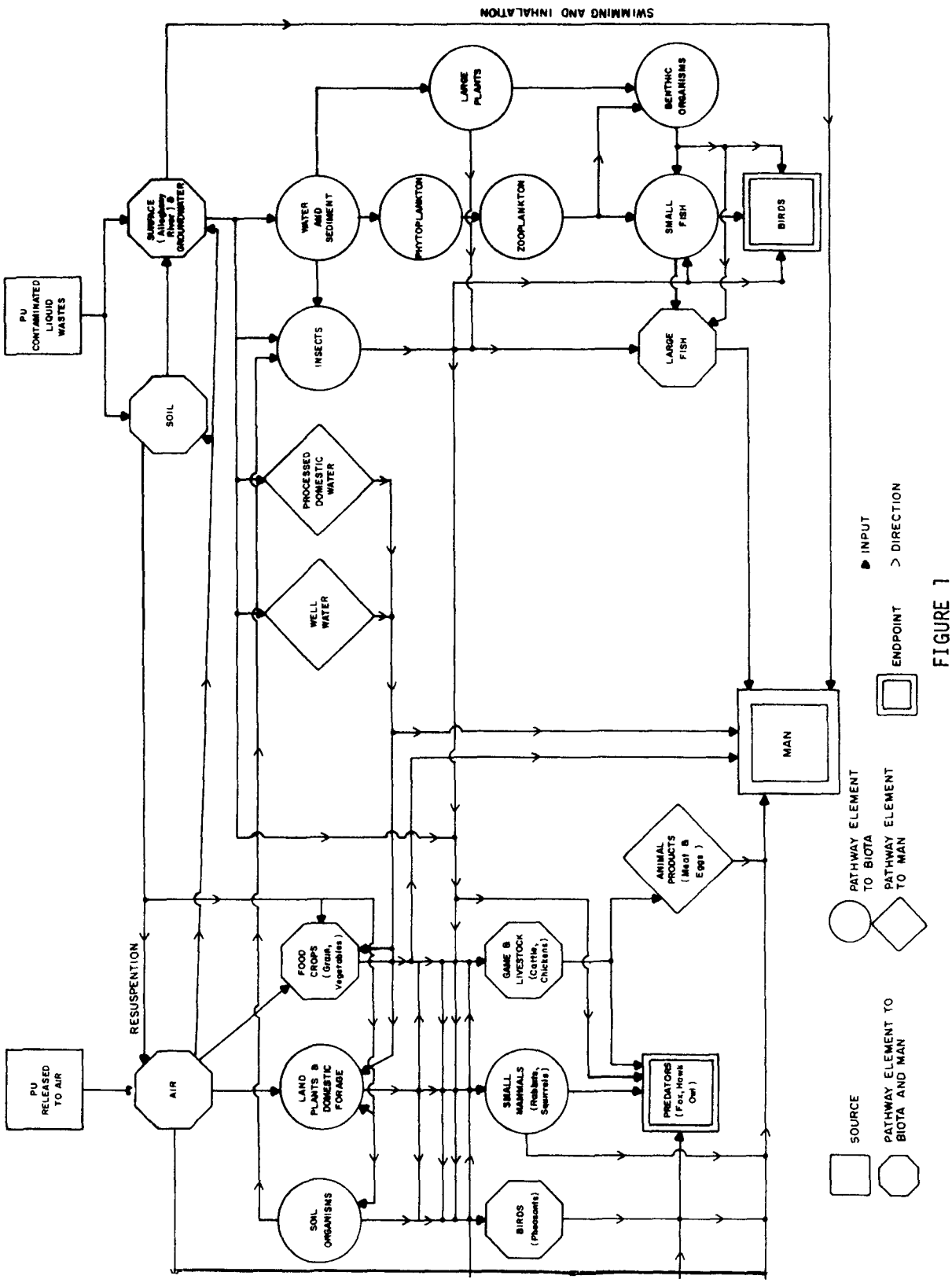


FIGURE 1

Principal Plutonium Pathways to Man and Other Biota

ATTACHMENT

BIOGRAPHY

OF

DR. JAMES H. WRIGHT

Dr. James H. Wright is Director of the Environmental Systems Department of the Westinghouse Electric Corporation. In this position he is responsible for organizing and managing a unique team of environmental experts involved in analyzing and interpreting environmental problems associated with electric power production and transmission and in assisting utilities and government regulatory agencies in solving these problems. His Department has conducted environmental studies for industry or governmental agencies in over half of the fifty states in the United States, the Commonwealth of Puerto Rico, Italy, France, Romania and Japan, and many of its members are internationally recognized experts in the environmental impact of power systems operations. His Department also conducts the Westinghouse International School for Environmental Management.

Dr. Wright holds a bachelor's degree in Chemical Engineering from Texas Tech University and a master's and Ph.D. degree in chemical engineering from the University of Pittsburgh. His professional career began in the oil fields of Texas developing and operating the first

industrial desulfurization plant for natural gas and he continued his research in desulfurization of petroleum and ionizing radiation in later work at Mellon Institute of Industrial Research.

