THE UNITED STATES ENVIRONMENTAL PROTECTION AGENCY

Legal Compilation

Statutes and Legislative History
Executive Orders
Regulations
Guidelines and Reports

JANUARY 1973

WILLIAM D. RUCKELSHAUS
Administrator

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FOREWORD

It has been said that America is like a gigantic boiler in that once the fire is lighted, there are no limits to the power it can generate. Environmentally, the fire has been lit!

With a mandate from the President and an aroused public concern over the environment, we are experiencing a new American Revolution, a revolution in our way of life. The era which began with the industrial revolution is over and things will never be quite the same again. We are moving slowly, perhaps even grudgingly at times, but inexorably into an age when social, spiritual and aesthetic values will be prized more than production and consumption. We have reached a point where we must balance civilization and nature through our technology.

The U.S. Environmental Protection Agency, formed by Reorganization Plan No. 3 of 1970, was a major commitment to this new ethic. It exists and acts in the public's name to ensure that due regard is given to the environmental consequences of actions by public and private institutions.

In a large measure, this is a regulatory role, one that encompasses basic, applied, and effects research; setting and enforcing standards; monitoring; and making delicate risk-benefit decisions aimed at creating the kind of world the public desires.

The Agency was not created to harass industry or to act as a shield behind which man could wreak havoc on nature. The greatest disservice the Environmental Protection Agency could do to American industry is to be a poor regulator. The environment would suffer, public trust would diminish, and instead of free enterprise, environmental anarchy would result.

It was once sufficient that the regulatory process produce wise and well-founded courses of action. The public, largely indifferent to regulatory activities, accepted agency actions as being for the "public convenience and necessity." Credibility gaps and cynicism make it essential not only that today's decisions be wise and well-founded but that the public know this to be true. Certitude, not faith, is de rigueur.

In order to participate intelligently in regulatory proceedings, the citizen should have access to the information available to the agency. EPA's policy is to make the fullest possible disclosure of

information, without unjustifiable expense or delay, to any interested party. With this in mind, the EPA Compilation of Legal Authority was produced not only for internal operations of EPA, but as a service to the public, as we strive together to lead the way, through the law, to preserving the earth as a place both habitable by and hospitable to man.

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PREFACE

Reorganization Plan No. 3 of 1970 transferred 15 governmental units with their functions and legal authority to create the U.S. Environmental Protection Agency. Since only the major laws were cited in the Plan, the Administrator, William D. Ruckelshaus, requested that a compilation of EPA legal authority be researched and published.

The publication has the primary function of providing a working document for the Agency itself. Secondarily, it will serve as a research tool for the public.

A permanent office in the Office of Legislation has been established to keep the publication updated by supplements.

It is the hope of EPA that this set will assist in the awesome task of developing a better environment.

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ACKNOWLEDGEMENT

The idea of producing a compilation of the legal authority of EPA was conceived and commissioned by William D. Ruckelshaus, Administrator of EPA. The production of this compilation involved the cooperation and effort of numerous sources, both within and outside the Agency. The departmental libraries at Justice and Interior were used extensively; therefore we express our appreciation to Marvin P. Hogan, Librarian, Department of Justice; Arley E. Long, Land & Natural Resources Division Librarian, Department of Justice; Frederic E. Murray, Assistant Director, Library Services, Department of the Interior.

For exceptional assistance and cooperation, my gratitude to: Gary Baise, formerly Assistant to the Administrator, currently Director, Office of Legislation, who first began with me on this project; A. James Barnes, Assistant to the Administrator; K. Kirke Harper, Jr., Special Assistant for Executive Communications; John Dezzutti, Administrative Assistant, Office of Executive Communications; Roland O. Sorensen, Chief, Printing Management Branch, and Jacqueline Gouge and Thomas Green, Printing Management Staff; Ruth Simpkins, Janis Collier, Wm. Lee Rawls, Peter J. McKenna, James G. Chandler, Jeffrey D. Light, Randy Mott, Thomas H. Rawls, John D. Whittaker, Linda L. Payne, Dana W. Smith, and John M. Himmelberg, a beautiful staff who gave unlimited effort; and to many others behind the scenes who rendered varied assistance.

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INSTRUCTIONS

The goal of this text is to create a useful compilation of the legal authority under which the U.S. Environmental Protection Agency operates. These documents are for the general use of personnel of the EPA in assisting them in attaining the purposes set out by the President in creating the Agency. This work is not intended and should not be used for legal citations or any use other than as reference of a general nature. The author disclaims all responsibility for liabilities growing out of the use of these materials contrary to their intended purpose. Moreover, it should be noted that portions of the Congressional Record from the 92nd Congress were extracted from the "unofficial" daily version and are subject to subsequent modification.

EPA Legal Compilation consists of the Statutes with their legislative history, Executive Orders, Regulations, Guidelines and Reports. To facilitate the usefulness of this composite, the Legal Compilation is divided into the eight following chapters:

A. General
B. Air
C. Water
D. Solid Waste
E. Pesticides
F. Radiation
G. Noise
H. International

RADIATION

The chapter labeled "Radiation" and color coded tan contains the legal authority of the Agency as it applies to radiation pollution abatement. It is well to note that any law which is applicable to more than one chapter of the Compilation will appear in each of the chapters; however, its legislative history will be cross referenced into the "General" chapter where it is printed in full.

SUBCHAPTERS

Statutes and Legislative History

For convenience, the Statutes are listed throughout the Compilation by a one-point system, i.e., 1.1, 1.2, 1.3, etc., and Legislative History begins wherever a letter follows the one-point system. Thusly, any 1.1a, 1.1b, 1.2a, etc., denotes the public laws comprising the 1.1, 1.2 statute. Each public law is followed by its

legislative history. The legislative history in each case consists of the House Report, Senate Report, Conference Report (where applicable), the Congressional Record beginning with the time the bill was reported from committee.

Example:

1.1 1954 Atomic Energy Act, as amended, 42 U.S.C. §§2013(d), 2021, 2051, 2073(b), (e), 2092, 2093, 2099, 2111, 2112, 2132, 2133, 2134, 2139, 2153, 2201, 2210 (1970).

1.1a Atomic Energy Act of 1946, August 1, 1946, P.L. 79–585, 60 Stat. 755.

(1) Senate Special Committee on Atomic Energy, S. REP. No. 1211, 79th Cong., 2d Sess. (1946).

(2) House Committee on Military Affairs, H.R. REP. No. 2478, 79th Cong., 2d Sess. (1946).

(3) Committee of Conference, H.R. REP. No. 2670, 79th Cong., 2d Sess. (1946).

(4) Congressional Record, Vol. 93 (1946):

(a) June 1: Passed Senate, pp. 6076–6098;

(b) July 16: House disagrees to Senate bill, pp. 9135–9144;

(c) July 17, 18, 19, 20: House debates and amends Senate bill, pp. 9249–9275, 9340–9386, 9463–9477, 9545–9563;

(d) July 22: Senate disagrees with House bill, asks for conference, pp. 9609–9611;

This example not only demonstrates the pattern followed for legislative history, but indicates the procedure where only one section of a public law appears. You will note that the Congressional Record cited pages are only those pages dealing with the discussion and/or action taken pertinent to the section of law applicable to EPA. In the event there is no discussion of the pertinent section, only action or passage, then the asterisk (*) is used to so indicate, and no text is reprinted in the Compilation. In regard to the situation where only one section of a public law is applicable, then only the parts of the report dealing with same are printed in the Compilation.

Secondary Statutes

Many statutes make reference to other laws and rather than have this manual serve only for major statutes, these secondary statutes have been included where practical. These secondary statutes are indicated in the table of contents to each chapter by a bracketed cite to the particular section of the major act which made the reference.

Citations

The United States Code, being the official citation, is used throughout the Statute section of the Compilation.

TABLE OF STATUTORY SOURCE

	Statutes	Source
1.1	1954 Atomic Energy Act, as amended, 42 U.S.C. §§2013(d), 2012, 2051, 2073(b), (e), 2092, 2093, 2099, 2111, 2112, 2131, 2133, 2134, 2139, 2153, 2201, 2210 (1970).	Direct reference in Reorg. Plan No. 3 of 1970.
1.2	Public Health Service Act, as amended, 42 U.S.C. §§203, 215, 241, 242(b), (c), (d), (f), (i), (j), 243, 244, 244a, 245, 246, 247 (1970).	Reorg. Plan No. 3 of 1970.
1.3	Public Contracts, Advertisements for Proposals for Purchases and Contracts for Supplies or Services for Government Departments; Application to Government Sales and Contracts to Sell and to Government Corporations, as amended, 41 U.S.C. §5 (1958).	Referred to in Public Health Service Act at §242c(e).
1.4	Research and Development Act, Contracts, as amended, 10 U.S.C. §§2353, 2354 (1956).	Referred to in Public Health Service Act at §241(h).
1.5	International Health Research Act, 22 U.S.C. §2101 (1960).	Referenced to in the Public Health Service Act at §242f(a).
1.6	Per Diem, Travel and Transportation Expenses; Experts and Consultants; Individuals Serving Without Pay, as amended, 5 U.S.C. §5703 (1966).	Referenced to in Public Health Service Act at §242f(b)(5), (6).
1.7	The Solid Waste Disposal Act, as amended, 42 U.S.C. §3254f (1970).	Section cited refers directly to national disposal sites for storage and disposal of hazardous waste including radioactivity.
1.8	National Environmental Policy Act, 42 U.S.C. §§4332(2)(c), 4344(5) (1970).	Reorganization Plan No. 3 of 1970.

Executive Orders

The Executive Orders are listed by a two-point system (2.1, 2.2, etc.). Executive Orders found in General are ones applying to more than one area of the pollution chapters.

Regulations

The Regulations are noted by a three-point system (3.1, 3.2, etc.). Included in the Regulations are those not only promulgated by the Environmental Protection Agency, but those under which the Agency has direct contact.

Guidelines and Reports

This subchapter is noted by a four-point system (4.1, 4.2, etc.). In this subchapter is found the statutorily required reports of EPA, published guidelines of EPA, selected reports other than EPA's and interdepartmental agreements of note.

UPDATING

Periodically, a supplement will be sent to the interagency distribution and made available through the U.S. Government Printing Office in order to provide an accurate working set of EPA Legal Compilation.

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1.4a ARMED FORCES RESEARCH AND DEVELOPMENT

July 16, 1952, P.L. 82–557, §§4, 5, 66 Stat. 725

SEC. 4. Any contract of the military departments for research or development, or both, may provide for the acquisition or construction by, or furnishing to, the contractor of such research, developmental, or test facilities and equipment as may be determined by the Secretary concerned to be necessary for the performance thereof. Such research, developmental, or test facilities and equipment, including specialized housing therefor, may be acquired or constructed at Government expense, and may be furnished to the contractor by lease, loan, or sale at fair value, and with or without reimbursement to the Government for the use thereof: *Provided,* That nothing contained in this subsection shall be deemed to authorize new construction or improvements having general utility: *Provided further,* That nothing contained herein shall be deemed to authorize the installation or construction of facilities on property not owned by the Government which would not be readily removable or separable without unreasonable expense or unreasonable loss of value, unless adequate provision is made in the contract for (1) reimbursement to the Government of the fair value of such facilities upon the completion or termination of the contract, or within a reasonable time thereafter, or (2) an

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option in the Government to acquire the underlying land, or (3) such other provisions as will in the opinion of the Secretary concerned be adequate to protect the Government's interest in such facilities: *And provided further,* That all moneys arising from sales or reimbursement under this section shall be covered into the Treasury as miscellaneous receipts, except to the extent otherwise authorized by law with respect to contractor-acquired property. The Secretary of each of the military departments shall transmit to the Congress reports covering contracts for research or development entered into during each six months following the enactment of this Act. Each such report shall contain (1) a list of each contract for research or development entered into during such period the total cost of which to the Government will exceed $50,000, and (2) specific information with respect to each such contract, except that specific information the disclosure of which he deems incompatible with the security of the United States may be excluded from such reports.

SEC. 5. With the approval of the Secretary concerned, any contract of the military departments for research or development, or

both, may provide that the Government will indemnify the contractor against either or both of the following, to the extent that they arise out of the direct performance of said contract and are not compensated by insurance or otherwise: (1) Liability on account of claims (including reasonable expenses of litigation or settlement of such claims) by third persons, including employees of the contractor, for death, bodily injury, or loss of or damage to property, arising as a result of a risk defined in the contract to be unusually hazardous: [*Provided,* That any contract so providing shall also contain appropriate provisions for notice to the Government of suits or actions filed or claims made, against the contractor, with respect to any alleged liability for such death, bodily injury, or loss of or damage to property, and for control of or assistance in the defense of any such suit, action, or claims, by the Government, at its election;] and (2) loss of or damage to property of the contractor arising as a result of a risk defined in the contract to be unusually hazardous: *And provided further,* That no payment shall be made by the Government under authority of this section unless the amount thereof shall first have been certified to be just and reasonable by the Secretary concerned or by an official of the department designated for such purpose by the Secretary. Any such payment may be made, with the approval of the Secretary concerned, out of any funds obligated for the performance of such contract or out of funds available for research and development work and not otherwise obligated; or out of any funds appropriated by the Congress for the making of such payments.

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1.4a(1) HOUSE COMMITTEE ON ARMED SERVICES

H.R. REP. No. 548, 82d Cong., 1st Sess. (1951)

FACILITATING THE PERFORMANCE OF RESEARCH AND DEVELOPMENT WORK BY AND ON BEHALF OF THE DEPARTMENTS OF THE ARMY, NAVY, AND AIR FORCE

JUNE 12, 1951.—Committed to the Committee of the Whole House on the State of the Union and ordered to be printed

---

Mr. HÉBERT, from the Committee on Armed Services, submitted the following

REPORT

[To accompany H.R. 1180]

The Committee on Armed Services, to whom was referred the bill (H.R. 1180) to facilitate the performance of research and development work by and on behalf of the Departments of the Army, the Navy, and the Air Force, and for other purposes, having considered the same, report favorably thereon without amendment and recommend that the bill do pass.

The purpose of the proposed legislation is to provide the armed services with powers which are considered to be necessary to facilitate the carrying on of their research and development programs.

* * * * * * *

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SECTIONAL ANALYSIS

Section 4 provides for the furnishing of necessary research, developmental or test facilities to contractors, subject to adequate protection of the Government's interests therein. It is the committee's understanding that, under the provisions of this section, the military departments may utilize research and development funds for the furnishing or construction of equipment or facilities for the use of contractors where appropriate. Wartime experience indicates that situations arise in which contractors require special facilities for the performance of their contracts. Since in many cases these facilities would be of no use to them apart from the performance of such contracts, they are unable to provide the fa-

cilities at their own expense. On the other hand, to permit contract prices to include sufficient amounts to cover the cost of such facilities, would obviously be unfair to the Government in that the Government would, in effect, be not only buying the facilities, but would then leave them in the possession of the contractor. The solution proposed herein is to authorize the Government to provide such facilities, at the same time protecting its interest therein.

Section 5 provides authority for the military departments to agree to indemnify contractors against liability and loss resulting from injury to persons or damage to property arising out of the direct performance of a research and development contract, to the extent that such losses are not compensated by insurance or otherwise. In many cases, contractors are reluctant to undertake a research or development contract involving extremely hazardous new developments without adequate protection in the event of liability resulting from claims made as a result of damage from those experiments. No provision can be made

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for such protection by including a reserve in the contract price, and the cost of insurance, if at all obtainable, would be prohibitive. The solution is for the Government to agree to indemnify such a contractor subject to the safeguards provided in this section.

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1.4a(2) SENATE COMMITTEE ON ARMED SERVICES

S. REP. No. 936, 82d Cong., 1st Sess. (1951)

FACILITATING THE PERFORMANCE OF RESEARCH AND DEVELOPMENT WORK BY AND ON BEHALF OF THE DEPARTMENTS OF THE ARMY, THE NAVY, AND THE AIR FORCE

OCTOBER 11 (legislative day, OCTOBER 1), 1951.—Ordered to be printed

---

Mr. STENNIS, from the Committee on Armed Services, submitted the following

REPORT

[To accompany H.R. 1180]

The Committee on Armed Services, to whom was referred the bill H.R. 1180, to facilitate the performance of research and development work by and on behalf of the Departments of the Army, the Navy, and the Air Force, and for other purposes, having considered the same, report favorably thereon, without amendments, and recommend that the bill do pass.

PURPOSE OF THE BILL

The proposed legislation would provide the three military departments with certain administrative authority required to carry out their research and development programs.

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EXPLANATION OF BILL

Major provisions of the bill

The more important administrative powers which the bill provides are listed below:

* * * * * * *

(4) The furnishing of Government facilities;

(5) The indemnification against damage loss, where the contractor is unable to procure insurance coverage;

* * * * * * *

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SECTION-BY-SECTION ANALYSIS

Section 4. Furnishing of certain essential facilities to contractors

This section provides for the furnishing of necessary research, developmental or test facilities to contractors, subject to adequate protection of the Government's interests therein. Under the provisions of this section, the military departments may utilize research and development funds for the furnishing or construction of equipment or facilities for the use of contractors where appropriate. Wartime experience indicates that situations arise in which contractors require special facilities for the performance of their contracts. Since in many cases these facilities would be of no use to them apart from the performance of such contracts, they are unable to provide the facilities at their own expense. On the other hand, to permit contract prices to include sufficient amounts to cover the cost of such facilities, would obviously be unfair to the Government in that the Government would,

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in effect, be not only buying the facilities, but would then leave them in the possession of the contractor. The solution proposed herein is to authorize the Government to provide such facilities, at the same time protecting its interest therein.

Section 5. Authority to indemnify contractors against liability and loss arising from injury or damage

This section provides authority for the military departments to agree to indemnify contractors against liability and loss resulting from injury to persons or damage to property arising out of the direct performance of a research and development contract, to the extent that such losses are not compensated by insurance or otherwise. In many cases, contractors are reluctant to undertake a research or development contract involving extremely hazardous new developments without securing adequate protection in the event of liability resulting from claims made as a result of damage from those experiments. No provision can be made for such protection by including a reserve in the contract price and the cost of insurance, if at all obtainable, would be prohibitive. The solution is for the Government to agree to indemnify such a contractor, subject to the safeguards provided in this section.

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1.4a(3) CONGRESSIONAL RECORD

1.4a(3)(a) VOL. 97 (1951), Aug. 2: Passed House, p. 9433

Mr. HÉBERT.

* * * * *

The most important feature of the bill is that section which in effect indemnifies private contractors who are contracted to the Government to conduct these experimental features. I may point out the necessity for this is pointed up perhaps in the development of the supersonic plane by the Bell Airplane Co. In that particular instance it was impossible to indemnify a civilian test pilot, and an Army lieutenant was used to fly that ship on its first flight.