Dr. Wright joined the Westinghouse nuclear program in 1956 as a reactor physicist and has since held key positions (Manager, Advanced Reactor Systems and Technical Director, Advanced Reactors Divisions) of responsibility in designing, development and planning nuclear tehcnology and projects. Before his present assignment, he was Senior Consultant to the Executive Vice President for Westinghouse Nuclear Energy Systems.

Dr. Wright has been working the fields of energy systems and pollution abatement in areas of design, research and development, construction, operation of energy use processes and environmental effects for more than 20 years and has published more than ninety papers in the technical literature, holding numerous patents for pollution abatement processes.

Dr. Wright is a member of several professional societies including the American Institute of Chemical Engineers, the American Chemical Society, the American Society of Engineering Education and the American Nuclear Society and is a registered professional engineer in the State of Pennsylvania. He is also a consultant to various government agencies, including the President's National Water Commission, and serves on the Committee on Power Plant Siting for the National Academy of Engineers.

Dr. Wright is a dedicated conservationist, an ardent fisherman, an amateur mountaineer and maintains an active membership in the Sierra Club, Trout Unlimited and other responsible environmental organizations.

Dr. Mills: Thank you, Dr. Wright.

I notice in your recommendation you do not recommend that EPA set standards for plutonium.

Dr. Wright: No, I did not.

Dr. Mills: I have an initial question for Mr. Kramer. Could you give me a comment, please?

In one case we are talking about planned releases of plutonium in fuel fabrication plants and so forth; in another case, we are talking about those I would classify as activities in which our concern is with standards that are to keep the plutonium out of the environment. Is it the decommission aspect we are talking about, or restorative kind, to put the environment back? Would you care to comment on how you see the differences in these two types of standards?

Mr. Kramer: I think the first commitment we have is to be certain in the design of the plant that any possible releases and exposures, not only to the public at large, but to the people working in the plant, are kept to an absolute minimum.

I think in a sense by doing that you already have come part of the way in achieving the second part of the goal, the ultimate restoration of the environment.

I cannot really speak in great detail to that latter aspect. I did note in reading this article which I referred to, they have pretty high levels of activities. I guess it was at the Savannah River Plant where this dismantling took place.

By going through a very carefully planned program, I believe they were able to package up the material and equipment and actually dispose of it.

Our particular design in our recycled fuels plant is going to be devoted more towards internal, inside the plant decontamination of equipment in a special facility, away from the basic process which will allow us to reuse or repair equipment and keep it on plant site rather than ship things offsite unnecessarily.

Dr. Mills: What I had in mind, let us take the current standards. The current federal radiation guides that were incorporated under the AEC regulations, that is, recognizing that you are not planning to release in any kind of fashion -- What I am trying to get to is, is it reasonable to assume that we may, in fact, have to establish one type of standard to restore the environment as opposed to a different kind of standard when you are talking of preventive modes?

In this reasonable? I could discuss, Dr. Wright, to some length the EPA environmental dose commitment paper; however, I do not think we have the time. But I will write to you and respond.

One point having to do with the resuspension or the loss in inventory; you made the comment that the number had been taken from one single operation to the end. I think the careful reading of that would probably indicate the extension to the industry as a whole was the loss in the whole inventory, not what each plant was supposed to do from a single operation.

That is the fuel fabrication plant. It addressed the question of the loss of plutonium across the board in the matter of transportation or what have you.

Dr. Wright: I recognize that I could not tell where a major change or effect occurred. I had assumed it had something to do with transportation, but I would like to discuss it with you at another time.

Dr. Mills: Dr. First?

Dr. First: First, on your discussion of the experience with the PFDL and then the extrapolation of this information to the plant that you are currently putting together, what are the relative sizes?

And will the emissions be in proportion to the scale up factor?

Mr. Kramer: The PFDL at this time has a capacity of approximately five to ten metric tons of fabricated mixed oxide fuel per year. The initial design level for the recycle fuels plant is 175 tons, but I believe our environmental report and license application was based on a 350 ton size.

So it is an extrapolation factor of 35 to 70.

I will let Jim answer the second part of the question.

Dr. Wright: In looking at the plutonium releases, we assume many relationships between tons and releases. We used the performance numbers of the little plant and said, that is what the big plant would be.

Dr. First: Presumably, the emissions to the atmosphere, at least, would land at about the same places in the environment. We would then

have an increase of 35 to 70 times on the concentrations at maximum ground level.

Is that correct?

Dr. Wright: No, because there is an entirely different air flow, air mixing and dispersion scheme. There is an entirely different basis of site parameters there.

So the calculated concentrations, while the quantity is up by a factor of 35 to 70, the concentrations factor because of this, varies by a factor of, I think, about three instead of 35 to 70.

Dr. First: Looking at your recommendation that we should look to the fallout information for interpretation of plant emissions, I am wondering whether the analogy is exact enough in terms of the chemical form and physical form; the fact that around an operating plant, we will have plutonium deposited in a steep gradient, I would think, rather than a very uniform deposition.