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1.4a(3)(b) VOL. 98 (1952), July 3: Amended and passed Senate, pp. 9053–9054

[No Relevant Discussion on Pertinent Section]

1.4a(3)(c) VOL. 98 (1952), July 4: House concurs in Senate amendments, pp. 9374–9475

[No Relevant Discussion on Pertinent Section]

1.4b ARMED SERVICES PROCUREMENT AMENDMENTS OF 1956

August 10, 1956, P.L. 84–1028, §§2353, 2354, 70A Stat. 134

§2353. Contracts: acquisition, construction, or furnishing of test facilities and equipment

(a) A contract of a military department for research or development, or both, may provide for the acquisition or construction by, or furnishing to, the contractor, of research, developmental, or test facilities and equipment that the Secretary of the military department concerned determines to be necessary for the performance of the contract. The facilities and equipment, and specialized housing for them, may be acquired or constructed at the expense of the United States, and may be lent or leased to the contractor with or without reimbursement, or may be sold to him at fair value. This subsection does not authorize new construction or improvements having general utility.

(b) Facilities that would not be readily removable or separable without unreasonable expense or unreasonable loss of value may not be installed or constructed under this section on property not owned by the United States, unless the contract contains—

(1) a provision for reimbursing the United States for the fair value of the facilities at the completion or termination of the contract or within a reasonable time thereafter;

(2) an option in the United States to acquire the underlying land; or

(3) an alternative provision that the Secretary concerned considers to be adequate to protect the interests of the United States in the facilities.

(c) Proceeds of sales or reimbursements under this section shall be paid into the Treasury as miscellaneous receipts, except to the extent otherwise authorized by law with respect to property acquired by the contractor.

§2354. Contracts: indemnification provisions

(a) With the approval of the Secretary of the military department concerned, any contract of a military department for research or development, or both, may provide that the United States will indemnify the contractor against either or both of the following, but only to the extent that they arise out of the direct performance of the contract and to the extent not compensated by insurance or otherwise:

(1) Claims (including reasonable expenses of litigation or settlement) by third persons, including employees of the contractor, for death, bodily injury, or loss of or damage to property, from a risk that the contract defines as unusually hazardous.

(2) Loss of or damage to property of the contractor from a risk that the contract defines as unusually hazardous.

(b) A contract, made under subsection (a), that provides for indemnification must also provide for—

(1) notice to the United States of any claim or suit against the contractor for the death, bodily injury, or loss of or damage to property; and

(2) control of or assistance in the defense by the United States, at its election, of that suit or claim.

(c) No payment may be made under subsection (a) unless the Secretary of the department concerned, or an officer or official of his department designated by him, certifies that the amount is just and reasonable.

(d) Upon approval by the Secretary concerned, payments under subsection (a) may be made from—

(1) funds obligated for the performance of the contract concerned;

(2) funds available for research or development, or both, and not otherwise obligated; or

(3) funds appropriated for those payments.

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1.4b(1) HOUSE COMMITTEE ON THE JUDICIARY

H.R. REP. No. 970, 84th Cong., 1st Sess. (1955)

REVISION OF TITLE 10, U. S. CODE, ENTITLED "ARMED FORCES", AND TITLE 32, U. S. CODE, ENTITLED "NATIONAL GUARD"

JUNE 28, 1955.—Committed to the Committee of the Whole House on the State of the Union ordered to be printed

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Mr. WILLIS, from the Committee on the Judiciary, submitted the following

REPORT

[To accompany H.R. 7049]

The Committee on the Judiciary, to whom was referred the bill (H.R. 7049) to revise, codify, and enact into law title 10 of the United States Code, entitled "Armed Forces", and title 32, United States Code, entitled "National Guard", having considered the same, report favorably thereon and recommend that the bill do pass.

I. EXPLANATION OF REVISED TITLE 10, ARMED FORCES, AND TITLE 32, NATIONAL GUARD

1. PURPOSE AND HISTORY

The Constitution, in article I, section 8, lists among the powers of Congress the powers "To raise and support Armies" and "To provide and maintain a Navy". In the exercise of these powers,

Congress has enacted hundreds of laws regulating the structure of the armed forces and the functioning of its members, in some cases down to the smallest detail.

These laws have been enacted over a long period extending from 1789 to the present date. They have been drawn by many draftsmen, some good, some poor, and some indifferent. Even where laws have been excellently drawn, they often reflect inconsistent approaches and means of expression. The result has been laws full of contradictions, duplications, ambiguities, obscurities, and obsolete provisions. This problem has existed not only for the armed forces but the Government as a whole.

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SECTION 2353

Revised Section	*Source (U.S. Code)*	*Source (Statutes at Large)*
2353 (a)	5:235e (1st sentence; and 2d sentence, less 2d and last provisos) 5:475j (1st sentence; and 2d sentence, less 2d and last provisos) 5:628e (1st sentence; and 2d sentence, less 2d and last provisos)	July 16, 1952, ch. 882, §4 (less 3d and last sentences), 66 Stat. 725.
2353 (b)	5:235e (2d proviso of 2d sentence) 5:475j (2d proviso of 2d sentence) 5:628e (2d proviso of 2d sentence)	
2353 (c)	5:235e (last proviso of 2d sentence) 5:475j (last proviso of 2d sentence) 5:628e (last proviso of 2d sentence)	

In subsection (a), the words "furnished to" and "for the use thereof" are omitted as surplusage.

In subsections (a) and (b), the words "United States" are substituted for the word "Government".

In subsection (b), the introductory clause is substituted for 5:235e (words of 2d proviso before clause (1)), 475j, and 628e. The words "that . . . considers" are substituted for the words "as will in the opinion". The words "an alternative" are substituted for the words "such other".

In subsection (c), the words "Proceeds of" are substituted for the words "That all moneys arising from".

SECTION 2354

Revised Section	*Source (U.S. Code)*	*Source (Statutes at Large)*
2354 (a)	5:235f (1st sentence, less provisos) 5:475k (1st sentence, less provisos) 5:628f (1st sentence, less provisos)	July 16, 1952, ch. 882, §5, 66 Stat. 726.
2354 (b)	5:235f (1st proviso of 1st sentence) 5:475k (1st proviso of 1st sentence) 5:628f (1st proviso of 1st sentence)	
2354 (c)	5:235f (last proviso of 1st sentence) 5:475k (last proviso of 1st sentence) 5:628f (last proviso of 1st sentence)	
2354 (d)	5:235f (less 1st sentence) 5:475k (less 1st sentence) 5:628f (less 1st sentence)	

In subsection (a), the words "Liability on account of", and "of such claims" are omitted as surplusage. In clauses (1) and (2), the word "from" is substituted for the words "arising as a result of".

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1.4b(2) SENATE COMMITTEE ON THE JUDICIARY
S. REP. No. 2484, 84th Cong., 2d Sess. (1956)

REVISION OF TITLE 10, UNITED STATES CODE, ENTITLED "ARMED FORCES", AND TITLE 32, UNITED STATES CODE, ENTITLED "NATIONAL GUARD"

JULY 9, 1956.—Ordered to be printed

Mr. O'MAHONEY, from the Committee on the Judiciary, submitted the following

REPORT

[To accompany H.R. 7049]

The Committee on the Judiciary, to which was referred the bill (H.R. 7049) to revise, codify, and enact into law title 10 of the United States Code, entitled "Armed Forces", and title 32 of the United States Code, entitled "National Guard", having considered the same, reports favorably thereon with amendments and recommends that the bill, as amended, do pass.

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SECTION 2353

Revised Section	*Source (U.S. Code)*	*Source (Statutes at Large)*
2353 (a)	5:235e (1st sentence; and 2d sentence, less 2d and last provisos) 5:475j (1st sentence; and 2d sentence, less 2d and last provisos) 5:628e (1st sentence; and 2d sentence, less 2d and last provisos)	July 16, 1952, ch. 882, §4 (less 3d and last sentences), 66 Stat. 725.
2353 (b)	5:235e (2d proviso of 2d sentence) 5:475j (2d proviso of 2d sentence) 5:628e (2d proviso of 2d sentence)	
2353 (c)	5:235e (last proviso of 2d sentence) 5:475j (last proviso of 2d sentence) 5:628e (last proviso of 2d sentence)	

In subsection (a), the words "furnished to" and "for the use thereof" are omitted as surplusage.

In subsections (a) and (b), the words "United States" are substituted for the word "Government".

In subsection (b), the introductory clause is substituted for 5:235e (words of 2d proviso before clause (1)), 475j, and 628e. The words "that . . . considers" are substituted for the words "as will in the opinion". The words "an alternative" are substituted for the words "such other".

In subsection (c), the words "Proceeds of" are substituted for the words "That all moneys arising from".

SECTION 2354

Revised Section	*Source (U.S. Code)*	*Source (Statutes at Large)*
2354 (a)	5:235f (1st sentence, less provisos) 5:475k (1st sentence, less provisos) 5:628f (1st sentence, less provisos)	July 16, 1952, ch. 882, §5, 66 Stat. 726.
2354 (b)	5:235f (1st proviso of 1st sentence) 5:475k (1st proviso of 1st sentence) 5:628f (1st proviso of 1st sentence)	
2354 (c)	5:235f (last proviso of 1st sentence) 5:475k (last proviso of 1st sentence) 5:628f (last proviso of 1st sentence)	
2354 (d)	5:235f (less 1st sentence) 5:475k (less 1st sentence) 5:628f (less 1st sentence)	

In subsection (a), the words "Liability on account of", and "of such claims" are omitted as surplusage. In clauses (1) and (2), the word "from" is substituted for the words "arising as a result of".

[p. 149]

1.4b(3) CONGRESSIONAL RECORD

1.4b(3)(a) VOL. 101 (1955), Aug. 1: Amended and passed House, pp. 12718–12719

[No Relevant Discussion on Pertinent Section]

1.4b(3)(b) VOL. 102 (1956), July 23: Amended and passed Senate, p. 13953

[No Relevant Discussion on Pertinent Section]

1.4b(3)(c) VOL. 102 (1956), July 25: House concurs in Senate amendments, p. 14455

[No Relevant Discussion on Pertinent Section]

1.5 INTERNATIONAL HEALTH RESEARCH ACT, 22 U.S.C. §2101 (1960)

[Referred to in 42 U.S.C. §242f(a)]

22 § 2101. Statement of purpose

It is the purpose of this chapter and section 242f of Title 42—

(1) to advance the status of the health sciences in the United States and thereby the health of the American people through co-operative endeavors with other countries in health research, and research training; and

(2) to advance the international status of the health sciences through cooperative enterprises in health research, research planning, and research training.

Pub.L. 86–610, § 2, July 12, 1960, 74 Stat. 364.

1.5a FOREIGN ASSISTANCE ACT OF 1961, SEPTEMBER 4, 1961

P.L. 87–195, Pt. I, §241, 75 Stat. 433

TITLE V—DEVELOPMENT RESEARCH

SEC. 241. GENERAL AUTHORITY.—The President is authorized to use funds made available for this part to carry out programs of research into, and evaluation of, the process of economic development in less developed friendly countries and areas, into the factors affecting the relative success and costs of development activities, and into the means, techniques, and such other aspects of development assistance as he may determine, in order to render such assistance of increasing value and benefit.

[p. 433]

1.5a(1) SENATE COMMITTEE ON FOREIGN RELATIONS

S. REP. No. 612, 87th Cong., 1st Sess. (1961)

FOREIGN ASSISTANCE ACT OF 1961

JULY 24, 1961.—Ordered to be printed

Mr. FULBRIGHT, from the Committee on Foreign Relations, submitted the following

REPORT

[To accompany S. 1983]

The Committee on Foreign Relations, having had under consideration the bill (S. 1983), the Foreign Assistance Act of 1961, reports the bill favorably with amendments and recommends that, as amended, it be passed by the Senate.

1. MAIN PURPOSE OF THE BILL

The main purpose of the bill is to give vigor, purpose, and new direction to the foreign aid program. Thus, the stress of the program is shifted to development loans repayable on manageable terms and conditions but in dollars. Long-term financing becomes available to the new aid agency, a simpler structure which will include the Development Loan Fund and the International Coopera-

tion Administration. Less emphasis is placed on and fewer funds are granted to direct support programs. Self-help and long-term development planning are now the chief criteria against which the bulk of economic aid is programed.

Funds for categories of economic and technical assistance other than the contingency fund, are authorized to be made available until expended. The same is true of military assistance. This means that unused funds in these categories are carried over into another fiscal year instead of automatically returning to the Treasury. The bill, in short, stresses orderly economic growth and gives continuity to the programs that will encourage and sustain much of this growth.

[p. 1]

1.5a(2) HOUSE COMMITTEE ON FOREIGN AFFAIRS

H.R. REP. No. 851, 87th Cong., 1st Sess. (1961)

MUTUAL SECURITY ACT OF 1961

AUGUST 4, 1961.—Committed to the Committee of the Whole House on the State of the Union and ordered to be printed

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Mr. MORGAN, from the Committee on Foreign Affairs, submitted the following

REPORT

[To accompany H.R. 8400]

The Committee on Foreign Affairs, to whom was referred the bill (H.R. 8400) to promote the foreign policy, security, and general welfare of the United States by assisting peoples of the world in their efforts toward economic and social development and internal and external security, and for other purposes, having considered the same, report favorably thereon without amendment and recommend that the bill do pass.

[p. 1]

TITLE V—DEVELOPMENT RESEARCH

This title represents a new program designed to contribute the results of systematic investigation to the improvement and the direction of economic aid programs. The President is authorized to use funds available for part I for the purposes of this title.

In his special message on foreign aid of March 22, 1961, the President proposed—

> a program of research, development, and scientific evaluation to increase the effectiveness of our aid effort.

The program authorized by this title is largely the product of recommendations put forward by the President's Scientific Advisory Committee. It is contemplated as a modest program, to be conducted on an experimental basis and involving an expenditure of not more than $20 million and possibly less. It represents an effort to minimize the difficulties inherent in economic and social development. In the southern continents, where the major portion of aid funds is programed, conditions are vastly different from those in our own country. Climate, soils, diseases, traditions, and social patterns all pose problems that can frustrate development programs.

A good deal of research being undertaken in this country by the foundations and universities is relevant to the problems in the less developed societies. One of the major purposes of the development research program is to relate this research more directly to specific problems. First, needs and requirements must be identified and given priorities. In some countries, the primary need is the development of people. Educational and training techniques normally used in the West may be irrelevant to problems that arise from mass illiteracy, absence of basic skills, and divergent cultural and social patterns. Thus, technical assistance programs will have the intended effect in a given country only if they are designed to cope with the problems peculiar to that country. The hope is that our research programs may discover more appropriate educational and training techniques.

In some countries, the main problem is finding a way to harness the resources of the country to its development plan. The technical problems may involve agriculture, mining, power, industry, and public administration. The techniques and methods suitable for tackling one country's combination of technical problems may not be applicable to another's. Again, it is hoped that research programs will find some answers for specialized situations.

It is contemplated that most of the activities under this program will serve the purpose of improving the capability of less developed

countries to analyze their own problems. The committee heard testimony that—

> In the end it is they who will have to deal with their own technical, economic, and social problems. One of the most

[p. 18]

> critical bottlenecks is the very limited number of people in the underdeveloped countries capable of analyzing their own problems systematically. Wherever possible research should be carried on jointly by people and institutions with research experience in the United States and Europe and by analysts in the underdeveloped countries themselves.

Another big need is a better understanding of the interrelationships among economic, political and social changes.

The program should encourage the research community to undertake more projects that are relevant to the problems of the societies we are seeking to assist. And it should serve as a clearinghouse in which research activities can be evaluated and related to these societies.

The committee, in approving this program, was mindful that research and development occupies an important role in private enterprise and in Government operations. More than 9 percent of the Federal budget is spent on research and development. It would seem highly advisable to expose the complicated and difficult problems of the less developed areas to the formidable talents of the American research community.

[p. 19]

TITLE V—DEVELOPMENT RESEARCH

Section 241. General authority

Title V authorizes the President to carry out programs of evaluation and research designed to contribute the results of systematic investigation into the improvement and effectiveness of the development assistance program in economically underdeveloped countries and areas. The President is authorized to use funds available for part I to carry out the purposes of this title.

In his special message on foreign aid of March 22, 1961, the President asked that there be initiated "a program of research, development and scientific evaluation to increase the effectiveness of our aid effort." The program authorized by this title is largely the product of the recommendations in the report of the Develop-

ment Assistance Panel of the President's Science Advisory Committee. (See hearings, p. 971.)

Research in many branches of the Government and private activity throughout the United States and the industrialized world has shown how enormously the capacity to deal with complex, new, and unfamiliar problems can be accelerated and improved, and, effectively

[p. 40]

applied, may result in reduction in costs. The committee is convinced that there is a real and definite need for a research program within the AID agency.

The research program will be called upon to fill the gap in the development phase of research activities, that is, testing new techniques in the environment in which they will actually be used. A systematic evaluation of new ideas, as they are put into practice, will therefore be a key function. In addition, the program will direct its overall efforts to encouraging an innovative attitude toward their own problems by the underdeveloped countries themselves, since in the long run it is they who will have to deal with their own economic and social problems. Wherever possible, projects of joint research will be promoted in which research specialists and institutions in the United States will cooperate with analysts in the underdeveloped countries. Finally, as stated by Dr. Max Millikan of MIT and a member of the President's Science Advisory Committee, before the Committee on Foreign Affairs—

> an AID agency-sponsored research program can perform an enormously valuable function in stimulating a wider awareness in the research community of the United States of the problems of the underdeveloped countries and in generating, over time, a much larger pool of talent in this country with the training and interests required for participation in the development program.

Examples of the kinds of research projects which might be undertaken were cited in the testimony given the committee, such as simple power systems; transportation network requirements in underdeveloped countries and areas; educational systems to meet the needs of predominantly illiterate societies at the local level, and public health programs geared to the resources available. Whatever the area of research is determined to be, the basic knowledge available to the research unit will have to be imaginatively adapted to local conditions.

It is contemplated that the research program will be directed within the Office of Development Research and Assistance in the AID agency by a small staff, numbering about 20, of the highest quality from the scientific research community. Research projects will be undertaken mainly by contract with universities and other research institutions and agencies, although the research unit may be called upon to provide direct research assistance to the regional bureaus during the course of planning, execution, or evaluation of specific projects. As findings are tested and become available for field application, this Office will suggest the best ways of incorporating them into national development plans and programs. Finally, the Office will provide professional and technical leadership and overall guidance to the regional bureaus in matters relating to the development and utilization of human resources, that is, training of people to participate in the development of their countries. In addition, the Office will maintain liaison with the academic and scientific community, both private and governmental.

The research program will not duplicate other research work undertaken in the field of economic development assistance; rather, it will at first rely heavily on material already available. The committee believes that primary consideration should be given to comprehensive

[p. 41]

analysis and evaluation of the processes of giving assistance, as well as to actual projects involved. American religious and other voluntary agencies have for decades been conducting educational, medical, agricultural, social and cultural programs in the cities, villages and countryside of all the underdeveloped countries of the world. A vast amount of invaluable experience has been gained by the most reliable method of all: trial and error. It was unfortunate and caused unnecessary delay in our governmental foreign assistance programs that too little study was given earlier to these worldwide operations. The committee believes that perhaps the first major effort of the new Office of Development Research and Assistance should be to collect, organize and evaluate the data already available. The findings and considerations of such evaluation can give guidance to the fields and methods which new research should most profitably explore.