I am sure there are other differences. Would you care to comment on that?

Dr. Wright: Yes. I believe as long as it is deposited, the fact that it may be in a steep gradient or not, to my way of thinking, it becomes a far less difficult problem to deal with.

It's that which is still in the air which is a greater concern to me, because again, the resuspension is fairly low, probably.

In a country like Pennsylvania that has a fair amount of continuing rain and moisture-- I have forgotten the first part of your question.

Dr. First: It was related to whether the analogy is close enough with a good deal of certainty.

Dr. Wright: Yes. I certainly would not advise that there is a one to one relationship, but I suspect, and this point has been made twice by Dr. Radford in discussions but with others, it has been discussed extensively in the halls --

Again, I did not understand in the EPA model, I do not believe the gradient system was used. If it were, then the minimum dosage would have been far, far less. I believe they used a much broader dispersal area, because that is the only way to have gotten enough people exposed to even get some indication of this.

I was more or less going along with the EPA idea saying, this would be over a wide dispersion.

Point three, the comparison of the fallout with the plutonium from fuel fabrication plants may be very close indeed. I am not beginning to suggest that it is as similarly close for the processing plants, but from the fuel fabrication plants, we have a typical mass median diameter that would be 0.3 of a micron for plutonium oxide material.

Thermodynamically, one certainly would predict the bomb test fallout is in the form of plutonium oxide. One finds also from other evidence that they are using .4 particles in the air aerosols as a sink for the plutonium that went into the atmosphere from the bomb.

So I think there is far more similarity there. I think this hearing has done a great deal towards developing considerably more similarity.

Dr. First: Most of the material from the bomb, for example, was under very high heat conditions; at least the few particles that I have observed under the microscope has been sterile and quite distinct in their shape and appearance.

I wonder whether this might have some influence in its redispersal in the environment, for example. I am not saying this is true. I am just bringing up the general question of the relationship.

Dr. Wright: Certainly I am not claiming one for one, but I think the fact that these particles are said to go on to .4 micron aerosols suggests that as far as pathways to man, there is a great deal of similarity.

Dr. Mills: Dr. Radford?

Dr. Radford: I would like to ask Mr. Kramer first, at the end of his presentation, he implied a change in the current standards for plutonium could be modified at a subsequent time.

Based on experience and need, I think, is the wording here. Now, we have heard from various people, including Dr. Parker and Dr. Morgan, I believe also, and others, that maybe there should be some predominant revision of the plutonium standard at this time, somewhere between a factor of ten and 100, depending on the number of factors.

I get the impression from Jim Wright's presentation that this would cause no difficulty whatever to Westinghouse in operating its fuel fabrication facility. Is that correct?

Mr. Kramer: Based on the experience we have had today, I would

have to say that we would be able to meet such new regulations.

Dr. Radford: All right. Now, you state that the environmental safety requirements for such a facility, this is a commercial facility handling plutonium, are already rigorous and demanding.

Does that mean that all plutonium handling facilities might have difficulty in meeting more stringent standards?

Mr. Kramer: I am afraid that is a question which I have not got the experience or information to be able to talk about. I can discuss our facility, but I am really not aware of detailed experience from others, whether that would be a true statement or not.

Dr. Radford: Well, I asked the representative from another company which will remain nameless, whether he thought that the handling of plutonium at other facilities had been appropriate, proper, et cetera, other than his own, so I am asking you the same question.

Do you think that meeting these rigorous and demanding standards has been achieved at other commercial facilities?

Dr. Wright: You threw me with that clause, you put "other commercial facilities" right at the end.

Dr. Radford: OK. I am making it commercial facilities.

Dr. Wright: The reprocessing plants certainly constitute a problem to everyone; whether or not they constitute a problem at this moment, as the growth of nuclear power suggests that it would be well in time to establish a total curie limit in addition to 10 CFR 20 limits, which to my mind, are probably reasonable at the present time, from

everything I have heard over these two days.

Dr. Radford: With regard to operation of new plants, how would you characterize, either of you gentlemen, the performance characteristics so far in the whole nuclear cycle, as far as meeting emission limits and things of that type? Would you say it has been good, bad, or indifferent?

Dr. Wright: I would like refer on this to our plutonium fuel fabrication here. I think, as far as I know-- I was thinking about the other, the unnamed guy. As far as they are concerned, I have no problem, but there are some other parties which suggest —

Now, what was your question?

Dr. Radford: One of the issues very central to this matter is that much of the technology that we are talking about in dealing with alpha emitters in plutonium recycling is not on line.

It is projected. We do not have a body of experience. You have a pilot plant operation with five to ten tons per year. Are you going to scale it up to 350?

The point I am trying to make is, when such scale-ups have occurred throughout the nuclear industries, have in general the projections panned out?

Dr. Wright: I am sorry. I misinterpreted your question. I think generally, Dr. Radford, it certainly has projected out. What it amounted to, when we got the large plants and started measuring, in every case that I am aware of, we have found that large plants are better than

we would have extrapolated them to be from the total information on the smaller plants.