The specific technical assistance research programs already contracted for under the International Cooperation Administration will continue.

The Executive requested a separate authorization of $20 million

to carry out the program. Since the research effort in the development assistance program will begin on an experimental basis, and a vast amount of material in the field of economic growth and development will have to be reviewed and evaluated before the contribution of the program to the development assistance program gains impetus, the committee believes that the new research program can meet its initial requirement from the funds provided in part I.

Oceanography

The committee in the course of its consideration of title V discussed the possibility of an international cooperative effort in research and development of the ocean's resources. The committee recognizes the importance of such a program. Knowledge of the oceans (oceanography), the resources which are contained therein, and the manner in which the oceans are utilized and exploited by various foreign nations all have a direct application to the economic, military, and political postures of those nations. The economic and military aspects are particularly important and the oceanographic data or knowledge obtained for one aspect is directly useful for and applicable to the other. Testimony before the committee mentioned fundamental research in oceanography as one of the scientific areas which the development research program can draw upon where applicable to the problems of economically underdeveloped countries. Where activities in the field of oceanography complement assistance furnished under other parts of this bill, it may be appropriate to finance them with mutual security funds.

[p. 42]

1.5a(3) COMMITTEE OF CONFERENCE
H.R. REP. No. 1088, 87th Cong., 1st Sess. (1961)

FOREIGN ASSISTANCE ACT OF 1961

AUGUST 30, 1961.—Ordered to be printed

Mr. MORGAN, from the committee of conference, submitted the following

CONFERENCE REPORT

[To accompany S. 1983]

The committee of conference on the disagreeing votes of the two Houses on the amendment of the House to the bill (S. 1983) to promote the foreign policy, security, and general welfare of the United States by assisting peoples of the world in their efforts toward economic development and internal and external security, and for other purposes, having met, after full and free conference, have agreed to recommend and do recommend to their respective Houses as follows:

That the Senate recede from its disagreement to the amendment of the House and agree to the same with an amendment as follows:

In lieu of the matter proposed to be inserted by the House amendment insert the following:

* * * * * * *

[p. 1]

TITLE V—DEVELOPMENT RESEARCH

SEC. 241. GENERAL AUTHORITY.—*The President is authorized to use funds made available for this part to carry out programs of research*

[p. 9]

into, and evaluation of, the process of economic development in less developed friendly countries and areas, into the factors affecting the relative success and costs of development activities, and into the means, techniques, and such other aspects of development assistance as he may determine, in order to render such assistance of increasing value and benefit.

[p. 10]

1.5a(4) CONGRESSIONAL RECORD, VOL. 107 (1961)

1.5a(4)(a) Aug. 16: Passed Senate, p. 16411

[No Relevant Discussion on Pertinent Section]

1.5a(4)(b) Aug. 17: Amended and passed House, p. 16501

[No Relevant Discussion on Pertinent Section]

1.5a(4)(c) Aug. 31: Senate agrees to conference report, p. 17712

[No Relevant Discussion on Pertinent Section]

1.5a(4)(d) Aug. 31: House agrees to conference report, p. 17862

[No Relevant Discussion on Pertinent Section]

1.5b FOREIGN ASSISTANCE ACT OF 1963

December 16, 1963, P.L. 88–205, Pt. I, §105, 77 Stat. 382

SEC. 105. Section 241 of the Foreign Assistance Act of 1961, as amended, which relates to development research, is amended by inserting "(a)" after the section heading and by adding at the end thereof the following new subsection:

"(b) Funds made available to carry out this section may be used to conduct research into the problems of population growth."

[p. 382]

1.5b(1) HOUSE COMMITTEE ON FOREIGN AFFAIRS

H.R. REP. No. 646, 88th Cong., 1st Sess. (1963)

FOREIGN ASSISTANCE ACT OF 1963

AUGUST 8, 1963.—Committed to the Committee of the Whole House on the State of the Union and ordered to be printed

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Mr. MORGAN, from the Committee on Foreign Affairs, submitted the following

REPORT

[To accompany H.R. 7885]

The Committee on Foreign Affairs, to whom was referred the bill (H.R. 7885) to amend further the Foreign Assistance Act of 1961, as amended, and for other purposes, having considered the same, report favorably thereon without amendment and recommend that the bill do pass.

[p. 1]

1.5b(2) SENATE COMMITTEE ON FOREIGN RELATIONS

S. REP. No. 588, 88th Cong., 1st Sess. (1963)

FOREIGN ASSISTANCE ACT OF 1963

OCTOBER 22, 1963.—Ordered to be printed

Mr. FULBRIGHT, from the Committee on Foreign Relations, submitted the following

REPORT

[To accompany H.R. 7885]

The Committee on Foreign Relations, to whom was referred the bill H.R. 7885, to amend further the Foreign Assistance Act of

1961, as amended, and for other purposes, having considered the same, reports the bill favorably with an amendment in the nature of a substitute and recommends that the bill as amended do pass.

[p. 1]

TITLE V—DEVELOPMENT RESEARCH

Population growth (sec. 105)

Section 241 of the act, which authorizes the President to carry out programs of research on processes and techniques of economic development, is amended by the addition of a provision authorizing the use of research funds to conduct studies of the problems of controlling population growth and to provide assistance to cooperating countries in carrying out programs of population control.

Because of the profound impact of population growth on economic development, the committee considers it appropriate to provide explicit authority for the conduct of research and technical assistance activities in this field. It is the view of the committee that population growth must be regarded as a critical factor in the development prospects of countries which receive development assistance from the United States.

No less than general education and technical, administrative, and managerial competence, the capacity of a country to maintain a reasonable balance between population and resources is a vital factor in its prospects for successful economic development. It is a well-known fact that in many less-developed countries rapid population growth has substantially or entirely negated the benefits of U.S. economic assistance. Even in some countries where economic growth has been impressive, per capita income levels have remained virtually stagnant as a result of mushrooming increases in population.

Substantial progress has been made in recent years in defining the preconditions of economic growth. To a great extent our economic assistance has been refocused on those countries which have largely fulfilled these preconditions. The one vital criterion of successful development which has been neglected is that of population control. The purpose of the committee's amendment to title V of the act is to encourage research into appropriate measures to correct this omission.

[p. 14]

TITLE V—DEVELOPMENT RESEARCH

SEC. 241. GENERAL AUTHORITY.—(*a*) The President is authorized to use funds made available for this part to carry out programs of research into, and evaluation of, the process of economic

development in less developed friendly countries and areas, into the factors affecting the relative success and costs of development activities, and into the means, techniques, and such other aspects of development assistance as he may determine, in order to render such assistance of increasing value and benefit.

(*b*) *Funds made available to carry out this section may be used to conduct research into the problems of controlling population growth and to provide technical and other assistance to cooperating countries in carrying out programs of population control.*

[p. 52]

1.5b(3) COMMITTEE OF CONFERENCE

H.R. REP. No. 1006, 88th Cong., 1st Sess. (1963)

FOREIGN ASSISTANCE ACT OF 1963

DECEMBER 6, 1963.—Ordered to be printed

Mr. MORGAN, from the committee of conference, submitted the following

CONFERENCE REPORT

[To accompany H.R. 7885]

The committee of conference on the disagreeing votes of the two Houses on the amendment of the Senate to the bill (H.R. 7885) to amend further the Foreign Assistance Act of 1961, as amended, and for other purposes, having met, after full and free conference, have agreed to recommend and do recommend to their respective Houses as follows:

That the House recede from its disagreement to the amendment of the Senate and agree to the same with an amendment as follows:

In lieu of the matter proposed to be inserted by the Senate amendment insert the following: *That this Act may be cited as the "Foreign Assistance Act of 1963".*

[p. 1]

TITLE V—DEVELOPMENT RESEARCH

SEC. *105. Section 241 of the Foreign Assistance Act of 1961, as amended, which relates to development research, is amended by inserting "(a)" after the section heading and by adding at the end thereof the following new subsection:*

"(b) Funds made available to carry out this section may be used to conduct research into the problems of population growth."

[p. 5]

POPULATION PROBLEMS (SEC. 105)

The Senate amendment included a provision that "funds made available to carry out this section may be used to conduct research into the problems of controlling population growth and to provide technical and other assistance to cooperating countries in carrying out programs of population control."

The House bill did not contain a comparable provision.

The managers on the part of the House agreed to a modification of the Senate provision so that it provides that "funds made available to carry out this section may be used to conduct research into the problems of population growth."

The managers on the part of the House accepted the language as modified in the belief that in view of the population problems in the less developed countries, research on such problems appears to be warranted.

[p. 21]

1.5b(4) CONGRESSIONAL RECORD, VOL. 109 (1963)

1.5b(4)(a) Aug. 23: Passed House, p. 15678

[No Relevant Discussion on Pertinent Section]

1.5b(4)(b) Oct. 24, Nov. 15: Debated, amended and passed Senate, p. 21978

MEMORANDUM TO SENATOR HUMPHREY FROM PAT HOLT

* * * * *

3. A new subsection (b) was added to section 241, relating to development research, which reads as follows:

"Funds made available to carry out this section may be used to conduct research into the problems of controlling population growth and to provide technical and other assistance to cooperating countries in carrying out programs of population control."

The committee report (p. 14) states:

"Because of the profound impact of population growth on economic development, the committee considers it appropriate to provide explicit authority for the conduct of research and technical assistance activities in this field. It is the view of the committee that population growth must be regarded as a critical factor in the development prospects of countries which

receive development assistance from the United States."

"No less than general education and technical, administrative, and managerial competence, the capacity of a country to maintain a reasonable balance between population and resources is a vital factor in its prospects for successful economic development. It is a well-known fact that in many less-developed countries rapid population growth has substantially or entirely negated the benefits of U.S. economic assistance. Even in some countries where economic growth has been impressive, per capita income levels have remained virtually stagnant as a result of mushrooming increases in population.

"Substantial progress has been made in recent years in defining the preconditions of economic growth. To a great extent our economic assistance has been refocused on those countries which have largely fulfilled these preconditions. The one vital criterion of successful development which has been neglected is that of population control. The purpose of the committee's amendment to title V of the act is to encourage research into appropriate measures to correct this omission."

* * * * *

[p. 21978]

1.5b(4)(c) Dec. 9: Conference report submitted in House and agreed to, p. 23850

[No Relevant Discussion on Pertinent Section]

1.5b(4)(d) Dec. 13: Conference report agreed to in Senate, pp. 24453–24454

FOREIGN ASSISTANCE ACT OF 1963—CONFERENCE REPORT

The Senate resumed the consideration of the report of the committee of conference on the disagreeing votes of the two Houses on the amendment of the Senate to the bill (H.R. 7885) to amend further the Foreign Assistance Act of 1961, as amended, and for other purposes.

Mr. MORSE. Mr. President, at this time I suggest that there be a quorum call, with the understanding that the time required for it not be charged to the time available to either side.

The ACTING PRESIDENT pro tempore. Is there objection? Without objection, it is so ordered; and the clerk will call the roll.

The Chief Clerk proceeded to call the roll.

Mr. MORSE. Mr. President, I ask unanimous consent that the order for the quorum call may be rescinded.

The ACTING PRESIDENT pro tempore. Without objection, it is so ordered.

Mr. MORSE. Mr. President, I yield 5 minutes to the Senator from Pennsylvania [Mr. CLARK] from the time available on the conference report.

Mr. CLARK. Mr. President, I should like to express my keen disappointment in the action of the conferees in striking from the conference report one-half of section 105 of the Senate bill, which dealt with the problem of controlling population growth.

Senators will recall the Senate provision stated on page 21 of the report of the managers on the part of the House:

Funds made available to carry out this section may be used to conduct research into the problems of controlling population growth and to provide technical and other assistance to cooperating countries in carrying out programs of population control.

The report of the managers on the part of the House states that the managers agreed to a modification of the

[p. 24453]

Senate provision so that it would include the first part of the Senate amendment. The conferees, however, struck out the second part of the Senate amendment, which would have authorized the provision of technical and

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other assistance to cooperating countries in carrying out programs of population control.

The second part of section 105—that is, the part which the conferees struck out at the insistence of the House—was a valuable provision and should have been retained.

Senators will recall that this year, for the first time, the Senate took formal cognizance of the existence of the population problem, not only in the United States, but all over the world. I have had occasion frequently to advert to the problem, and so has the Senator from Alaska [Mr. GRUENING].

The chairman of the Senate Foreign Relations Committee, the Senator from Arkansas [Mr. FULBRIGHT] took the initiative in inserting section 105 into the Senate version of the Foreign Assistance Act of 1963. So far as I know, there was no objection either in the Foreign Relations Committee or on the floor of the Senate to section 105, as the Senator from Arkansas [Mr. FULBRIGHT] had steered the bill through committee and through floor action.

The Senator from Alaska [Mr. GRUENING] and I had occasion to point out that the attitude of the Catholic Church toward measures of population control has drastically altered.

Dr. John Rock has published, with substantial support from the Catholic Church, of which he is a devout member, a book entitled "The Time Has Come." The burden of the book is that the time has come to speak out on the critical problem of population control. A number of other eminent Catholics, including Monsignor O'Brien of Notre Dame University, have spoken out on the same subject.

There is now developing a consensus among all religious bodies and thoughtful citizens of the need for the Government to take a good, hard look at problems of population control, particularly in underdeveloped countries.

I regret, therefore, that the House conferees were unwilling to accept the provision which passed the Senate without objection. I am glad, however, that the conference report recommends the expenditure of funds to conduct research into the problem of controlling population growth. I would hope that the Administrator of the program would construe this provision very broadly indeed.

The ACTING PRESIDENT pro tempore. The time of the Senator from Pennsylvania has expired.

Mr. CLARK. Mr. President, will the Senator yield me 1 additional minute?

Mr. MORSE. I yield the Senator 1 more minute.

The ACTING PRESIDENT pro tempore. The Senator from Pennsylvania is recognized for 1 additional minute.

Mr. CLARK. Mr. President, I reiterate my hope that the Administrator of the program will construe the authorization retained in the conference report very broadly and that in the next fiscal year we shall see a real breakthrough in efforts to establish, through programs of research, a meaningful series of methods for investigating through statistical data, and for creating through planning programs population control which can begin to make an impact on the quite frightening problem of population growth which confronts the whole world.

I point out that two of every three human beings will go to bed hungry tonight and that an unlimited birth rate is perhaps the single most serious obstacle to bringing to those two of every three people an adequate diet and an opportunity for a healthy and useful life.

I thank my friend for yielding.

Mr. MORSE. Mr. President, I yield 3 minutes to the Senator from Ohio [Mr. YOUNG].

The ACTING PRESIDENT pro tempore. The Senator from Ohio [Mr. YOUNG] is recognized for 3 minutes.

[p. 24454]

1.6 PER DIEM, TRAVEL AND TRANSPORTATION EXPENSES; EXPERTS AND CONSULTANTS; INDIVIDUALS SERVING WITHOUT PAY, AS AMENDED

5 U.S.C. §5703 (1966)

[Referred to in 42 U.S.C. §242f(b)(5),(6)]

(See, "General 1.15a–1.15d(3)(c)" for legislative history)

5 § 5703.

(a) For the purpose of this section, "appropriation" includes funds made available by statute under section 849 of title 31.

(b) An individual employed intermittently in the Government service as an expert or consultant and paid on a daily when-actually-employed basis may be allowed travel expenses under this subchapter while away from his home or regular place of business, including a per diem allowance under this subchapter while at his place of employment.

(c) An individual serving without pay or at $1 a year may be allowed transportation expenses under this subchapter and a per diem allowance under this section while en route and at his place of service or employment away from his home or regular place of business. Unless a higher rate is named in an appropriation or other statute, the per diem allowance may not exceed—

(1) the rate of $25 for travel inside the continental United States; and

(2) the rates established under section 5702(a) of this title for travel outside the continental United States.

(d) Under regulations prescribed under section 5707 of this title, the head of the agency concerned may prescribe conditions under which an individual to whom this section applies may be reimbursed for the actual and necessary expenses of the trip, not to exceed an amount named in the travel authorization, when the maximum per diem allowance would be much less than these expenses due to the unusual circumstances of the travel assignment. The amount named in the travel authorization may not exceed—

(1) $40 for each day in a travel status inside the continental United States; or

(2) the maximum per diem allowance plus $18 for each day in a travel status outside the continental United States.

Pub.L. 89–554, Sept. 6, 1966, 80 Stat. 499; amended Pub.L. 91–114, § 2, Nov. 10, 1969, 83 Stat. 190.

1.7 THE SOLID WASTE DISPOSAL ACT, AS AMENDED

42 U.S.C. §3254f (1970)

42 § 3254f. National disposal sites study for the storage and disposal of hazardous wastes

The Secretary shall submit to the Congress no later than two years after October 26, 1970, a comprehensive report and plan for the creation of a system of national disposal sites for the storage and disposal of hazardous wastes, including radioactive, toxic chemical, biological, and other wastes which may endanger public health or welfare. Such report shall include: (1) a list of materials which should be subject to disposal in any such site; (2) current methods of disposal of such materials; (3) recommended methods of reduction, neutralization, recovery, or disposal of such materials; (4) an inventory of possible sites including existing land or water disposal sites operated or licensed by Federal agencies; (5) an estimate of the cost of developing and maintaining sites including consideration of means for distributing the short- and long-term costs of operating such sites among the users thereof; and (6) such other information as may be appropriate.

Pub.L. 89–272, Title II, § 212, as added Pub.L. 91–512, Title I, § 104(b), Oct. 26, 1970, 84 Stat. 1233.

1.7a THE RESOURCE RECOVERY ACT OF 1970

October 26, 1970, P.L. 91–512, Title I, §104(b), 84 Stat. 1233

SEC. 104.

(b) The Solid Waste Disposal Act is amended by redesignating sections 207 through 210 as sections 213 through 216, respectively, and by inserting after section 206 (as so redesignated by subsection (a) of this section) the following new sections:

* * * * * * *

"NATIONAL DISPOSAL SITES STUDY

"SEC. 212. The Secretary shall submit to the Congress no later than two years after the date of enactment of the Resource Recovery Act of 1970, a comprehensive report and plan for the creation of a system of national disposal sites for the storage and disposal of hazardous wastes, including radioactive, toxic chemical, biological, and other wastes which may endanger public health or welfare. Such report shall include: (1) a list of materials which should be subject to disposal in any such site; (2) current methods of disposal of such materials; (3) recommended methods of reduction, neutralization, recovery, or disposal of such materials; (4) an inventory of possible sites including existing land or water disposal sites operated or licensed by Federal agencies; (5) an estimate of the cost of developing and maintaining sites including consideration of means for distributing the short- and long-term costs of operating such sites among the users thereof; and (6) such other information as may be appropriate."