Dr. Radford: Specifically scaling up the number of fuel rods, did not Westinghouse experience some unexpected cladding problems when you went to scale up?

Dr. Wright: No. That was not a scale-up.

Mr. Kramer: This was not associated with scale-up, Dr. Radford. They were associated with specific, single, and I might say one-time occurrences, which were corrected and have not recurred.

The causes of the specific instances to which I think you are referring were not in any way associated with the size or volume effects.

Dr. Radford: But it is fair to say there was an unanticipated occurrence?

Dr. Wright: This was a design change; a new fuel element was developed, and with just a small number of modifications, it created problems.

But it really was not related to scale. I have no evidence that would suggest that our problems come on as we go up in scale. My evidence suggests the contrary.

Dr. Radford: Maybe the PWR has been lucky in this regard. What is the throughput on the current leading plant, fuel fabrication plant?

Mr. Kramer: I do not know.

Dr. Radford: Is it bigger than yours or smaller than yours, the one in Oklahoma?

Mr. Kramer: Bigger than PFDL? I have no idea what the size of that plant is.

Dr. Radford: Does it even make oxide fuel commercially?

Mr. Kramer: I do not know.

Dr. Wright: That is why I stopped.

Dr. Radford: I have, I think, just one more question here.

I have no disagreement with several of your recommendations which obviously are aimed at fuel fabrication facilities.

Would you just make some record statement as to how much more difficult you think the problem may be in the fuel reprocessing facilities than you believe they may be for fuel fabrication facilities in containing the transuranics?

Dr. Wright: Certainly they have a much more difficult problem to begin with. They have all the radioactive isotopes from the fuel to deal with. They, fortunately, take out most of the curium, or we never see any.

They definitely have a much larger problem than we do from the feedstock that they have to deal with. I am persuaded that a good processing of fuel, considerable recycling of liquids, can do a good job; but it is a much more difficult job than what we are involved in.

I think I would better leave by just saying that it is a much more difficult job.

Dr. Mills: Dr. Garner?

Dr. Garner: I would like to make just one comment rather than put in a question.

Several people during the course of these hearings have suggested that we have plenty of time to conduct research programs. You mentioned there is going to be a slow building up that would give us plenty of time to monitor such programs.

I would like to point out many of the research programs we need to resolve the problems we are faced with take considerably longer than ten years to accomplish, and we would be in a very much worse position than we are.

I would like to say this. It has taken much foresight. We are to start the second set of experiments.

Dr. Wright: My recommendations dealt specifically with your comment. Let us get on with research now.

Dr. Mills: Dr. Morgan?

Dr. Morgan: Dr. Kramer, you indicated that Westinghouse engaged in detailed evaluations of the impact of plutonium, perhaps mostly from the LMFBR operations and associated operations.

Have you carried out detailed studies, also, in reference to the fact breeder LMFBR and the light-water reactors?

Mr. Kramer: Most of the evaluations to which I referred and those which I am personally familiar with are in regard to recycle fuel in light-water reactors.

I do not know, Jim, whether you can address the LMFBR question?

Dr. Wright: Yes. I think the question was answered by Dr. Rogers just a few moments ago. We can certainly respect the performance of the breeder in fabricated fuel as well as the operation of its reactor.

We would expect the operation of the reactor would be comparable in terms of transuranic elements, in this light-water reactor to be comparable to what we are predicting for the mixed oxide fuels for the light-water reactors. We can see no reason to predict otherwise.

Mr. Kramer: I might add that, to the extent that the breeder uses a mixed oxide fuel, we do not see any differences in the basic technology of fuel production between the light-water recycle or breeder type fuel.

Dr. Morgan: One reason I asked is, I am a bit apprehensive in studying over the draft reports of the analyzed fuel recycling, in that they seem to assume that there be no additional problems, even in the plant.

For example, working with gloveboxes when you have a fairly consistent and effective neutron source and high gammas around from some of the other actinide elements.

I hope these same inconsistencies are unreasonable assumptions, that goes into the environment and estimates the risks.

I have another question. I suppose this refers more to some of the discussions I unfortunately missed yesterday; but in your text and discussion, you mentioned it.

Namely, it is assumed, certainly in the draft report of the MOX fuels that it is economically essential or very desirable to use this plutonium mixed oxide in light-water reactors, but there are some nuclear engineers that do not agree with this.

They feel that if the LMFBRs are willing to make their imprint in time and to supply their own sources, that there will be a scarcity of plutonium and there will have to be some way of supplementing it.

Perhaps you have some comment on this?

Dr. Wright: Yes. I think that both points are right. If we had the breeders and light-water reactors on an optimum schedule, we would never perform any plutonium recycle. The plutonium would be, from the first, fed into the breeder reactor.

The breeder reactor, in order for this to have happened, would have to be entering into the commercial stage.

In 1980, where we would be building much or our breeders from 1980 on, use of the plutonium from light-water reactors in breeders makes more sense, quite frankly; but our schedules are not coordinated.

The breeder is on a much more delayed schedule than the light-water reactors. Instead of having a commercial industry starting up its first breeders in 1980, there is some question whether or not we will have a first prototype operating in 1980.

So the time scales on the breeder are such that it opens quite a window for plutonium recycling.

Dr. Morgan: I gather, then, paraphrasing what you are saying, is that this money that we have, it is better to invest it now at three percent than wait later and invest it at ten percent?

Dr. Wright: Well stated, sir.

Dr. Morgan: Dr. Wright, I believe it was indicated that one over

30 billion of the plutonium fallout found its way to man. Presumably, this is the fallout that occurred, that which is accrued in man over the relatively short period since atmospheric testing occurred.

But since even plutonium 239 has a long half-life, if we estimate the infinity of these effects and assume continuous availability of certain -- this still may not be as good as we would like to have it. Is that right?

Dr. Wright: I would view it somewhat differently, Dr. Morgan. I would suggest if we integrated to infinity, we would get a diminishing annual dose and therefore, any projections made on total dose today would be because data shows that the atmospheric level where most of our dose term has come from, up to the present time, is through the atmosphere. It is diminishing quite rapidly, having reached a peak in 1963, and then falling.

Dr. Morgan: So this one part of 30 million was an annual basis?

Dr. Wright: That was a gross basis, total curies. It is integrating over the 1950 to 1972 period. I think that is when the data was actually produced, so it is an integral over a 20 year period, but going down rather strongly since 1963 in man.

Dr. Morgan: I believe you have a greater confidence in monitoring the plants than I would have from my limited experience. I gather that if the levels were, I think you said, 100 or less of the MPC, that monitoring the plant at least implied it can be relied upon.

Certainly, one would not neglect certain essential verification of the released data because with some reactors the inputs released were

not recognized, assumptions in meteorology that were not correct -- So I would think it would behoove us to store quite a bit of good data, autopsy data, for example, from people living in the environment and other information to verify this data we have, regardless of how low the estimated releases are.

Dr. Wright: I certainly agree, and my conclusions recommend that a frequent environmental monitoring certainly should be done to justify the calculated low levels, that we must try to keep both ends of the puzzle placed together.

I quite agree.

Dr. Mills: Thank you very much, gentlemen.

Dr. Rowe has indicated he would like to make an announcement.

Dr. Rowe: I just wanted to announce that we have scheduled extensions of this hearing for January 10th at 9 o'clock in Denver, at the Post Office Building.

It will be an extension of this record. It will not be a duplication of what has gone on. However, there will be new testimony inserted.

We have five people who have requested us to have that hearing in Denver, and the record will still be open for further entries at that time.

Thank you.

Dr. Mills: Let us take a break and reconvene in ten minutes.

(Brief recess)

The concluding participant on our agenda is Ms. Judith Johnsrud, from the Environmental Coalition on Nuclear Power.

Ms. Johnsrud: Gentlemen, it is very late and you have questions for the AEC panel.

My name is Judith Johnsrud from the state of Pennsylvania. I am a geographer by profession.

As a geographer, and as a member of the Environmental Coalition on Nuclear Power, which is one of the Middle Atlantic States organizations, I looked rather carefully over the last few years at the Atomic Energy Commission's documents and at industry publications.

I find a great deal to criticize, of course. I am distressed today to hear the comment that we need not worry about plutonium that is essentially grounded in the soil.

I wonder if perhaps the Westinghouse person who made this statement has failed to consider deflations in periods of cyclical drought, for example, which could very much change the locale. This is one example of the kind of thing we find.

I am very much disturbed as this hearing has progressed at what I, as a member of the public listening to the technical people speak, feel is perhaps a diversion from the fundamental charge to this organization, to EPA, and to this hearing board.

You are much wrapped up in the details of how much plutonium we are to receive. This is how it appears to a member of the public. I wonder, perhaps, if there is not a tendency in a standard setting body

of this nature to consider the production, and therefore the need for the standard to be a given of our society.

That is to say, in view of the manner in which the nuclear industry has grown and the weapons industry as well, to say, well, yes, we must have plutonium. Now our decision is to say how much plutonium.

Let me ask you, please, as you conclude this phase of the hearings, to keep very carefully in mind the real nature of the decision that you will be making, which is a decision for society; not for our society, really, so much as for future societies.

Your decision on a standard allowable, which will in turn determine the economic factors of a growing nuclear industry and perhaps weapons industry continuing to grow, will affect far beyond all of us.

I do not say this with disrespect to you, but I do have the feeling that the details of standard setting, perhaps, have overwhelmed your remembrance of this, as charged.

Now, I hope not to have offended you. May I give my very brief prepared statement, which will be much more general than what you have been hearing; but I hope you will find it pertinent.