[p. 1233]

1.7a(1) HOUSE COMMITTEE ON INTERSTATE AND FOREIGN COMMERCE

H.R. REP. No. 91–1155, 91st Cong., 2d Sess. (1970)

RESOURCE RECOVERY ACT OF 1970

JUNE 4, 1970.—Committed to the Committee of the Whole House on the State of the Union and ordered to be printed

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Mr. STAGGERS, from the Committee on Interstate and Foreign Commerce, submitted the following

REPORT

[To accompany H.R. 11833]

The Committee on Interstate and Foreign Commerce, to whom was referred the bill (H.R. 11833) to amend the Solid Waste Disposal Act in order to provide financial assistance for the construction of solid waste disposal facilities, to improve research programs pursuant to such act, and for other purposes, having considered the same, report favorably thereon with an amendment and recommend that the bill as amended do pass.

The amendment strikes out all of the bill after the enacting clause and inserts in lieu thereof a substitute which appears in the reported bill in italic type.

[p. 1]

1.7a(2) SENATE COMMITTEE ON PUBLIC WORKS

S. REP. No. 91–1034, 91st Cong., 2d Sess. (1970)

RESOURCE RECOVERY ACT OF 1970

JULY 23, 1970.—Ordered to be printed

Mr. MUSKIE, from the Committee on Public Works, submitted the following

REPORT

together with an

INDIVIDUAL VIEW

[To accompany S. 2005]

The Committee on Public Works, to which was referred the bill (S. 2005) to amend the Solid Waste Disposal Act, as amended, relating to financial assistance for the construction of solid waste disposal facilities, improving research programs pursuant to such Act, establishing a National Commission on Materials Policy, and for other purposes, having considered the same, reports favorably thereon with amendments and recommends that the bill as amended do pass.

[p. 1]

NATIONAL DISPOSAL SITES STUDY

Considerable recent attention has been focused on disposal of materials which present a high risk to public health and welfare because of their toxicity or mutagenic effects. Congressional attention to such hazardous materials was reflected in the Water Quality Improvement Act of 1970, which requires identification of hazardous materials and a study of liability for the cost of cleaning up such materials when discharged into the navigable waters of the United States.

Hazardous materials are often present in solid wastes. When released into the environment, they often cause ecological damage and risks to public health.

Frequently such materials are dumped into the ocean. The environmental implications of this practice are not understood. A

prudent public policy necessitates discouraging or prohibiting this practice. Alternative methods must be developed and provided for disposal of these wastes.

The objective must be to dispose of these hazardous materials so that their deleterious impact is eliminated. One approach is to provide a system of national disposal sites which would be supported by user fees.

It is the opinion of the committee that further information is needed on the desirability and feasibility of a system of solid waste disposal sites for hazardous materials.

The bill directs the Secretary to prepare a report and plan for the creation of a system of national disposal sites for the storage and disposal of hazardous wastes. The report is to include a list of materials which may endanger public health and welfare as well as current and recommended methods for disposal of these materials. This section directs that the study include disposal methods for radioactive materials, toxic chemical wastes, biological materials, and other hazardous materials.

This study would provide an inventory of disposal sites currently operated or licensed by Federal agencies including both land and water disposal sites.

The report required by this legislation should include a compilation of current practices for the disposal of hazardous materials on land and at sea, including recommendations on practices that should be discontinued.

In proposing possible sites for inclusion in a system of national disposal sites, the Secretary is expected to estimate the costs of developing and maintaining such a system. These estimates should include proposals for distributing the costs for operating such sites between public and private users of such sites, and contract arrangements for employing any expertise of the private sector to operate such sites.

[p. 16]

1.7a(3) COMMITTEE OF CONFERENCE
H.R. REP. No. 91-1579, 91st Cong., 2d Sess. (1970)

RESOURCE RECOVERY ACT OF 1970

OCTOBER 7, 1970.—Ordered to be printed

Mr. STAGGERS, from the committee of conference, submitted the following

CONFERENCE REPORT

[To accompany H.R. 11833]

The committee of conference on the disagreeing votes of the two Houses on the amendment of the Senate to the bill (H.R. 11833) to amend the Solid Waste Disposal Act in order to provide financial assistance for the construction of solid waste disposal facilities, to improve research programs pursuant to such Act, and for other purposes, having met, after full and free conference, have agreed to recommend and do recommend to their respective Houses as follows:

That the House recede from its disagreement to the amendment of the Senate and agree to the same with an amendment as follows:

In lieu of the matter proposed to be inserted by the Senate amendment insert the following:

[p. 1]

"NATIONAL DISPOSAL SITES STUDY

"SEC. *212. The Secretary shall submit to the Congress no later than two years after the date of enactment of the Resource Recovery Act of 1970, a comprehensive report and plan for the creation of a system of national disposal sites for the storage and disposal of hazardous wastes, including radioactive, toxic chemical, biological, and other wastes which*

[p. 7]

may endanger public health or welfare. Such report shall include: (1) a list of materials which should be subject to disposal in any such site; (2) current methods of disposal of such materials; (3) recommended methods of reduction, neutralization, recovery,

or disposal of such materials; (4) an inventory of possible sites including existing land or water disposal sites operated or licensed by Federal agencies; (5) an estimate of the cost of developing and maintaining sites including consideration of means for distributing the short- and long-term costs of operating such sites among the users thereof; and (6) such other information as may be appropriate."

[p. 8]

New section 212 of act (national disposal sites study)

The Senate amendment inserted a new section 212 in the act, which provided for a 2-year national disposal sites study. The Secretary was directed to make a comprehensive report and plan for the creation of a system of national disposal sites for the storage and disposal of hazardous wastes, including radioactive, toxic chemical, biological, and other wastes which may endanger public health or welfare. The report would include (1) a list of materials subject to disposal; (2) current methods of disposal of such materials; (3) recommended methods of disposal of such materials; (4) an inventory of possible sites; and (5) cost estimates.

The House bill had no comparable provision. The House recedes on this provision.

[p. 16]

1.7a(4) CONGRESSIONAL RECORD, VOL. 116 (1970)

1.7a(4)(a) June 23: Passed House, p. 20893

[No Relevant Discussion on Pertinent Section]

1.7a(4)(b) Aug. 3: Considered, amended and passed Senate, p. 26942

[No Relevant Discussion on Pertinent Section]

1.7a(4)(c) Oct. 7: Senate agreed to conference report, pp. 35511, 35516

[No Relevant Discussion on Pertinent Section]

1.7a(4)(d) Oct. 13: House agreed to conference report, p. 36587

[No Relevant Discussion on Pertinent Section]

1.8 NATIONAL ENVIRONMENTAL POLICY ACT OF 1969

42 U.S.C. §§4332(2)(c), 4344(5) (1970)

(See, "General 1.2a–1.2a(4)(e)" for legislative history)

§4332. Cooperation of agencies; reports; availability of information; recommendations; international and national coordination of efforts

The Congress authorizes and directs that, to the fullest extent possible:

* * * * * * *

(2) all agencies of the Federal Government shall—

* * * * * * *

(C) include in every recommendation or report on proposals for legislation and other major Federal actions significantly affecting the quality of the human environment, a detailed statement by the responsible official on—

(i) the environmental impact of the proposed action,

(ii) any adverse environmental effects which cannot be avoided should the proposal be implemented,

(iii) alternatives to the proposed action,

(iv) the relationship between local short-term uses of man's environment and the maintenance and enhancement of long-term productivity, and

(v) any irreversible and irretrievable commitments of resources which would be involved in the proposed action should it be implemented.

Prior to making any detailed statement, the responsible Federal official shall consult with and obtain the comments of any Federal agency which has jurisdiction by law or special expertise with respect to any environmental impact involved. Copies of such statement and the comments and views of the appropriate Federal, State, and local agencies, which are authorized to develop and enforce environmental standards, shall be made available to the President, the Council on Environmental Quality and to the public as provided by section 552 of Title 5, and shall accompany the proposal through the existing agency review processes;

* * * * * * *

§4344. Duties and functions

It shall be the duty and function of the Council—

* * * * * * *

(5) to conduct investigations, studies, surveys, research, and analyses relating to ecological systems and environmental quality;

* * * * * * *

Executive Orders

2.1 E.O. 10831, ESTABLISHMENT OF THE FEDERAL RADIATION COUNCIL

August 14, 1959, 24 Fed. Reg. 6669 (1959)

By virtue of the authority vested in me as President of the United States, it is hereby ordered as follows:

Section 1. (a) There is hereby established the Federal Radiation Council (hereinafter referred to as the "Council").

(b) The Council shall be composed of the Secretary of Defense, the Secretary of Commerce, the Secretary of Health, Education, and Welfare, and the Chairman of the Atomic Energy Commission.

(c) The Chairman of the Council shall be designated by the President, from time to time, from among the members of the Council.

Section 2. The Council shall advise the President with respect to radiation matters directly or indirectly affecting health, including matters pertinent to the general guidance of executive agencies by the President with respect to the development by such agencies of criteria for the protection of humans against ionizing radiation applicable to the affairs of the respective agencies. The Council shall take steps designed to further the interagency coordination of measures for protecting humans against ionizing radiation.

Section 3. The Special Assistant to the President for Science and Technology, or his representative, is authorized to attend meetings of, to participate in the deliberations of, and to advise with, the Council.

Section 4. For the purpose of effectuating this order, each executive agency represented on the Council shall furnish necessary assistance to the Council, in consonance with section 214 of the act of May 3, 1945, 59 Stat. 134 (31 U.S.C. 691). Such assistance may include detailing employees to the Council to perform such duties consistent with the purposes of this order as the Chairman of the Council may assign to them. Upon the request of the Chairman of the Council, the heads of executive agencies shall so far as practicable provide the Council information and reports relating to matters within the cognizance of the Council.

Section 5. The Council may seek technical advice, in respect of its functions, from any source it deems appropriate.

DWIGHT D. EISENHOWER

Regulations

EPA's Office of Radiation Programs has not promulgated any regulations. Guidelines for Uranium Miner Exposure are found under the "Guidelines and Reports" section. Reorganization Plan No. 3 of 1970 transferred to EPA certain powers previously held by the Atomic Energy Commission. EPA is currently establishing a viable "interface" with the AEC. AEC regulations which EPA is reviewing, are those that deal with releases of radiation to the environment and are currently found under Title 10 of the Code of Federal Regulations. Chapters of particular interest are ch. 20 ("Standards for Protection Against Radiation"), and ch. 30 ("Rules of General Applicability to Licensing of Byproduct Material").

Guidelines and Reports

4.1 BACKGROUND MATERIAL FOR THE DEVELOPMENT OF RADIATION PROTECTION STANDARDS, STAFF REPORT OF THE FEDERAL RADIATION COUNCIL

4.1a BACKGROUND MATERIAL FOR THE DEVELOPMENT OF RADIATION PROTECTION STANDARDS, REPORT NO. 1, STAFF REPORT OF THE FEDERAL RADIATION COUNCIL, MAY 13, 1960

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SECTION 1.—INTRODUCTION

1.1 It was recognized soon after discovery of x-rays that exposure to large amounts of ionizing radiation can produce deleterious effects on the human body so exposed. More recently, because of increased scientific knowledge and widespread use of radiation, additional attention has been directed to the possible effects of lower levels of radiation on future generations. Various scientific bodies have made recommendations to limit the irradiation of the human body. Probably the oldest of such scientific bodies are the International Commission on Radiological Protection (ICRP) and the U. S. National Committee on Radiation Protection and Measurements (NCRP). Initially, these bodies were interested primarily in the irradiation of those exposed occupationally, but recently they have been concerned with those who are non-occupationally exposed.

1.2 The ICRP was formed in 1928 under the auspices of the International Congress of Radiology. It is now a Commission of the International Society of Radiology. This Commission has published recommendations about every three years except for the period 1938–49.

1.3 The NCRP was initially organized as the "Advisory Com-

mittee on X-ray and Radium Protection." The initial membership included representatives from the medical societies, x-ray equipment manufacturers, and the National Bureau of Standards. After the reorganization in 1946, the name was changed to the National Committee on Radiation Protection and Measurements, and additional representatives from other organizations having scientific interest in the field were included. The recommendations of this group have generally been published as National Bureau of Standards handbooks. Since 1947, 15 such handbooks have been made available on different aspects of the protection problem.

1.4 In 1956, the National Academy of Sciences-National Research Council published reports of its Committees on the Biological Effects of Atomic Radiation. For genetic protection this group recommended a maximum gonadal dose up to age 30 both for individual radiation workers and for the entire population. These committees published a revised report in 1960.

1.5 The recommendations of the NCRP, ICRP, and NAS-NRC are in rather close agreement. The recommendations of the NCRP have received wide acceptance in the United States.

1.6 In 1955, The United Nations established a Scientific Committee on The Effects of Atomic Radiation (UNSCEAR). The report of this group (UNSCEAR, 1958) summarized the current knowledge on effects of radiation exposure and on human exposure levels. The report also contained predictions on exposures from testing of nuclear devices under various assumptions.

1.7 The Joint Committee on Atomic Energy of the Congress held public hearings in 1957 on "The Nature of Radioactive Fallout and Its Effects on Man." The same committee held hearings in 1959 on "Industrial Radioactive Waste Disposal;" on "Employee Radiation Hazards and Workman's Compensation;" on "Fallout from Nuclear Weapons Tests;" and on "Biological and Environmental Effects of Nuclear War." In all these hearings, questions of the biological effects of radiation and of protection against excessive exposure to radiation received attention.

1.8 The Federal Radiation Council was formed in 1959 (Public Law 86–373) to provide a Federal policy on human radiation exposure. A major function of the Council is to ". . . advise the President with respect to radiation matters, directly or indirectly affecting health, including guidance for all Federal agencies in the formulation of radiation standards and in the establishment and execution of programs of cooperation with States. . . ." This staff report is a first step in carrying out this responsibility. As knowledge of the biological effects of radiation increases, and as factors

making exposure to radiation desirable undergo change, modifications and amplifications of the recommendations of this staff report probably will be required.

[p. 1]

SCOPE

1.9 This staff report seeks to provide some of the required radiation protection recommendations. These recommendations are of an interim nature. Periodic review will be necessary to incorporate new information as it develops. This staff report includes recommendations for additional research which will provide a firmer basis for the formulation of radiation standards.

1.10 Only peacetime uses of radiation which might affect the exposure of the civilian population are considered at this time. The staff report also does not consider the effects on the population arising from major nuclear accidents. Only that portion of the knowledge of the biological effects of radiation that is significant for setting radiation protection standards is considered. Published information by the groups indicated above is summarized in this staff report; details may be found in the original reports.

1.11 Certain of the classes of radiation sources are now regulated by various Federal agencies. There are some which are not so regulated but which should be considered as aspects of the overall exposure of the population to radiation. Therefore, this staff report will consider exposure of the population from all sources except those excluded above.

PREPARATION OF THE STAFF REPORT

1.12 In preparation of this staff report, a series of meetings was arranged with staff members of various Federal agencies concerned with radiation protection. The objectives of this first phase in the preparation were (1) to determine the problems unique to these agencies, (2) to define problem areas not adequately covered by current radiation protection recommendations of the National Committee on Radiation Protection and Measurements or the National Academy of Sciences; and (3) to discuss the implications of the above recommendations.

1.13 A second phase in the preparation of this staff report consisted of a series of consultations with Governmental and nongovernmental scientists in the various fields involved in the development of radiation protection standards. The purposes of these consultations were (1) to discuss the bases upon which recommendations on radiation protection standards are formulated; (2) to obtain the most up-to-date information on the biological ef-

fects of radiation and (3) to elucidate some of the physical and chemical problems involved in the establishment and implementation of radiation protection standards.

1.14 These consultations and the reports of the groups indicated above provided a basis for the present staff report.

DEFINITIONS [1]

1.15 The activity of a radioactive source is the number of nuclear disintegrations of the source per unit of time. The unit of activity is the curie. The weight of a radionuclide corresponding to one curie is directly proportional to the half-life and to the atomic weight of the nuclide. For example, uranium-235 with a half life of 7.07×10^8 years requires about 4.65×10^5 grams to obtain an activity of one curie. The mass-activity relationship for iodine-131 with a half life of 8.0 days is about 8.05×10^{-6} grams to produce a curie.

1.16 Any biological effect produced by radiation depends on an absorption of energy from the radiation. For many years the roentgen (r) [1] has been used as a measure of x- and gamma ray absorption in body tissue. Conceptually, the roentgen is only a measure of the ability of x- or gamma-rays to produce ionization in air and not of the absorption of these rays in tissue. More recently (ICRU H62, 1957), the absorbed dose of any radiation has been defined as "the energy imparted to matter by ionizing particles per unit mass of irradiated material at the place of interest." The unit of absorbed dose is the rad. However, under most conditions and to the accuracy required for radiation protection purposes, the number of roentgena is numerically equal to the number of rads in soft tissues.[2]

[p. 2]

1.17 The same absorbed dose of different kinds of radiation does not, in general, produce the same biological effect. Different kinds of radiation have a different relative biological effectiveness (RBE). It is well known that the RBE for a particular kind of radiation may be dependent upon such factors as the specific biological effect under consideration, the tissue irradiated, the radiation dose, and the rate at which it is delivered. Recommendations on radiation protection have generally assumed a specific RBE for each kind of radiation.[3] The RBE dose is equal numerically to the

[1] For detailed definitions see ICRU, H62, 1957.

[2] For the accuracy of this approximation and the conditions for its applicability, see the International Commission Radiological Units (ICRU) Report (1957).

[3] Currently used values of RBE (relative to x-rays) are one for x-rays, gamma rays and electrons, 10 for neutrons, and protons up to 10 Mev, and alpha particles, and 20 for heavy recoil nuclei. These are for chronic irradiation and should be used only for protection purposes.

product of the dose in rads and an agreed conventional value of the relative biological effectiveness. The unit of RBE dose is the rem, considered to be that dose which is biologically equivalent to one roentgen of x- or gamma-radiation. For example, one rad of neutrons is conventionally considered to be equivalent to 10 roentgens of gamma radiation, and this equivalence is expressed by saying that the RBE dose is 10 rem. However, it has been found experimentally that the same RBE dose of different radiation sources in the bone does not always produce the same biological effect. A numerical factor called the relative damage factor is introduced to take care of this difference. Thus, in the case of bone, the biological effect is represented by the product of the RBE dose and the relative damage factor.

1.18 Radiation Protection Guide (RPG) is the radiation dose which should not be exceeded without careful consideration of the reasons for doing so; every effort should be made to encourage the maintenance of radiation doses as far as below this guide as practicable.

1.19 Radioactivity Concentration Guide (RCG) is the concentration of radioactivity in the environment which is determined to result in whole body or organ doses equal to the Radiation Protection Guide.

CONTENTS OF THE STAFF REPORT

1.20 The following sections of this staff report provide information on human exposure from radiation sources, the present state of our knowledge on the genetic and somatic effects of radiation, the problems of formulating radiation protection standards from available scientific data, the basic and derived radiation protection guides, recommendations for further work by the Federal Radiation Council, and indications as to areas in which research is needed in order to fill gaps in our basic knowledge.

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SECTION II.—KNOWLEDGE OF RADIATION EFFECTS

INTRODUCTION

2.1 This section includes general summaries of knowledge of the biological effects of ionizing radiation on animals and man particularly pertinent to the problem of defining radiation protection standards. As noted in Section I (paragraph 1.13), this staff report was developed following a series of consultations with scientists who provided recent information on the genetic and somatic

effects of radiation. The consultations included the experimental evidence in animals and the observations on humans, as well as the assumptions, hypotheses, and unknowns in the relationships of radiation dose and effects.

DEFINITIONS OF GENERAL BIOLOGICAL FACTORS

2.2 Radiation exposure can be described in terms of the part of the body exposed, the total dose delivered, the dose rate, and the duration of the exposure. Acute exposure is usually considered an exposure to a single event of irradiation or a series of events in a short period of time. Continuous or fractionated exposures over a long period of time are considered chronic exposures.

2.3 Acute exposure can result in both immediate and delayed biological effects. Chronic exposure is usually considered to produce only delayed effects. The acute radiation syndrome will not be discussed in detail since it is applicable primarily to accidental or emergency exposures. The literature documents this effect (refer to Table 2.1).

2.4 The available data describing immediate effects on humans include:

(1) Medical data on effects following the therapeutic use of external sources such as X-rays, and of radionuclides such as radium, iodine, etc.;

(2) Occupational data on exposure of radiologists, cyclotron workers, and workers in nuclear industry as a result of certain accidents; and

(3) Population observations on atomic bomb survivors and on persons irradiated by heavy fallout in the vicinity of the Marshall Islands.

2.5 Most delayed effects, in man, are inferred from consideration of experimental knowledge in animals, from available epidemiological statistical observations, and from a limited number of medical and industrial case observations. Delayed effects are those effects observable at some time following exposure. The effects considered are: (1) genetic effects; and (2) somatic effects, including the appearance of leukemia, skin changes, precancerous lesions, neoplasms, cataracts, changes in the life span, and effects on growth and development. The delayed effects produced by ionizing radiation in an individual are not unique to radiation and are for the most part indistinguishable from those pathological conditions normally present in the population and which may be induced by other causes.

2.6 External radiation exposure refers to that exposure resulting from sources outside the body. Classifications of external radiation exposure are made on the basis of the portions of the body irradiated: whole body or partial body.

2.7 Internal radiation exposure is that which comes from radio-

active materials incorporated within the body following their ingestion, inhalation, injection, or absorption.

2.8 A critical organ is defined as that organ of the body whose damage by a given radiation source results in the greatest impairment to the body. Criteria appropriate to the determination of critical organs for external or internal exposure are: (1) the radiosensitivity of the organ, i.e., the organ damaged by the lowest

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TABLE 2.1.—SUMMARY OF EFFECTS RESULTING FROM ACUTE WHOLE BODY EXTERNAL EXPOSURE OF RADIATION TO MAN [1]

0–25 r	25–100 r	100–200 r	200–300 r	300–600 r	600 or more
No detectable clinical effects.	Slight transient reductions in lymphocytes and neutrophils.	Nausea and fatigue, with possible vomiting above 125 r.	Nausea and vomiting on first day.	Nausea, vomiting and diarrhea in first few hours.	Nausea, vomiting and diarrhea in first few hours.
			Latent period up to two weeks or perhaps longer	Latent period with no definite symptoms, perhaps as long as one week.	Short latent period with no definite symptoms in some cases during first week.
Delayed effects may occur.	Disabling sickness not common, exposed individuals should be able to proceed with usual duties.	Reduction in lymphocytes and neutrophils with delayed recovery.	Following latent period symptoms appear but are not severe: loss of appetite, and general malaise, sore throat, pallor, petecheae, diarrhea, moderate emaciation.	Epilation, loss of appetite, general malaise, and fever during second week, followed by hemorrhage, purpura, petecheae, inflammation of mouth and throat, diarrhea, and emaciation in the third week.	Diarrhea, hemorrhage, purpura, inflammation of mouth and throat, fever toward end of first week.
	Delayed effects possible, but serious effects on average individual very improbable.	Delayed effects may shorten life expectancy in the order of one per cent.	Recovery likely in about 3 months unless complicated by poor previous health, superimposed injuries or infections.	Some deaths in 2 to 6 weeks. Possible eventual death to 50% of the exposed individuals for about 450 roentgens.	Rapid emaciation and death as early as the second week with possible eventual death of up to 100% of exposed individuals.

[1] Adapted from "The Effects of Nuclear Weapons," U S. Government Printing Office, 1957.

dose; (2) the essentialness or indispensability of the organ to the well-being of the entire body; (3) the organ that accumulates the greatest concentration of the radioactive material; and (4) the organ damaged by the radionuclide enroute into, through, or out of the body. For a given situation, determination of the criteria chosen for internal emitters is subject to judgment based on var-

ious factors; physical (particle size), chemical (solubility; the compound form of a given chemical element), ecological (the environmental balance of calcium or iodine) and physiological (differential uptake by age and the metabolic condition of the organism).

2.9 On the basis of comparisons with known effects of x-rays in humans and animals, radioisotope experiments in animals, and the radium and other radioisotope observations in man, certain organs in the body appear to be the critical organs under various conditions of irradiation. These organs, and examples of the delayed effect of irradiation upon these organs are: (1) gonads: genetic alterations; (2) bone marrow and other blood forming organs: the leukemias, aplastic anemia; (3) whole body: life span shortening; (4) single organs (bone, skin, thyroid, etc): neoplasms, and other

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pathological effects; and, (5) the lens of the eye: cataracts. These are the effects ordinarily considered when assigning guides for external and internal exposure.

2.10 A body burden of a radionuclide is that amount present in the body. The organ burden is the amount present in an organ.

2.11 Multiple exposures may occur from diverse sources, e.g., from several sites of deposition and from several routes of entry into the body. Sources may be external or internal. An external source may irradiate the whole body or a portion of the body. An internal source or sources may produce radiation exposure in several ways: (1) a single radionuclide may produce whole body exposure or a single organ exposure; or (2) single nuclides may affect different body organs simultaneously; or lastly, (3) multiple radionuclides may be absorbed thereby producing whole body, or single, or several organ exposures.

BIOLOGICAL VARIABILITY

2.12 Variations of effect with age depend upon metabolic, cellular, and organ differences. Some factors of significance are:

(1) Radiation sensitivity of a cell in terms of chromosomal aberration depends on the stage of mitosis when radiation is delivered. Damage becomes manifest when cell division takes place; the more divisions that occur, the greater probability of manifestation.

(2) During fetal life there is a greater sensitivity to radiation and the median lethal dose (LD_{50}) of fetuses is less than that of adults. After birth, in certain strains of mice the radiosensitivity decreases until maturity is reached, and then remains relatively constant until late in life when radiosensitivity again rises sharply.

(3) Gross malformations may result from small amounts of radiation deliv-

ered to the developing embryo. The production of clinically evident malformations in fetal life depends on the stage of embryonic organ development when the radiation is delivered.

2.13 Although few data are available on human populations it is presumed from the analogy of other stresses that undernourishment and strain may affect radiosensitivity. Anemia renders mice more sensitive to radiation. However, from the evidence on radiobiological studies of tissue culture, and on the induction of mutations and biochemical effects, it has been shown that a reduction in oxygen tension produces a lowered response to radiation.

2.14 There is a scarcity of information on the effect produced by the simultaneous presence of bone-seeking nuclides (radium, strontium) and bone infection or bone conditions in which the mineral states are altered due to aging.

2.15 The minimum doses causing biological effects detectable by current methods differ among species. However, for most mammals the LD_{50} dose varies by less than an order of magnitude.[1] Comparison of genetic effects between the fruit fly and the mouse can be cited. The x-ray induced mutation rate per r per average gene locus varies by a factor of 15 between fruit fly and mouse. For mouse spermatogonia the sensitivity of the mutation rate per locus (at 90 r per min.) from least to most sensitive locus may vary by a factor of 30; while in the fruit fly the specific locus sensitivity varies by a factor of two. Our ability to extrapolate confidently the data from animal experience to man depends on whether there is sufficient evidence of similarity between humans and the experimental animals.

2.16 Within an individual, the range of tissue sensitivity varies by more than an order of magnitude from the more sensitive (blood forming organs) to the more resistant (the adult nervous system).

2.17 The apparent sensitivity of a tissue to damage depends on the index of measurement used, e.g., the biochemical effect, the mitotic effect, the cellular effect, or states of tissue derangement, tumor production, or life span changes. As examples, (1) for changes in the lens of the eye, one may measure the clinical appearance of cataracts years after radiation injury, or one may measure the immediate biochemical changes; (2) lymphocyte damage may be measured by the reduction in the number of lymphocytes, or by the structural changes in the cell nucleus, or by the chemical change in nuclear DNA content; and (3) the effect on bone marrow may be measured by the appearance of immature

[1] The term, an order of magnitude, as used in this staff report refers to a factor of ten.

cells in the blood stream or by the rate and amount of Fe-59 incorporated in the cells.

2.18 In an individual adult it is difficult or in some cases impossible to detect effects from a single external exposure of less than 25 to 50 r, and from continuing exposure to levels even about two orders of magnitude greater than natural background. It should be noted, however, that changes in the nucleus of lymphocytes have been described in some adult radiation workers after two weeks of exposure to levels as low as 0.20 r per week.

2.19 Man's sensitivity to radiation depends on his age at the time of exposure. Considering his long life, the time periods of importance are: for genetic considerations, the interval from conception to the end of the reproductive period; and for somatic effects, the total lifetime during which delayed effects may become manifest.

(1) Embryonic neuroblasts in vitro are sensitive to a dose of radiation of orders of magnitude smaller than the dose which kills adult nerve cells.

(2) In fetal organ systems, effects (e.g., delayed effects on blood forming tissues) may be evident with 2–10 r acute exposure, and skeletal effects with 24 r.

(3) The child's thyroid is more sensitive than the adult thyroid. Cancer of the thyroid has been observed in children after an acute external exposure of approximately 150 r. In adults the same effect has been observed only after exposures of more than several hundred r.

(4) A study of the differential sensitivity for induction of skin tumors by x-ray (used in the treatment of hemangiomas) showed that children were 3–4 times more sensitive than adults.

(5) In adults, the presence of disease states may be correlated with the later appearance of neoplasms, apart from the effects of radiation. This has been reported in ankylosing spondylitics who later developed leukemia.

2.20 In addition to differential sensitivity there are important factors of differential uptake between adults and children. Some of these are:

(1) The rate of deposition of skeletal calcium and the fractions of equilibrium Sr-90/Ca ratio for accretion and for remodeling of bone are each a complex function of age; each may vary by a factor of at least 10 from newborn to age twenty.

(2) The uptake of iodine per gram of tissue by the normally functioning thyroid gland differs widely between children and adults.

(3) Different age groups are exposed to different environmental radiation conditions. For example, because of differences in dietary intake an infant may be exposed to different total amounts of Sr-90 radiation than an adult.

2.21 There is a current definition for the "average" adult—"Standard Man." The "Standard Man" is defined in such terms as organ size, distribution of elements in the body organs, fluid intake and excretion, and air balance. Each of these factors differs

between adults and children, and also differs among various age groups of children. Therefore, there is a need for a comparable definition of "Standard Children" to be used in developing Radioactivity Concentration Guides.

DOSE-EFFECT RELATIONS FOR GENETIC AND SOMATIC EFFECTS

2.22 Among the possible dose-effect relationships at least three possibilities have been considered in the literature: (1) a linear, no threshold concept; (2) a nonlinear, no threshold concept; and (3) a nonlinear, threshold concept. Among the parameters which must be considered in the relationships are the total dose, the dose rate, the biochemical or clinical manifestation of effect, and the period of time in which the effect becomes manifest.

2.23 The evidence for linearity and no threshold for induction of mutations in the genetic material is based on work with fruit flies and mice. The method consists in the scoring of the occur-

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rence of specific traits in progeny of irradiated animals. In studying irradiated males, the experimenter can determine the genetic manifestations in the progeny corresponding to the stages of development of spermatogonia and spermatozoa in the parent. This can be accomplished by selecting suitable time intervals between irradiation and mating. Experimentally it measures visible traits in the offspring (such as coat color changes in the mouse or failing of pupal development in the fruit fly). These traits are then attributed to specific gene mutations in the parent germ cell. The effect is therefore considered to be directly proportional to the number of genetic changes induced in the parental germ cell. It is well demonstrated that the curve showing effect against dose in experimental animals is linear within the range of 37 r to 1,000 r total acute dose, and geneticists believe that there is no threshold for the genetic effect. The finding of a dose-rate dependence effect (chronic exposure is approximately one-fourth as effective in inducing mutations as is acute exposure) probably represents partial recovery at low dose-rates and does not conflict with the no threshold concept.

2.24 For somatic effects, unlike genetic mutation effects, there is no general agreement among scientists on the dose-effect relationships. It is known, for example, that the nature of the dose-response curve can be altered drastically by changes in the external environment of the organism. In addition, although radiation may be the initiating event, there may be other promoting factors operating before the manifestations are evident. Such factors men-

tioned in the literature include cocarcinogens: hormones, chemicals, and viruses.

2.25 Because of the complexities of animals and man, there may be many mechanisms by which radiation produces effects. One of the mechanisms may be the induction of a primary effect by radiation which, after a sequence of secondary events over a period of time, leads to a clinical manifestation such as neoplasia. In this hypothesis, the induction of the primary effect could be consistent with a linear no threshold concept of dose-effect relationship, yet the successive manifestations of the damage could be nonlinear and not consistent with a threshold concept. Therefore, in the case of neoplasia, the demonstration of linearity or nonlinearity for the gross effect does not predict the presence or absence of a threshold dose for the primary insult.

2.26 There are some somatic effects in animals which do not support a linear no threshold concept (e.g., acute mortality; splenic, thymic and testicular atrophy, incidence of lens opacity, duration of depression of mitotic activity, and incidence of heterologous tumor implants). However, the experiments demonstrating these effects were not performed primarily to examine threshold theory and were done at high dose ranges above 100 r. Considering the diversity of results in different species of animals, extrapolations to man for these effects at low doses should be made with caution.

2.27 In man, the chief evidence for a linear dose-effect relationship for somatic effects comes from some of the leukemia studies (see Table 2.2). Data are available for acute exposures above 50 rads in adults. Predictions of the incidence of leukemia in the general population per rad of exposure have been made by extrapolations from these data. Certain of these predictions have involved the assumption that the occurrence of radiation-induced leukemia per rad will remain constant for the life of the population, the assumption of no difference among effects of irradiation of various parts of the body and the assumption of a constant probability of occurrence of leukemia per rad of acute and chronic exposure. There is no direct evidence that justifies extrapolation from the condition of acute exposure to one of a low dose chronic external exposure, or to the radiation from internal emitters.

2.28 In summary, the evidence is insufficient to prove either the hypothesis of a damage threshold or the hypothesis of no threshold in man at low doses. Depending on the assumptions used, forceful arguments can be made either way. It is therefore prudent to adopt the working principle that radiation exposure be kept to the lowest practical amount.

GENETIC EFFECTS

2.29 The following working assumptions have been derived from the evidence considered in this staff report: (1) radiation induced mutations, at any given dose rate, increase in direct linear

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proportion to the genetically significant dose; [2] (2) mutations, once completed, are irreparable; (3) almost all the observed effects of mutations are harmful; (4) radiation-induced mutations are, in general, similar to naturally occurring mutations; and, (5) there is no known threshold dose below which some effect may not occur.

2.30 The linearity is established in fruit flies down to 25 r and is confirmed in mouse spermatogonia down to 37 r, but there is no direct evidence for linearity below these doses. Although the studies in animals do not involve a period comparable to the 30-year period of chronic irradiation in humans, the hypothesis used in this staff report is that the mutations induced by small dose rates of radiation to human reproductive cells are cumulative over long periods of time. Under this assumption, irradiation of the whole population from any source is expected to have genetic consequences.

2.31 In addition to genetic effects in the progeny of an exposed individual, attention must be given to the total genetic effect on the population. Within the working assumptions above, the total genetic load is independent of the distribution of the exposure within the population. Therefore, when radiation protection standards are established for large numbers of exposed persons, limitations may be imposed by considerations of population genetics (the effects on population as a whole).

2.32 Major areas of uncertainty in genetic information for man, with regard to both population and individual genetics, are the estimations of: the spontaneous and induced mutation rates; the genetic load of mutations; the influence of man-made factors (mortality reduction brought about by health protection, for example) operative in natural selection; and the influence of synergism of gene interaction.

2.33 Formulation of radiation protection standards has been based in part on estimates of genetic hazards to man. These in turn have been based chiefly on data from mice and from acute

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[2] The genetically significant dose to the individual is considered to be the accumulated dose to the gonads weighted by a factor for the future number of children to be conceived by the irradiated individual. The genetically significant dose for the population is defined as the dose which, if received by every member of the population, would be expected to produce the same total genetic injury to the population as do the actual gonad doses received by the various individuals.

rather than chronic irradiation. Results of recent experiments considered pertinent to the evaluation of genetic effects are:

(1) The genetic effects under some radiation conditions may not be as great as those estimated from the mutation rates obtained with acute irradiation. It has been shown in mice that fewer specific locus mutations are produced in spermatogonia and oocytes by a low dose rate (chronic gamma radiation at 90 r per week) than by a high dose rate (acute irradiation at 90 r per minute) for the same total accumulated dose above 100 r. A similar effect has been reported for sex-linked lethal mutations in the oogonia of fruit flies. The number of mutations induced in spermatogonia by chronic irradiation is smaller (about one fourth) than that induced by acute irradiation.

(2) Studies being planned may define quantitatively the dose-effect relationship with fractionated, low doses delivered at high dose rates. These data may be of direct significance to medical practice using fluoroscopy and radiography.

(3) Life shortening has been demonstrated in the offspring of male mice irradiated at high doses.

(4) Radiation doses of 25 r appear to produce chromosomal breakage in human cells grown in tissue culture.

Items (1) and (2) above indicate that in the preparation of radiation protection standards based on the genetic effects, consideration should be given to dose rate as well as total dose.

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LEUKEMIA

2.34 Information useful for study of the risk of leukemia among exposed persons is based on experimental data on animals, some observations on humans, and the rise in crude leukemia mortality rates observed in many countries. There is more information available on the correlation between radiation exposure and leukemia incidence in man than there is for other radiation effects.