This statement on the environmental impact of plutonium and the transuranium elements is provided for inclusion in the record of the Environmental Protection Agency hearings on that subject pursuant to the September 23, 1974, Federal Register notice 38FR24098, by the Environmental Coalition on Nuclear Power, representing some thirty non-profit public-interest citizens' organizations (approximately 10,000 members)

in Pennsylvania, New Jersey, Delaware, and Virginia. Our organization's member groups have participated in numerous reactor licensing proceedings (1), in state and federal agency hearings on nuclear reactor safety, siting, licensing and insurance issues (2), in varied public education programs, and in successful opposition to the sitings of both a Plowshare underground gas storage project and a Liquid Metal Fast Breeder Reactor demonstration plant in Pennsylvania (3).

The Environmental Coalition recommends, at least for the near term future, that a zero release standard be imposed on plutonium until the obviously fragmentary research on its impact upon ecosystems and upon man as well as the procedures for containment and control of plutonium is much greater advanced than it appears to be now. Plutonium is a man-made element; its extraordinary toxicity is attested to by others more expert than we elsewhere in these hearings; the length of its half-life makes of it in a human time scale an essentially permanent biological hazard when any amount is released to the environment.

That perfect containment of plutonium by the Atomic Energy Commission and U.S. military forces, much less by commercial users, can be achieved is not borne out by the record to date. Atmospheric testing during the 1950's; the loss of a nuclear power generator SNAP-9A in 1964 (4); the loss of the plutonium power source in the lunar module during the re-entry of the ill-fated Apollo 13 in 1970 (5); the Dow Chemical Company's Rocky Flats plutonium plant fire in 1969, as well as numerous earlier fires; the Hanford works Z-9 trench plutonium storage

problem; and the Mound Laboratory loss of plutonium to the Old Erie Canal, discovered in 1974 (7) are among instances of unplanned releases of plutonium to the environment. The Washington Post has recently carried a brief account of the EPA report of plutonium contamination of the lungs of cattle downwind from the Rocky Flats plant near Denver, Colorado (8). We would, in fact, amend our recommendation for a zero release standard to a negative release standard, and call for concerted effort by AEC's successor agencies and the military to recover and permanently store the plutonium already released to the environment.

The information which we submit to this hearing board relates to a particular aspect of control of special nuclear materials -- namely, blackmarket sales of plutonium. I include it to bring us back from the theoretical calculations that the industry has given you, its intention for perfect containment, to the way the world really works. In November 1973, individuals in our member groups were offered, through a reputable and reliable acquaintance, an opportunity to purchase alleged stolen plutonium. The particulars, as I received them, were these; the person known to us, who might be termed a dedicated environmentalist himself, had encountered an unnamed man who, in the course of conversation, mentioned that he had access to very valuable material that would fetch a high blackmarket price. The figure named was $1000/gram. Our acquaintance pursued the subject, discovered the man was talking about plutonium, and suggested that he knew of persons who might be interested in proving that a stolen plutonium blackmarket is more than mere conjecture. The offer came to us shortly after conclusion of Atomic Safety and Licensing

Board hearings on an operating license for Metropolitan Edison's Three Mile Island I reactor near Harrisburg, Pennsylvania, at which then-Commissioner Herbert S. Denenberg of the Pennsylvania Insurance Department had testified as a witness for our intervenors. Apparent effort on the part of the applicant's attorneys to block Dr. Denenberg's appearance aroused a certain subsequent question in our minds about the authenticity of the plutonium offer that came to us, as I recall, within a week of termination of the hearings.

We had no way of assessing the validity of the offer. We were unfamiliar with the proper legal procedure in such a situation. As law-abiding individuals, we were reluctant to pursue the offer at all; and yet an opportunity to demonstrate the ease with which this hazardous material might be obtained was tempting. Therefore, we suggested that the acquaintance try to learn more about the man who had made the initial proposal while we tried to find out what authorities we should contact. I would emphasize that it appeared to us mainly as an opportunity to gain public notice of what seemed to be the reality of a plutonium blackmarket.

Two or three weeks later, in early December, I spoke with a well-known investigative reporter in Washington about the matter. He advised precisely what we were doing; obtain more firm information before going to the authorities. A few days later, the initial installment of John McPhee's profile of Theordore B. Taylor was published in the New York magazine. Lacking any further information about the man who had

originated the offer, I concluded that we had insufficient facts to pursue the matter further. Nuclear theft and diversion became a much publicized issue through the efforts of Dr. Taylor and Mason Willrich during 1974 (9). Our small incident seemed insignificant, compared with the scenarios of sabotage and rings of international terrorists.

The point which we believe is pertinent to these proceedings, however, is this; in trying to figure out a way to maximize the publicity (10) value to be gained by proving the availability of illicit plutonium, one person suggested the following: rent a plane, fly over the nearby reactor, scatter the small quantity of plutonium, and then contact the press and the AEC to inquire how accruately the monitoring devices had been able to measure the amount released in the reactor vicinity. Those of us who understood the toxicity of plutonium were appalled by this suggestion and promptly squelched it.

It should be noted that Willrich and Taylor in general make the assumption of malicious intent to use plutonium as an anti-personnel device. But I suggest to this hearing board that, if a person devoted to environmental protection was so ignorant of the biological hazard presented by a minute quantity of plutonium, how much more ignorant are others who would be engaged in the commerce of this toxic substance in the quantitities anticipated in a fully developed breeder reactor program?