2.35 Most of the reported investigations indicate that the incidence of leukemia among irradiated persons increases with the exposure dose. A definitely increased incidence of leukemia occurs after one large whole body dose or a large accumulated dose. The available evidence applicable to the general population under the assumptions listed in paragraph 2.27 indicates a linear correlation of dose to incidence down to about 50 rads of whole body acute exposure. The specific findings in other studies vary with the type of exposure and are speculative at lower doses. There have been reports that, during prenatal life, fetal doses as low as 2–10 r may double the incidence of leukemia, although other studies have not confirmed this finding. Prenatal exposure may be quite different from exposure of adults and there is no evidence that these low dose levels may be effective later in life. There is also no satisfactory evidence that chronic lymphatic leukemia is produced by

radiation although this is the form of leukemia primarily responsible for the rising crude leukemia rate in the general population.

2.36 Past studies of leukemia-radiation correlations in human populations have limitations imposed by retrospective epidemiological techniques as well as factors inherent in the nature of leukemia. Epidemiological techniques which are retrospective in type are limited by the:

(1) difficulty of determination of the radiation dose;
(2) absence of uniform radiation recording methods;
(3) difficulty of associating medical and vital statistical records: i.e., such studies introduce biases inherent in the techniques of interview, questionnaire, or manual searching;
(4) statistical selection of cases which may be weighted with those cases having a disease related in some way to leukemia; and
(5) the fact that the numbers of persons in the population groups studied are usually small.

2.37 The following factors produce difficulties in the evaluation of the findings on possible radiation produced leukemia:

(1) Although leukemia has the advantage of the use of simpler procedures for the diagnosis of the disease than are available for other neoplastic diseases, it has the disadvantage that the classification of various types of leukemia is subject to debate. It is thus difficult to compare statistics of different origins.
(2) The hematological effects such as are seen in leukemia can also be observed in other diseases which may or may not be radiation induced.
(3) Leukemia ascribed to radiation cannot be distinguished from leukemia due to other causes.
(4) Leukemia in humans is a rare disease whose crude annual incidence in the population-at-large is about 5 per 100,000 persons.
(5) The various forms of leukemia have different clinical courses and the relative incidence of cytologic types varies with age. Not all the various forms of leukemia can be placed in one category since it does not appear that the chronic lymphatic form may be induced by radiation.

2.38 Considerations of the above factors require that epidemiological studies include large samples of exposed subjects, provide mechanisms for follow-up over long periods of time, provide adequate control groups, and provide ascertainable exposure and outcome.

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2.39 Conclusions drawn from the studies listed in Table 2.2, indicate that:

(1) Under certain conditions, there is a clear association between leukemia and prior radiation exposure. This association has been demonstrated only where the exposures are high. The effect may be discerned at doses of the order of several thousand r for prolonged intermittent exposure over many years in normal adults; or, doses of the order of 500 r for bone marrow exposure in adult males with pre-existing disease; or, doses of the order of 50–100 r

for acute whole body exposure in a general population of all ages; or at acute dose possibly as low as 2–10 r to the fetus;

(2) Long follow-up periods are required to assess cancer experience following irradiation.

(3) Little data exist on leukemia incidence among women exposed to therapeutic doses of radiation from radium or x-rays;

(4) It is unlikely that retrospective studies will definitely solve the question of the shape of the dose-response curve at low levels of exposure or the existence of a threshold. Additional retrospective studies on population groups receiving high doses of radiation may provide refined quantitative knowledge. There are only a few prospective studies reported that can provide information on both the quantitative and qualitative effects of chronic low doses received over many years;

(5) The risk of any one individual developing leukemia is small even with relatively large doses. However, when large populations are exposed, the absolute number of people affected may be considerable.

2.40 The leukemogenic effect of internally deposited isotopes requires special mention.

Strontium.—We have no documented evidence that bone depositions of strontium in humans have produced leukemia. Statements that radiostrontium is leukemogenic are based solely upon studies in mice. Since leukemia is a common disease spontaneously occurring in certain strains of mice, one cannot accept this observation as necessarily applicable to man.

Thorium.—Only a few cases of leukemia following thorium injections for medical diagnosis have been reported in the literature. The leukemias have occurred with latent periods up to 20 years. However, the dose calculations for irradiation of the bone are complicated by the presence of thorium daughters.

Radium.—No cases of leukemia have been reported in those persons who have had radium deposited in their bones, even though some persons developed bone cancers. This is not unexpected in view of the fact that radium deposited in bones results in a relatively small dose to the bone marrow.

Iodine.—Only a few cases of leukemia have been reported in patients receiving iodine-131 for the medical treatment of hyperthyroidism and cancer of the thyroid. It would seem that well planned large population studies on persons who received radioiodine medically would contribute to the knowledge of the leukemogenic and carcinogenic effect at the levels used.

2.41 The possibility of the detection of low doses of radiation by hematological techniques is deserving of high priority. The most sensitive indicator available at present may be the counting of binucleated lymphocytes, but the technique is not now practical for wide applications because of the need to examine large numbers of cells on hematology slides. The development of practical

electronic devices to screen these cytologic blood specimens should be encouraged. The prognostic significance of the observations of morphological changes in the lymphocytes will be elucidated by long term follow-up of selected study and control groups.

OTHER NEOPLASMS AND PREMALIGNANT CHANGES

2.42 Clinical evidence indicates that irradiation in a sufficient amount to most parts of the body may produce cancer as a delayed effect although no inference of an incidence-dose relationship should be drawn. Some of the evidence in humans is based on:

(1) skin cancers among radiologists in the early history of the use of x-ray;
(2) thyroid cancers in children irradiated in the neck region;

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(3) Leukemia among children who were exposed in utero to x-ray for pelvimetry of the mother;
(4) Bone sarcomas in radium dial painters and other persons exposed to radium-226;
(5) Liver sarcomas in medical patients given thorotrast; and
(6) Bronchogenic cancer in miners occupationally exposed to radon and its daughters.

2.43 The bulk of the evidence lies in the work done on animals with external whole and partial body doses, as well as with internally absorbed radionuclides. Both benign and malignant lesions have been produced, although the evidence is incomplete and there is no simple relationship between carcinogenesis and dose. Mice are more sensitive to all modalities of radiation exposure than man for the induction of skin and ovarian tumors and leukemia.

TABLE 2.2.—TYPES OF STUDIES THAT HAVE BEEN DONE IN HUMANS ON LEUKEMIA AND RADIATION

I. Occupational	1. Cases not reported in the literature. 2. Scattered reports in the literature. 3. Radiologists. 4. Uranium miners.
II. Therapeutic and Diagnostic ...	1. Children receiving partial body exposure to x-rays: a. Infants treated for thymus gland enlargement. b. Infants similarly treated who had normal size thymus glands. c. Children treated for pertussis and lymphoid hyperplasia. d. Children treated for other benign conditions of many different types. e. Children treated for neuroblastoma. 2. Adults: a. Patients with ankylosing spondylitis given x-ray treatment to the spine. b. Radiologists receiving partial body x-ray radiation over many years. c. Patients treated for hyperthyroidism with x-ray; and radioiodine d. Patients treated for polycythemia and radiophosphorus. 3. Prenatal· Maternal prenatal exposure to diagnostic doses of x-rays.
III. General Population	Japanese people who received whole body irradiation from A-bomb explosion.
IV. Internal Emitters	1. Thorotrast. 2. Radium. 3. Iodine. 4. Phosphorus.

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2.44 It is pertinent to the discussion of a threshold dose or dose rate dependence for carcinogenesis to describe two theories of radiation carcinogenesis: the direct somatic mutation effect and the theory of indirect effect.

2.45 The direct theory postulates that the incidence of tumors induced by radiation in a population is proportional to the dose. This theory states, by direct analogy with genetic theory, that the somatic cell may incur chromosomal changes which become evident on cell division and lead to a neoplastic change. So far it is impossible to test this on human populations. Animal experiments show that the effect is much more complicated. The theory of indirect effect considers that there are tissue and hormonal factors which mediate the occurrence and site of development of tumors following irradiation.

2.46 The evidence bearing on the two theories may be summarized as:

(1) The long latent period for development of tumors may indicate that they develop only after a series of premalignant changes or states of tissue alteration have taken place. As yet unknown is the sequence of events and how the events are correlated with dose or dose rate. For example, the deposition of

radium in bone may produce slight changes in the bone at lower levels, necrosis at increasing levels, and bone tumors at high levels.

(2) In man, the latent period for cancer induction by radiation is often from 10 to 20 years, although for leukemia the period may be from 5 to 10 years after a single whole body irradiation. For chronic exposure at low dose rates, it would appear that the latent period is longer.

(3) Tissue changes induced by radiation need not occur at the site of injury. There are indications that the critical factors may include responses of the whole body to the radiation, rather than the radiation effect upon a single cell exclusively; examples of this principle are:

(a) The primary cause of tumors such as mouse lymphomas or mouse ovarian and pituitary tumors may be disturbances of an endocrine gland.

(b) Mouse experiments show that shielding of a part of the body will prevent the appearance of radiation leukemia, or that shielding one ovary will prevent a tumor from developing in the other.

(c) Cells grown in tissue culture (where growth inhibitory factors which may be present in the body are lacking) have a tendency for malignant variance entirely apart from considerations of radiation. Under certain conditions, attempts to transplant a tumor to an animal are unsuccessful until the animal has developed an autogenous metastatic malignancy.

(d) The presence, in an animal or man, of a cancer is associated with an increased probability of occurrence of a second cancer, in a similar or other tissue.

2.47 At chronic low levels of radiation the combination of varying susceptibility with age and the long latent period for tumor induction complicates an analysis of dose-effect relationships. Experimental animals must be maintained for long periods of time and there must be large numbers of animals to achieve statistically significant results.

2.48 In man, the data seem to show that one must be exposed to relatively high external exposure levels to show a carcinogenic effect in certain tissues. For example, available information indicates that cancers have been observed in persons receiving doses in the range of 500 to 2,500 r to the skin. The thyroid carcinogenic dose has been shown to vary greatly with age and may be one of the most sensitive indices in children of the carcinogenic property of radiation.

BONE TUMORS FROM INTERNAL EMITTERS

2.49 The two sets of crucial data on the problem are the human radium experience and the animal experiments, now underway, on comparative toxicity of radium, strontium, plutonium, and thorium.

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2.50 Historically, the evidence leading to the first establishment of a radium body burden limit, for occupational workers only, was based on physical data and a small amount of biomedical informa-

tion on a few dozen adults. Summaries of new data on several hundred living persons have been reviewed for this report. Persons studied were workers who absorbed pure radium (or radium plus mesothorium and radiothorium) in the course of radium dial painting, or were patients treated medically with radium waters, or were persons drinking public water supplies relatively high in radium. The information permits the comparison of effect on bone with body burden estimates of radium-226-equivalent present after periods as much as 35 years of prolonged exposure. Present physical techniques of estimation of body burden are based on radon breath analysis, whole body gamma counting, excreta analysis, and the essay of teeth and bone. The complications of dosimetry in some of the dial painters arising from the presence of both radium and mesothorium are partially resolved, but the exact equivalence of radium to mesothorium is not well established.

2.51 The clinical evaluation of the living persons studied includes a history, physical examination, and radiographic and pathological studies. The criteria of effect are based on the differential diagnosis of x-ray evidence of bone changes, the presence of pathological fractures, bone tumors, changes in teeth or signs of other fiindings.[3] The period between exposure and observation of skeletal changes by x-ray examination is usually determined by the date of examination rather than the date of onset of skeletal changes. Rarely are serial radiographs available over a period during which the changes first appear. In other than special microradiographic studies, there is no evidence available of cellular or biochemical effects.

2.52 A major problem in evaluation of the hazard of radium exposure is the definition of a clinically significant effect. If clinically significant effect is defined in terms of significant injury to the person, it may include only the symptomatic factors which impair the person's daily living, energy or longevity (tumors and pathological fractures). If clinically significant effect is defined in terms of detectable changes, the index may be radiographic evidence discernable to a competent physician. In either case the changes indicate varying degrees of late effects and are observed after many years of exposure.

2.53 It can be hypothesized that, on a cellular level, the effect is linearly proportional to body burden. Gross demonstrable changes plotted against dose could follow a normal distribution even though the effect at the cellular level were linear.

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[3] The indices used are: absence or presence of x-ray evidence of localized areas of bone rarefaction, areas of increased density, abnormal trabecular pattern, severe aseptic necrosis, pathological fracture; abnormal tooth structure; sarcoma; carcinoma at other sites; leukemia; anemia.

2.54 In attempting to define effects which can be extrapolated to the general population the following unknowns are apparent:

(1) the sequence of events during the latent period, as a function of dose;
(2) the radiobiological effect on small volumes of tissue;
(3) the site of injury and the degree of recovery from injury;
(4) the elapsed period of time from cellular injury to the evidence of the effect and the possible interrelationships among bone osteitis, necrosis, pathological fracture, and bone tumors;
(5) the variance in biological sensitivity with age; also, the variance in bone physiology at all ages in humans, the structure of the organic matrix, the crystalline and vascular structure, and the differences in homogeneity of distribution of the bone seeking nuclides;
(6) the variations of body burden with time in the individual after a single or fractionated intake; more radium retention data are needed in humans to permit determination of body burdens at times less than the 35 years after initial intake;[4]

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(7) information from large populations on the correlation between the average background body burden of radium and the natural population incidence of osteogenic sarcoma; and
(8) uncertainties in the RBE for alphas on chronic exposure.

2.55 There is no evidence to establish definitely the presence or absence of a threshold for the effects of radium deposition in bone. However, the first appearance of minimal radiographic changes in bones of adults exposed to radium occurs with a residual body burden (measured several decades after exposure) of the order of 0.2 microgram. Whether this effect is attributable to radium is in doubt because of the absence of matched age group controls. There seems to be no doubt that, at 0.5 microgram burden, changes in adult bones, shown by radiographs, are manifest in some individuals. Radiographic changes are always seen above 0.8 microgram, and there is agreement that bone tumors begin to occur at about a burden of 0.8 to 1.0 microgram. Teeth changes were noted in a young person with a body burden of 0.15 microgram. Within the limits of the time duration for the effect and the relatively small numbers of individuals studied, there is a range of radium body burdens within which any specific clinically significant effect occurs. The body burdens among individuals with a given effect appear to be statistically normally distributed. At increasing burdens the curve of body burden against effect follows a steeply rising slope. At body burdens below 0.1 microgram, which is the area of our interest, prediction is hazardous.

2.56 It would appear that current radium studies (among the

[4] Some recent data suggest that, for oral intake of radium waters, the measured body burden of humans drinking the waters is about one-sixth of the body burden predicted by currently used biological models.

groups described in paragraph 2.50) may have a maximum number of about 2,000 persons available for body burden measurements. These numbers may be insufficient on a statistical basis to assure extrapolation of the probability of occurrence of an effect to the general population. It remains to be demonstrated whether or not, on an individual basis, the diagnostic methods used on humans can show "damage" below 0.1 microgram. This is true even if one studies a larger number of individuals, particularly if the group is composed of children with differential sensitivity or of older persons with intercurrent infections or increased bone fragility. It is hoped that pertinent data on the question of threshold will be forthcoming from animal studies. There is suggestive evidence that the length of the latent period for the development of "clinically significant findings" may increase as the body burden decreases. If this be true, depending on the age of the animal, the latent period may be greater than the remaining lifetime of the animal.

2.57 With other bone seeking radionuclides there are not as extensive data in man on biological effects as for radium. Therefore, it has become the custom to relate the biological effects of other bone seeking radionuclides to those of radium. Evidence for the relationships has been obtained at high doses in animals. For example, mouse experiments showed the ratio of body burden of radiostrontium to radium for the same tumor induction to be approximately 10 to 1. However, newer biological data in man on the skeletal escape and excretion of the radium daughter radon require further adjustment in the ratio when it is applied to man. Although bone tumors have been produced by radiostrontium in animals, it should be noted that no cases of bone tumors have been demonstrated in man as due to strontium-90.

LIFE SPAN SHORTENING

2.58 Radiation exposure does not produce in the individual a pattern of effects specific to radiation. Life span shortening has been demonstrated in animals by comparisons of mean life span between exposed and nonexposed groups. This involves observations continued to death of the cohorts of the irradiated individuals while controlling the intercurrent factors which might affect the study groups.

2.59 The experimental evidences of radiation effect on life span in animals includes:

(1) Exposure of animals to chronic high doses, in general, decreases their life span. A plot of the percentage survival vs. time yields an S shaped curve in both the exposed group and the unexposed controls. The mean survival time,

however, is shortened in the exposed group to the total dose. While the evidence is not conclusive, it appears that in mice the mean life span is lengthened at very low dose rates, at a total dose of about 100 r. However, in every piece of experimental evidence (except at about the 100 r level in animals described above) there is life span shortening at dosages above approximately 100–300 r total body dose. At such dosages the life span shortening in mice is in the order

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of 1 to 1.5 percent of total life span per 100 r total dose. The evidence for linearity of the dose-effect curve in other species (dogs) rests on only a few animals and, again, at doses greater than 100 r. There is suggestive evidence that protracted doses above 200 r have a lesser effect than a single acute dose. With protracted radiation, in some experimental animals, it appears that there is some life shortening from the range of 200 to 100 r, but that the chronic radiation is about 4 to 5 times less effective per r than a single very large dose. For radiations other than x- or gamma-rays the RBE for this effect is uncertain.

(2) A decrease in the median lethal dose is observed when pre-irradiated animals are exposed to a second course of irradiation in comparison to controls not previously irradiated. This decrease in the LD_{50} depends upon the elapsed time between first and second exposure.

2.60 The facts concerning acute injury and delayed effects described above might lead to the following assumptions; viz:

(1) The total injury produced by radiation varies linearly with the dose.

(2) Partial recovery from acute injury occurs, but an irreparable effect remains.

(3) Recovery from reparable injury is an exponential process. The recovery rate varies with the dose rate and whether the exposure is whole body or partial body. The exponential rate of recovery following acute exposure is the cumulative expression of the fact that different parts of the body repair at different rates.

(4) Irreparable injury is accumulated in proportion to the total dose. It may be measured by life shortening, or, for experimental purposes, by a reduction in the median lethal dose. Residual injury of irradiation occurs irrespective of the age of the animal when irradiation is begun.

2.61 Examination of the specific causes of death shows that the same causes of death, apart from tumors, occur generally in the same proportion but sooner in the irradiated than in the unirradiated individuals. It is to be noted that observations are sometimes made of some muscular impairment or accumulation of connective tissue, but these cannot be quantitated. Studies of performance tests may shed more light on this.

2.62 The effects from large acute exposure may conform to the assumptions outlined above but all of these assumptions may not be applicable to the effects of a chronic daily dose of 1 r. Lacking in our knowledge is a formulation of indices of recovery following irradiation at these low levels. The experimental use of the median lethal dose to measure recovery requires pre-irradiation doses of at least 40–50 r to yield definitive data with reasonable numbers of animals.