Next, we would direct your attention to an AEC document on "Reactor Fuel Cycle Costs for Nuclear Power Evaluation," in which charts appear to indicate anticipated losses of up to 1% of material at various stages

of the fuel cycle. Whether this estimate refers only to "not economically recoverable" fissionable material that remains in contained wastes or to that lost substance category, known as MUF, or "material unaccounted for," seems unclear.

I would, parenthetically, add that in that same document, adding to our skepticism of AEC predictions, I note that there is a cost statement attached to the G. E. Midwest fuel recovery plant of 17.4 million dollars. As you may recall, when it was announced that it would not go into operation, something in excess of 60 million dollars had been spent on the plant, the anticipation being that it would cost a factor of ten higher to put it into working order. We would ask that this board investigate and make public the records of the Numec Corporation operations in Apollo, Pennsylvania, with respect to inventory losses of fissionable materials during its years of operation. It seems clear from the 20-30 year operational record of the nuclear industry that materials handling systems are insufficiently perfected to ensure that plutonium will not be diverted, intentional or otherwise, and thereby reach the environment. Subsequent human injuries could not be compensated since the chain of causality could not be proven by the damaged party (12).

Finally, we suggest that the failure of the Atomic Energy Commission in nearly 30 years of research to develop and adequately test long-term, essentially permanent, effective storage methods for long-lived radioactive wastes argues strongly for zero production of these wastes. In

view of the faulty record during this full human generation of plutonium production, we contend that only a rigidly enforced zero release standard for plutonium is appropriate to the protection of present and future public health and safety. The best way to enforce a zero release standard is to set a standard of zero production of plutonium.

We appreciate the opportunity to present this information and our recommendations to the Environmental Protection Agency.

NOTES

1. Since 1970, the Environmental Coalition on Nuclear Power, or its member groups, have intervended in construction and operating license hearings before Atomic Safety and Licensing Boards in the cases of Philadelphia Electric Company's Limerick I and II reactors, Peach-bottom I and II, and Fulton I and II; Public Service Electric and Gas Company's Newbold Island I and II (Project cancelled at that site); and Duquesne Light Company's Beaver Valley I and II.

2. See, for example, proceedings of the Pennsylvania Senate Select Committee Hearings on Nuclear Power Plant Siting, Harrisburg, Pa., 1970; Governor's Select Committee Hearings on Alleged Health Effects from the Shipping port Reactor, Aliquippa, Pa., July, 1973; Pennsylvania Insurance Department Hearings on Nuclear Safety and Insurance Risks, Philadelphia, Pa., August, 1973; U.S. Congress, Appropriations Hearings, 1972; Joint Committee on Atomic Energy, Hearings on Siting and Licensing Legislation, March, 1972; Hearings on Proposed Siting and Licensing Legislation, 1974 (in press); Hearings on Possible Modifications or Extension of the Price-Anderson Insurance and Indemnity Act: Phase I: Review, January,

March, 1974; Phase II, May, 1974 (in press).

3. See Richard S. Lewis, The Nuclear Power Rebellion: Citizens vs the Atomic Establishment, 1972

4. U.S. AEC, Major Activities in the Atomic Energy Programs, Jan-Dec., 1965

5. See New York Times, April, 17, 22:7, April 18, 13:1, 1970

6. New York Times, June 25, 3:6; June 27, 10:3, 1969; Feb. 11, 1:5, 1970; Sept. 27, 77:2, Dec. 22, 9:4, 1973

7. New York Times, May 15, 48:2, 1974

8. The Washington Post, December 6, 1974

9. See Mason Willrich and Theodore B. Taylor, Nuclear Theft, Risks and Safeguards: A Report to the Energy Policy Project of the Ford Foundation, 1974. Also see John McPhee, The Curve of Binding Energy, 1974, originally appearing in The New Yorker, issues of December, 1973.

10. See accounts of Mr. Sam Lovejoy's encounter with the meterological tower at the Montague reactor site in Massachusetts, New Times, November, 1974, also in the New York Times.

11. U.S. AEC, Reactor Fuel Cycle Costs for Nuclear Power Plant Evaluation, WASH-109 December, 1971

12. See testimony of Dr. Chauncey R. Kepford, Joint Committee on Atomic Energy, Hearings on Possible Modification and Extension of the Price-Anderson Insurance and Indemnity Act, Jan.-March, 1974, pp. 200-253.

Dr. Mills: Thank you very much.

I appreciate your patience in waiting around to be able to have the opportunity to make your statement.

Ms. Johnsrud: I have learned a great deal.

Dr. Mills: I have one comment. To perhaps clarify the function of this particular hearing, I do not believe that we would be investigating or able to investigate the Numec Corporation.

Ms. Johnsrud: I understand that, sir, certainly, although I certainly would like for someone to let us know, really.

Dr. Mills: We appreciate the fact that you have stated so.