2.63 Little is known of the nature of the pathological process responsible for life shortening. One theory considers, by analogy to genetic mutations, that the accumulation of radiation injury to the somatic cell chromosomes leads to reproductive death of a somatic cell. This process occurring in a large number of cells may be responsible for the aging of an organism. In the present state of knowledge it is premature to attribute the complex processes of aging to somatic mutations. It seems that extensive studies of the causes of death shown by animal experiments and human surveys may further our knowledge of chronic radiation effects in man.

2.64 In humans the evidence for life span shortening is limited. Mortality studies among U.S. physicians, comparing the effects of occupational exposure of radiologists with other physicians and with the general male population, have not produced definitive answers to the question of whether a decrease in life span occurred in the radiologists. For the general population, estimations of a non-specific life shortening effect from whole body radiation continues to be based on experiments on animals exposed to large doses. There are as yet no data in man to answer the questions of quantitative estimates of life shortening effect per rad of whole body exposure. Equally in question are the existence of a threshold dose, or the dose fractionation effect for exposures commonly experienced by the general population.

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GROWTH AND DEVELOPMENT

2.65 Only a portion of developmental defects are attributable to genetic origins. It is necessary to distinguish within the totality of congenital defects, those attributable to changes in the genetic material; and of the latter, those which may be due to environmental causes, including radiation. Some geneticists estimate that 10 percent of fertilized ova have some congenital defect (malformation) detectable during that generation. Of this 10 percent, about 0.1 are ascribed to an environmental insult to the developing fetus (such as rubella and other viruses, toxic chemicals, maternal nutritional disturbances, radiation, etc.); about 0.1 are clearly due to simple mendelian genetic systems; and about 0.1 are due to chromosomal aberrations of a particular type. The great bulk of the remaining 0.7 are believed to be due to complex genetic systems whose expression depends on environmental variables operating on alterations of the homeostatic balances of life. Radiation may be one of a myriad of possible causes of congenital defects.

2.66 In animals, effects of radiation on prenatal embryonic de-

velopment have been demonstrated from 25 r to several hundred r or more, and are closely correlated with the time of gestation at which radiation is given. The prenatal effects include (1) failures of uterine implantation leading to a maternal missed period, or to miscarriages and stillbirths; (2) alterations induced in the varying stages of development of fetal organs which lead to a high neonatal death rate and abnormalities at term; and (3) late stage manifestations, such as subtle changes in physiological states.

2.67 Parts of the human brain and eye are probably susceptible to injury until the last months of gestation. In mice, acute doses of 25–30 r (whole body x-rays) to the fetus produce discernible skeletal defects. It is known from bone studies on human stillbirths that radiostrontium may pass through the placental barrier and become fixed in the skeleton and other organs. It is presumed that exposure of this type may in the early stages of the growing embryo resemble whole body exposure.

2.68 Effects of irradiation on postnatal development are also described. Although it is known that regeneration and repair processes are sensitive to radiation, more quantitative studies under conditions of whole or partial body exposure are needed. In rats, quantitative studies show that growth in body weight is decreased as a result of about 24 r per week whole body irradiation. Localized irradiation of the epiphysis of bones at high doses in humans and animals will cause measurable shortening of the bones. Studies on children exposed to the atomic bomb in Japan indicate that there may be depression of growth rates after irradiation as has been observed in animals. However, little is known in either animals or humans of the after-effects of whole or partial body irradiation in the young in comparison to mature animals, and of the subtle changes induced in their physiological efficiency.

SKIN EFFECTS

2.69 Knowledge of effects to the skin of localized exposure to radiation of low penetrating power has accumulated since the discovery of x-rays. The early promulgation of a "tolerance dose" of x-radiation was established by quantitating skin reactions (erythema) with dose. Among early radiologists the chronic radiation produced erythema, dermatitis, and skin cancers. Under modern practices, these conditions should no longer be seen.

EYE EFFECTS

2.70 Injury to the lens serves as a sensitive detecting index of the effect of radiation on the eye. Lens opacities (cataracts) have

occurred following exposure of the eye in animals (exposed to neutrons and x-rays), and cyclotron workers, nuclear physicists, and Japanese survivors at Hiroshima and Nagasaki. In man, the minimal single dose producing cataracts is estimated to be approximately 200 rads acute exposure of x- or gamma-rays. In animals the production of cataracts depends on the age and health of the animal, the exposed lens area, and the RBE of the source

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of radiation. There are no quantitative dose-effect data relating the incidence of cataracts late in life in humans or animals to the acceleration of aging processes.

SUMMARY

1. Acute doses of radiation may produce immediate or delayed effects, or both.

2. As acute whole body doses increase above approximately 25 rems (units of radiation dose), immediately observable effects increase in severity with dose, beginning from barely detectable changes, to biological signs clearly indicating damage, to death at levels of a few hundred rems.

3. Delayed effects produced either by acute irradiation or by chronic irradiation are similar in kind but the ability of the body to repair radiation damage is usually more effective in case of chronic than acute irradiation.

4. The delayed effects from radiation are in general indistinguishable from familiar pathological conditions usually present in the population.

5. Delayed effects include genetic effects (effects transmitted to succeeding generations), increased incidence of tumors, life span shortening, and growth and development changes.

6. The child, the infant, and the unborn infant appear to be more sensitive to radiation than the adult.

7. The various organs of the body differ in their sensitivity to radiation.

8. Although ionizing radiation can induce genetic and somatic effects (effects on the individual during his lifetime other than genetic effects), the evidence at the present time is insufficient to justify precise conclusions on the nature of the dose-effect relationship especially at low doses and dose rates. Moreover, the evidence is insufficient to prove either the hypothesis of a "damage threshold" (a point below which no damage occurs) or the hypothesis of "no threshold" in man at low doses.

9. If one assumes a direct linear relation between biological effect and the amount of dose, it often becomes possible to relate

very low dose to an assumed biological effect even though it is not detectable. It is generally agreed that the effect that may actually occur will not exceed the amount predicted by this assumption.

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III. SOURCES OF RADIATION EXPOSURE

3.1 For convenience, the exposure of persons to radiation will be divided into three classes: (a) exposures from natural sources; (b) exposures from man-made sources other than environmental sources; and (c) exposures from environmental contamination. Where data are available, the exposures of various critical portions of the body are indicated separately. Of special interest are the gonadal dose because of its genetic significance and the bone marrow dose because of possible leukemogenesis. Therefore, the following discussions center their attention on the genetically significant and bone marrow doses as examples of the general problem.

NATURAL SOURCES

3.2 Table 3.1 lists the doses received by persons in the United States from natural sources. The principal exposures from radiation sources outside of the body (external sources) and from sources inside of the body (internal sources) are listed separately.

3.3 The dose from cosmic rays for 38 principal cities in the United States was determined from data on the variation of cosmic ray dose with altitude [1] (Solon et al—1959). As most of the large centers of population are near sea level, the mean dose to the population of the United States from cosmic rays is nearer the lower than the upper limit.

3.4 The dose from terrestrial external gamma rays was estimated by subtracting the cosmic ray component from measurements of the sum of the two components (Solon et al, 1959) and applying an approximate correction (0.6) for the average shielding of the outer tissues of the body. The resulting range of values includes mean values for 38 of the principal cities of the United States. However, it should be noted that doses obtained at different locations within a city varied in several cases by a factor of 2 or 3 for the limited data available. In part, this may be due to shielding of heavy structures or the proximity of structures whose building materials contained small quantities of gamma emitting nuclides.

[1] Variation of the dose from cosmic rays with latitude is small compared to that with altitude.

3.5 When doses from internal sources are added, it appears (Table 3.1) from the limited data available that the radiation dose to soft tissue from all natural sources varies by at least a factor of 2 in the United States.

MAN-MADE SOURCES OTHER THAN ENVIRONMENTAL CONTAMINATION

3.6 Exposure of persons to man-made radiation other than environmental contamination arises principally from (1) exposures received during medical procedures, (2) exposures received by radiation workers during their working hours, (3) exposures to persons in the vicinity of medical and industrial radiation sources (environs), and (4) exposure produced by other sources, such as radium dialed watches, television sets, etc. Table 3.2 summarizes the estimated per capita mean marrow doses and genetically significant doses to the population from man-made sources other than environmental contamination. The per capita dose is the sum of all of the doses received by the population divided by the number of individuals in the population. The annual genetically significant dose to the population is the average of the gonadal doses received by the individuals each weighted for the expected number of children to be conceived subsequent to the exposure.

3.7 For the occupational exposure it is assumed that as much as a half of one per cent of the population might be exposed in the future to as much as an average annual dose of 4 rems. Both estimated figures are high because the fraction of the population occupationally exposed to radiation and the annual dose they re-

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ceive at the present time is considerably less than that assumed in Table 3.2. There are presently only about 66,000 radiation workers out of a total employment approximating 120,000 in the Atomic Energy Commission and its contractors (see Table 5.1) and perhaps 250,000 persons occupationally exposed to x-rays in medical application. Persons in these two areas plus the industrial radiography field probably do not constitute more than 0.2 per cent of the population at the present time. Morgan (1959) indicates that the average annual exposure of radiation workers at Oak Ridge National Laboratory is 0.4 r, and at Hanford, 0.2 r (see Table 5.1). In the fields of medical applications and industrial radiography, the annual doses received by most radiation workers falls within the range of 0.5 to 5 rems. Most of them probably receive doses in the lower half of this range but a few possibly receive more than 5 and some less than 0.5 rems. Thus, the average annual dose for

all radiation workers is probably much less than the 4 rems assumed for the calculation at the present time.

3.8 For exposure of persons in the environs it is assumed that one per cent of the population might be involved and they would have an annual dose of as much as 0.5 rems. This assumption concerning per capita dose from the exposure of environs is probably larger than will be obtained in the foreseeable future. The fraction of the population assumed is quite large and it is unlikely that the average individual will receive as much as 0.5 rem per year.

3.9 Unfortunately, there are no data on the mean marrow dose from medical therapy, but it is obvious that diagnostic x-rays contribute considerably to the total exposure from man-made sources other than environmental contamination. While diagnostic x-rays are an important clinical tool, the practitioner of the healing arts should always attempt to balance the risk against the gain for each exposure. He should also assure himself that the most modern techniques are being used in order that the dose is reduced as much as practicable. Current recommendations of the NCRP (H54, 1954 and H60, 1955) indicate methods by which the gonadal dose can be minimized. If these recommendations are observed the bone marrow dose will also be minimized.

MAN-MADE ENVIRONMENTAL CONTAMINATION

3.10 Sources of environmental contamination may result from fallout after the explosion of nuclear devices and during the use and processing of fuels for reactors. There are other sources which contribute relatively smaller amounts to environmental contamination.

3.11 Environmental contamination from fallout has received considerable attention over the past decade. When there is a nuclear explosion in the megaton range, the gases cool so slowly that a major portion of the fission products enter the stratosphere where they are distributed widely. Some fission products drift back into the troposphere before losing their radioactivity and are deposited in patterns which depend at least in part upon meteorological conditions. This final fallout, however, takes a long time to drift back to earth so that the fission products from this stratospheric source consist mainly of the long-lived nuclides. For nuclear explosions in the kiloton range, the heat of the fireball is considerably less so that the fission products do not reach the stratosphere but stay in the troposphere. About half of the radioactive material from the troposphere comes back to the earth in about three weeks and most of the fallout reaches the earth in

about three months (UNSCEAR p. 99, 1958). From such a fallout, many of the nuclides are of short half-life.

3.12 According to reported estimates,[2] the genetically significant per capita dose in the United States from both external and internal radiation from fallout of cesium-137 will be about 53 millirem in 30 years providing nuclear weapons testing in the atmosphere is not resumed after the cessation at the end of 1958. It was also reported that the per capita mean marrow dose in the United States would be, under the same conditions, about 331 millirem in 70 years from cesium-137 and strontium-90. For continued testing at the same rate as in the previous 5 years, it was estimated that the above numbers should be multiplied by a factor of 8. Other estimates (UNSCEAR 1958 and Feeley 1960) are somewhat lower.

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3.13 Under normal operating conditions, most industries in the nuclear engineering field, including the use of reactors, do not now release activity which will give significant contributions to the population dose.

3.14 It is usually considered very unlikely that the core of a reactor would melt down accidentally and release fission products. This possibility, however remote, is considered in designing a reactor. Modern reactors are designed with a containment shell which would permit only a very small portion of the fission products, from a melt-down, to contaminate the environment. However, according to the best engineering estimates, this and other containment provisions will not trap all of the activity. An additional major reduction in the activity released by the shell would substantially increase the cost of the reactor.

3.15 Plants used for the processing of spent fuel elements have a larger potential for contaminating the environment. Here the fuel element is dissolved and the radioactive material is liberated from the fuel element. However, the amount of material treated at any one time is much less than the material present in a reactor. In this process, fission product gases, such as radioactive iodine, bromine, xenon, and krypton are released from the fuel element. Most of the other radionuclides remain in the solutions. Some nuclides, such as cesium-137 and strontium-90, may be separated out for other uses. The remainder of the radionuclides are now stored in huge tanks. Such storage is, of course, expensive.

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[2] W. Langham and E. C. Anderson, Fallout from Nuclear Weapons Tests, Hearings of the Joint Committee on Atomic Energy, Congress of the United States, May 1959, p. 1061 ff.

SUMMARY

3.16 From a limited survey it appears that the human annual gonadal, soft tissue, and bone marrow doses from natural sources may be from 80 to 170 millirem (see Table 3.1).

3.17 The estimated annual genetically significant dose from all man-made sources except environmental contamination probably is about 80 to 280 millirem. The per capita annual mean marrow dose is probably greater than 100 millirem, although no data are available on the contribution from medical radiation therapy. The genetically significant dose and the mean marrow dose are each of the order of the dose received from natural sources. Diagnostic x-rays provide a substantial contribution to these totals (see Table 3.2).

3.18 It has been estimated [3] that fallout will contribute about 53 millirem to the genetically significant per capita dose of the population in 30 years if nuclear weapons testing in the atmosphere is not resumed after the cessation at the end of 1958. If testing were to continue at the same rate as in the previous 5 years, it was estimated that the above number should be multiplied by a factor of 8. The estimated corresponding per capita mean marrow doses for 70 years are 331 millirem and 2648 millirem respectively.

3.19 Under normal operating conditions, most industries in the nuclear engineering field, including the use of nuclear power plants do not now release activity which will give a significant contribution to the population dose.

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TABLE 3 1 —ANNUAL RADIATION DOSES [1] FROM NATURAL SOURCES

Irradiation	Millirem
By external sources:	
Cosmic rays	32–73
Terrestrial gamma rays	25–75
By internal sources:	
K^{40}	[2] 19
C^{14}	[2] 1.6
Ra^{226}	[3] ?
Total	[4] 80–170

[1] Doses to the gonads and other soft tissue including bone marrow.

[2] Report of United National Scientific Commission on the Effects of Atomic Radiation (UNSCEAR, p. 58, 1958).

[3] Unconfirmed research of Muth et al, Brit. J. of Radiol. Suppl. No. 7, 1957, indicates that the dose may be of the order of 2 millirem per year to the gonads and 5 to 15 millirem per year to other soft tissue.

[4] The lungs may receive an additional dose of from 125 to 1570 millirem per year from radon given off by building structures. The spread is caused by variations in ventilation and differences in building materials (UNSCEAR, p. 58, 1958).

[3] W. Langham and E. C. Anderson, Fallout From Nuclear Weapons Tests, Hearings of the Joint Committee on Atomic Energy, Congress of the United States, May 1959, p. 1061 ff.

TABLE 3 2.—ESTIMATED EXPOSURE FROM MAN-MADE SOURCES (OTHER THAN ENVIRONMENTAL CONTAMINATION) [1]

Irradiation	Average annual genetically significant dose to the population	Per capita annual mean marrow dose
	(millirem)	(millirem)
Medical (exposure of patients):		
Diagnostic x-rays	[2 3] 40–240	[4] 50–100
Therapy	[5] 12	Not available
Internal (radionuclides)	[5] 1	10
Occupational	20	20
Environs	5	5
Other (luminous dials, TV, etc.)	[6] 2	[6] 1–3
Total	80–280	.. ..

[1] Fallout from tests of nuclear weapons is not included (see sub-section on environmental contamination).

[2] International Commission on Radiological Protection (ICRP) and International Commission on Radiological Units and Measurements (ICRU) Joint Study Group Report. Physics in Med. and Biology, 2 107 (1957).

[3] These are probable values.

[4] Report UNSCEAR, p. 66.

[5] Clark, S. H., Bull. of the Atomic Scientists 12 14 (1956). The 12 millirem per year may be an underestimate because patients treated for malignancies are not included. Martin (1958), who assumed that these patients might procreate after treatment, obtained a value of 28 for Australia.

Report of UNSCEAR, p. 11.

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SECTION IV.—THE DERIVATION OF RADIATION PROTECTION STANDARDS

4.1 Shortly after the discovery of x-rays and natural radioactivity in the late 19th century, it became apparent that exposure to sufficiently large doses could produce both acute manifestations and serious later sequelae in man. Based on relatively limited observations on a rather small number of individuals, attempts were made to define a level at which these obvious deleterious effects would not be seen. With increasing scientific knowledge, based on observations of larger numbers of individuals and laboratory animals and a better understanding of radiation damage, these suggested levels have undergone continuous downward revision. For some time, however, the underlying basic philosophy remained unchanged, and radiation protection standards were based on the premise that there was a dose ("tolerance dose") below which damage would not occur. The validity of this basic assumption was subject to increasing question, first in the field of genetic damage, and later in connection with somatic effects. Thus, by 1954, the National Committee on Radiation Protection and Measurements included the following statement in Handbook 59 (NCRP, H59, 1954):

"The concept of a tolerance dose involves the assumption that if the dose is

lower than a certain value—the threshold value—no injury results. Since it seems well established that there is no threshold dose for the production of gene mutations by radiation, it follows that strictly speaking there is no such thing as a tolerance dose when all possible effects of radiation on the individual and future generations are included . . ." and ". . . the concept of a permissible dose envisages the possibility of radiation injury manifestable during the lifetime of the exposed individual or in subsequent generations. However, the probability of the occurrence of such injuries must be so low that the risk would be readily acceptable to the average individual. Permissible dose may then be defined as the dose of ionizing radiation that, in the light of present knowledge, is not expected to cause appreciable bodily injury to a person at any time during his lifetime. As used here, 'appreciable bodily injury' means any bodily injury or effect that the average person would regard as being objectionable and/or competent medical authorities would regard as being deleterious to the health and well-being of the individual . . ."

4.2 With the accumulation of even more quantitative information concerning radiation effects in both animals and humans, and some increased understanding of the mechanisms of radiation injury, the possibility that somatic effects as well as genetic effects have no threshold appeared acceptable, as a conservative assumption, to increasing numbers of scientists. In discussing its recommendations for additional downward revision of the maximum permissible occupational radiation exposure, the NCRP in 1958 stated (2):

"The changes in the accumulated MPD (maximum permissible dose) are not the result of positive evidence of damage due to the use of earlier permissible dose levels, but rather are based on the desire to bring the MPD into accord with the trends of scientific opinion; it is recognized that there are still many uncertainties in the available data and information . . . ," and, "The risk to the individual is not precisely determinable but, however small, it is believed not to be zero. Even if the injury should prove to be proportional to the amount of radiation the individual receives, to the best of our present knowledge, the new permissible levels are thought not to constitute an unacceptable risk . . ."