Let me also say, from the EPA's standpoint, that the concern with the public is on our mind. We recognize the technical problem, but I think if you were here at the first part to hear Dr. Rowe's opening remarks, the concern with the public reaction is one reason we are holding this hearing.

Ms. Johnsrud: Yes. I think perhaps I might add, if I may, the Atomic Energy Commission was developed during a period of American industrial growth and development. That certainly seems to be approaching an end, at least in the manner in which it has been conducted for much of the past half century.

I think the Environmental Protection Agency represents the direction that our society wants to go in the future. Let me emphasize, again, from the public point of view: We would feel much more comfortable if Dr. Radford and Dr. Tamplin were discussing the existence or non-existence of the hot particle problem while we had the cushion of a zero release, or better, a zero production of plutonium.

Maybe 30 years from now, your offspring can sit on such a committee to decide that, yes, we know how to handle these materials and now is the time to begin to go ahead.

What I am saying is, of course, that essentially we are dealing with a highly hazardous and immature technology. Better to wait a little. I think that really represents a public point of view, when they understand what the hazard may be for them and their children.

Dr. Mills: Are there any questions?

Dr. Garner: I would like to make a comment.

It is a philosophical comment. I do appreciate what you say about what the public feels. I personally do not think that we are resorting to detail. I try very hard to put the problem of plutonium in perspective. I just wish the public would try to do the same thing.

I am not trying to downgrade plutonium. We have heard enough about it. We point out we live with a great many other risks that the public is willing to accept; for example, we push the use of natural gas and liquefied gas to the hilt because it is non-polluting source, but if we scour the newspapers of this country, we would find that almost every day, a life is lost because of an accident involving natural gas and liquefied gas.

People do not seem to realize this, or if they do, they do not seem to take account of it, that is what I want to say.

Ms. Johnsrud: If I may respond to that very briefly, I think perhaps when the public looks at the major uses of plutonium which, on the one hand, have recently been for nuclear weapons and on the other

hand, for power production and electricity production; we do have to consider also just what the nature of the cost benefit analysis that you will be engaging in, presumably, really is.

What are these costs? Who gets the benefits? I would submit to you that increasingly the American public is pretty unhappy with the notion that the major benefits of massive quantities of plutonium will accrue to the investors of utilities.

Dr. Morgan: Ms. Johnsrud, I would certainly commend you and I am proud of the position you have taken in expressing your views.

However, I feel it would be a wonderful world if we had given the same consideration to other environmental insults as we have given from the beginning to nuclear energy.

If you feel a bit disillusioned by the discussions here, I think it is because this is a rather new experience, to examine in detail what effects something like plutonium in industry would have on this and coming generations.

This has never been done with respect to some of the other pollutants that we consider.

You suggest that the best solution would be to have no plutonium released. I suspect all of us agree to that, except we are realists and we know, as you are yourself, we know that if you have nuclear industry, you will have some release. There will be some accidents.

So then, your suggestion would be or was, we would have no production of plutonium, and discontinue the industry. Maybe if we could back up 20 or 30 years, that might be done or might be considered.

But even to give it consideration today, of course, would mean tremendous sacrifices and inconveniences and poverty far greater, I believe, than the risks we even dream of in reference to plutonium, that we are talking about.

The plutonium will not be an important problem indefinitely. I do not believe many of us feel that more than a few hundred years, the use of plutonium will be an important contribution to our energy needs.

Ms. Johnsrud: Quite so. I think that our difficulty with the comment that you have just made would lie, perhaps, in the cumulative curve that was shown to us yesterday with respect to the already existing accidental releases, plus the weapons program, and tthe ever-rising nature of that curve within, again, the bounds of human time-scales.

Then, of course, when we speak of plutonium let loose in the environment, I look at it as a geographer. I know the spatial distribution, the possibility of tracing the various mechanisms that are potentially available and subsequent damage to be done by the substance that is produced now within our peculiar society, at this strange point in human history, for a very short time and highly questionable uses.

There are reams of reports now with respect to energy conservation alternatives. If we say, for example, we will pose a "no release" standard, the fast breeder obviously is in trouble. What does that do?

That gives us, perhaps, the time period in the near-term future while we do have available possible alternatives, to support adequately

the funding needed for the development of other alternatives. It solves our problem, or what it does is postpone the creation of the problem that we do not now know enough about, nor how to contain, nor how to control.

So, we would hope there would be a time in the future when all the research that AEC says will be done in the next 10 or 20 years has been accomplished. If they were right, and their research proves out correctly, fine. Then we can go ahead.

But there are so many unresolved questions now that members of the public who look to this source as essentially a prominent contaminant are very unhappy about proceeding at this stage.

I hope that comes clear.

Dr. Mills: Thank you very much.

I suppose this brings us to a conclusion of this public hearing.

Before I close, I want to express my thanks to all participants for the long time that you put into these efforts, especially to the reporter, and the people who have been kind to sit with us.

Also, I would like to thank the panel members for volunteering to be of some assistance to EPA in this effort.

Thank you very much.

(Whereupon, the hearing in the above-entitled matter was concluded at 6:25 p.m.)

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