4.3 Thus, over the past decade or two, there has been an increasing reluctance on the part of knowledgeable scientists to establish radiation protection standards on the basis of the existence of a threshold for radiation damage and on the premise that this threshold lies not too distant from the point at which impairment is detectable in an exposed individual. Although many scientists are prepared to express individual opinions as to the likelihood that a threshold does or does not exist, we believe that there is insufficient scientific evidence on which to base a definitive conclusion in this regard. Therefore, the establishment of radiation protection guides, particularly for the whole population, should take into account the possibility of damage, even though it may

be small, down to the lowest levels of exposure. This involves considerations other than the presence of readily detectable damage in an exposed individual. It also serves as a basis for such fundamental principles of radiation protection as: there should not be any man-made radiation exposure without the expectation of benefit resulting from such exposure; activities resulting in man-made radiation exposure should be authorized for useful applications provided the recommendations set forth in this staff report are followed.

4.4 If the presence of a threshold could be established by adequate scientific evidence, and if the threshold was above the background level and sufficiently high to represent a reasonable working level, a relatively simple approach to the establishment of radiation standards would be available.

4.5 On the assumption that there is no threshold, every use of radiation involves the possibility of some biological risk either to the individual or his descendents. On the other hand, the use of radiation results in numerous benefits to man in medicine, industry, commerce, and research. If those beneficial uses were fully exploited without regard to radiation protection, the resulting biological risk might well be considered too great. Reducing the risk to zero would virtually eliminate any radiation use, and result in the loss of all possible benefits.

4.6 It is therefore necessary to strike some balance between maximum use and zero risk. In establishing radiation protection standards, the balancing of risk and benefit is a decision involving medical, social, economic, political, and other factors. Such a balance cannot be made on the basis of a precise mathematical formula but must be a matter of informed judgment.

4.7 Risk can be evaluated in several different ways before it is balanced against benefit. A logical first step is the identification of known or postulated biological effects. The uncertainty of our present knowledge is such that the biological effects of any given radiation exposure cannot be determined with precision, so it is usually necessary to make estimates with upper and lower limits.

4.8 It is helpful to compare radiation risk to other known hazards in order to maintain perspective or a sense of proportion with respect to the risk. For example, attempts have been made to compare the relative biological risks of various radiation exposure levels to such other industrial hazards as traumatic injuries and to toxic agents employed in industrial processes. Likewise, the possible hazards from various radiation levels have been reviewed in relation to such everyday risks to the general population as the operation of motor vehicles, the possibility of home accidents, and

the contamination of our environment with industrial wastes.

4.9 Effects can also be evaluated in terms of the normal incidence of disease conditions usually present in the population which may also be caused by radiation. In a given instance, the portion of the total number of cases of a given disease which might be attributed to radiation may be quite small. Therefore, the significance of a given radiation exposure can appear superficially to be quite different depending upon whether the data are expressed in terms of the absolute numbers of cases of a given condition which will possibly result, or be expressed as percentages of the normal incidence. However, it is extremely difficult to assign any numerical value to the increase which should be permitted in a given abnormal condition. It is also important to remember that at the present time, any numerical predictions of the number or percentage increase in any given condition anticipated as a result of radiation exposure are based on inadequate data and have extremely limited reliability, even though upper and lower limits can be stipulated.

4.10 The biological risk attributable to man-made radiation may also be compared with that from natural sources. This approach is also important in maintaining perspective. Man and lower forms of life have developed in the presence of such natural sources in spite of any radiation damage that may have been present. Perhaps one of the more important advantages to this approach is that it makes due allowance for qualitative as well as quantitative ignorance of yet unrecognized radiation effects, if such exist. Weighing for various somatic as well as genetic effects is also inherently included. It automatically includes a consideration of the largest body of human and subhuman data on radiation effects. One disadvantage is the degree of conservatism

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introduced by this approach, since it is likely that only a small fraction of the total incidence of disease results from background radiation.

SUMMARY

4.11 Two factors need to be considered in the formulation of radiation protection standards: biological risk, and the benefits to be derived from radiation use. Maximum benefits cannot be obtained without some risk, and risk cannot be eliminated without foregoing benefits. Therefore some balance must be struck between risk and benefit.

4.12 Since an accurate delineation of risk is impossible, a number of approaches can usefully be employed to aid in the evaluation

of risk, and to put risk in reasonable perspective. Each has merit, but such approaches are not mutually exclusive and should be used in combination. An evaluation of benefits in addition to an evaluation of risk is also necessary.

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SECTION V.—BASIC GUIDES

5.1 The philosophical bases for derivation of radiation protection standards have been discussed in Section IV, with the conclusion that they are not mutually exclusive, and that consideration should be given to all in the final selection of numerical values. We believe, however, that there are reasons why the relative emphasis placed on the various bases may appropriately be different for the radiation worker and the general population. Additionally, there appear to be a number of reasons why the exposure to the general population should be less than that for occupationally exposed groups. For example:

(1) There is reason to believe that the child and the infant may be particularly sensitive to radiation damage. Children and infants are not included in occupationally exposed groups.

(2) The number of years of exposure to radiation in the course of employment will be less than the average total life span. Therefore, the total accumulated dose will be less for an individual exposed only during a working life than for an individual exposed at the same level from birth through a normal life span to death.

(3) There is considerable evidence that, at least for certain effects, there is a latent period between the time of exposure and the time at which effects are first detectable. The effects of exposure late in life may not become manifest during the normal remaining life span. Whereas, the effects of exposure early in life may well become manifest during the longer remaining life span.

(4) Industrial workers undergo at least some degree of preplacement selection. It is thus possible to exclude from exposure those individuals with intercurrent disease who might be more susceptible to injury.

(5) Insofar as an individual has a choice of occupations, there is, at least in principle, voluntary acceptance of the small risk potentially involved.

(6) Considerations of population genetics make it desirable to limit gonadal exposure of the whole population.

RADIATION PROTECTION GUIDES FOR THE GENERAL POPULATION [1]

5.2 We believe that the current population exposure resulting from background radiation is a most important starting point in the establishment of Radiation Protection Guides for the general population. This exposure has been present throughout the history of mankind, and the human race has demonstrated an ability to survive in spite of any deleterious effects that may result. Radiation exposures received by different individuals as a result

[1] See Section VII for applicability of these guides.

of natural background are subject to appreciable variation. Yet, any differences in effects that may result have not been sufficiently great to lead to attempts to control background radiation or to select our environment with background radiation in mind.

5.3 On this basis, and after giving due consideration to the other bases for the establishment of Radiation Protection Guides, it is our basic recommendation that the yearly radiation exposure to the whole body of individuals in the general population (exclusive of natural background and the deliberate exposure of patients by practitioners of the healing arts) should not exceed 0.5 rem. We note the essential agreement between this value and current recommendations of the ICRP and NCRP. It is not reasonable to establish Radiation Protection Guides for the population which take into account all possible combinations of circumstances. Every reasonable effort should be made to keep exposures as far below this level as practicable. Similarly, it is obviously appropri-

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ate to exceed this level if a careful study indicates that the probable benefits will outweigh the potential risk. Thus, the degree of control effort does not depend solely on whether or not this Guide is being exceeded. Rather, any exposure of the population may call for some control effort, the magnitude of which increases with the dose.

5.4 Under certain conditions, such as widespread radioactive contamination of the environment, the only data available may be related to average contamination or exposure levels. Under these circumstances, it is necessary to make assumptions concerning the relationship between average and maximum doses. The Federal Radiation Council suggests the use of the arbitrary assumption that the majority of individuals do not vary from the average by a factor greater than three. Thus, we recommend the use of 0.17 rem for yearly whole-body exposure of average population groups. (It is noted that this guide is also in essential agreement with current recommendations of the NCRP and the ICRP.) It is critical that this guide be applied with reason and judgment. Especially, it is noted that the use of the average figure, as a substitute for evidence concerning the dose to individuals, is permissible only when there is a probability of appreciable homogeneity concerning the distribution of the dose within the population included in the average. Particular care should be taken to assure that a disproportionate fraction of the average dose is not received by the most sensitive population elements. Specifically, it would be inappropriate to average the dose between children and adults, especially if it is believed that there are selective factors making

the dose to children generally higher than that for adults.

5.5 When the size of the population group under consideration is sufficiently large, consideration must be given to the contribution to the genetically significant population dose. The Federal Radiation Council endorses in principle the recommendations of such groups as the NAS-NRC, the NCRP, and the ICRP concerning population genetic dose, and recommends the use of the Radiation Protection Guide of 5 rem in 30 years (exclusive of natural background and the purposeful exposure of patients by practitioners of the healing arts) for limiting the average genetically significant exposure of the total U.S. population. The use of 0.17 rem per capita per year, as described in paragraph 5.4 as a technique for assuring that the basic Guide for individual whole body dose is not exceeded, is likely in the immediate future to assure that the gonadal exposure Guide is not exceeded. The data in Section III indicates that allocation of this population dose among various sources is not needed now or in the immediate future.

RADIATION PROTECTION GUIDES FOR OCCUPATIONAL EXPOSURE [2] [3]

5.6 Extrapolation from experience with background radiation to the exposure of the relatively small percentage of the population in the radiation industry is rather unsatisfactory. The difficulties inherent in a careful mathematical balancing of the biological risk against the total gain have been outlined previously. It is possible to estimate the maximum biological damage which could be reasonably expected to result from a given radiation exposure. Using such estimates, a numerical value can be selected at which the radiation risk appears so small as to be justified by even a relatively minor benefit. The NCRP recommends that, for occupational exposure, the radiation dose to the whole body, head and trunk, active blood forming organs, or gonads, accumulated at any age, shall not exceed 5 rems multiplied by the number of years beyond age 18, and that the dose in any 13 consecutive weeks shall not exceed 3 rems. The Federal Radiation Council agrees with the opinion of the NCRP that this dose of ionizing radiation is not expected to cause appreciable body injury to a person at any time during his lifetime. Thus, while the possibility of injury may exist at this dose, the probability of detectable injury is almost certain to be extremely low. Even the use of the more pessimistic assumptions would indicate that the small risk involved is acceptable

[2] See Section VII for applicability of these guides.

[3] In the formulation of Radiation Protection Guides for occupational exposure, special consideration has not been given in this staff report to the possible existence of pregnancy among female workers.

if the gain is of any significance. Fortunately, this level also appears to be one which is not unduly restrictive in ordinary working circumstances.

5.7 There will be individual circumstances under which compliance with this guide would not be feasible. For example, accidents will occur, but the dose received will usually be determined by the [p. 27] nature and conditions of the accident and consequently, the dose does not lend itself to prior planning. In addition to accidents, emergency situations will almost certainly arise, but here too, the dose should be determined by the nature of the emergency.

5.8 It is recognized that, even though small, there is a possibility of biological damage to the individual or his progeny from exposures of less than 5 rem per year. For this reason, radiation exposures should always be maintained at the minimum practicable level. Thus, it seems inadvisable to expose man to radiation if no benefit is anticipated.

5.9 It is to be noted that these recommendations are expressed in terms of rem. While the rad is the basic unit in physical dosimetry, some adjustment for the relative damage produced, even in the same individual, by one rad of gamma-rays as compared to one rad of alpha-rays, for example, must be included. (For a definition of terms and a list of RBE conversion factors, refer to Section I.) Because the value for the RBE may change with newer scientific knowledge, and in view of the relative importance of the total accumulated dose throughout a worker's lifetime, agencies and departments may wish to consider the desirability of maintaining exposure records in such a fashion that recalculation of the accumulated dose in rem can be made at any time when changes in the RBE are justified. One technique would be to keep primary exposure records in terms of rads with a stipulation as to the type of radiation involved.

5.10 One can examine the difficulties arising if the average yearly dose of 5 rems for occupational exposure is increased or decreased. Immediately, it is seen from the information in Section II that one cannot increase this level by as much as a factor of 10 without materially increasing the possibility of biological harm, for this is close to the level at which biological damage has been observed (see paragraphs 2.18 and 2.19).

5.11 Fortunately, it appears that there is no necessity for setting the level this high because the doses actually received are generally much less at the present time. It also appears that these recommended levels do not unduly restrict the beneficial use of radiation. In this connection, it is interesting to examine the

distribution of doses received by radiation workers. Figure 5.1 shows the dose distribution for all AEC radiation workers. Each of these persons was supposed to receive less than 12 r yearly and not more than 5 r when averaged over a number of years. It appears that about 3 persons per 10,000 were involved in accidents, so they received more than 12 r. Only about 3 per 1,000 received more than 5 r and only about 1 per 100 received more than 3 r. Thus, if there is some assurance that those receiving the high doses in any year are not those who receive them every year, the accumulated dose received by each worker during 50 years of radiation employment will be considerably less than 250 r or $50 \times 5r$.

5.12 On the other hand, for economic and other operational reasons, one cannot set the level too low. This is not only because of the cost of extra radiation shielding and other radiation protection measures, but even more because of the difficulty of radiation measurements in regions where the radiation levels vary widely in both time and space.

MEASURABILITY OF EXTERNAL EXPOSURE

5.13 After the selection of Radiation Protection Guides, it is necessary to examine the numbers so selected for their measurability. Measurability here is used in the sense of both sample selection and sample measurement.

5.14 The radiation worker who has a reasonable chance of receiving radiation as a result of his employment can be monitored essentially for the entire time he is on the job. There are instruments available to make measurements with acceptable precision and accuracy at the levels recommended in the Radiation Protection Guides.

5.15 The problem of sampling the human population in the vicinity of an operation which might expose people to radiation may be a very simple one or a very complex one depending on the operation and the distribution of people around the operation. The actual measurement of 0.5 rem per year is usually a difficult one to make. This number is near or below the accurate level of many widely used monitoring instruments. It will take special methods on the part of the monitoring group to measure this number with sufficient accuracy.

TABLE 5.1.—DOSE DISTRIBUTION, AEC RADIATION WORKERS, 1958 [1]

Operation office	Total employees monitored external	Number of annual accumulated exposures in ranges reported														
		0–1	1–2	2–3	3–4	4–5	5–6	6–7	7–8	8–9	9–10	10–11	11–12	12–13	13–14	14–15	15 +
1	3,411	3,359	47	5													
2	3,288	2,785	260	143	47	24	11	9	4	4	1						8
3	11,377	10,825	383	97	32	16	9	6	0	1							3
4	8,089	7,672	373	44													
5	15,018	12,152	1,845	697	198	78	26	5	4	2	1	1	1	3	2	0	
6	1,647	1,533	61	26	9	3	3	0	3	1	3						
7	3,332	2,867	198	117	67	37	9	4	9	15	6	3					
8	10,758	9,774	573	405	6												1
9	3,670	3,479	96	49	21	11	6	5	3								
10	1,394	1,279	82	25	5	1	1										(15 rem ± 40 percent)
11	3,838	3,645	118	44	22	1	1	2	4								
12	85	80	5														
Totals	65,907	59,455	4,041	1,652	407	171	67	31	27	23	11	4	1	3	2	0	12

[1] Data supplied by the Atomic Energy Commission.

ORGAN DOSES

5.16 The recommendations of this staff report include (paragraph 7.10) recommendations of organ doses to the radiation worker which are believed to carry a biological risk not greater than that represented by 5 rem of whole body exposure. These organ doses may also represent a starting point for the derivation of Radioactivity Concentration Guides for the worker.

5.17 The establishment of individual organ doses for the general population involves additional considerations which preclude the possibility of relating them to the Guides for the radiation worker by a simple mathematical relationship that is applicable to all situations. An extension of the recommendations contained in this document in order to provide guidance in the derivation of Radioactivity Concentration Guides for the population is recognized as an important responsibility of the Federal Radiation Council. The complexities are such that a detailed study is required. In order to make our basic recommendations known as soon as possible, it was deemed advisable not to delay the release of our initial recommendations pending the completion of our studies of this and certain other important problems. It appears that there will be no undue risk nor undue hardship if the Federal agencies and departments continue their present practices concerning organ doses for the general population during this interim period. [4]

SUMMARY

5.18 It appears feasible to establish a Radiation Protection Guide for the general population with primary relationship to background radiation levels. For radiation workers a Guide can be established which appears to be generally practicable in its application, and for which even pessimistic predictions of biological damage would be so small as to warrant acceptance if any appreciable benefit results.

5.19 It is not reasonable to establish Radiation Protection Guides which take into account all possible combinations of circumstances. Every reasonable effort should be made to keep exposures below any level selected. Similarly, it is obviously appropriate to exceed the level if careful study indicates that the probable benefits will outweigh the potential risk. Thus, the degree of control effort does not depend solely on whether or not this Guide is being exceeded. Rather, any exposure may call for some control effort, the magnitude of which increases with the dose.

[4] For one approach to this problem, see Recommendations of the International Commission on Radiological Protection, (Sept. 9, 1958), page 16, paragraph 68.

5.20 There are many pertinent reasons why the Radiation Protection Guide for the general population should be lower than that for the radiation worker. Although it is feasible to monitor essentially all exposure to radiation workers, a similar approach to exposure of the general population is not generally feasible. As an operational technique, where the individual whole body doses are not known, a suitable sample of the exposed population should be developed whose protection guide for annual whole body dose will be 0.17 rem per capita per year. It is emphasized that this is an operational technique which should be modified to meet special situations.

5.21 The complexities of establishing guides applicable to radiation exposure of all body organs for the population preclude their inclusion in the staff report at this time. However, current concentration guides now used by the Federal agencies appear appropriate on an interim basis.

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SECTION VI.—DERIVED GUIDES

6.1 This section is concerned with the amount of radioactive material, deposited internally in the body or its organs ("body burdens" and "organ burdens"), which results in a certain physical radiation dose; the amount of environmental contamination with radioactive material which produces a given body or organ burden (Radioactivity Concentration Guides); and accompanying levels in the body excreta.

BODY AND ORGAN BURDENS

6.2 Calculation of the physical dose delivered to a given mass of material as the result of homogeneous distribution of a known quantity of radioactive material throughout a volume is rather straight-forward, and can be made with considerable precision and accuracy. This statement is especially valid if the volume involved is in some standard geometric arrangement, such as a sphere. Similar calculations regarding the physical dose to all or a part of the human body as a result of radioactive material deposited within it will yield data which diverge from the true value for several reasons, including the following:

(1) Distribution of the radioactive material may be nonhomogeneous because of selective distribution between organs or between portions of the same organ. For example, the thyroid gland has a high degree of selective uptake for radioactive iodine as compared to the body as a whole; various major portions of the same bone may contain differing amounts of radium, dependent, at least in part, upon relative growth rates.

(2) At the microscopic level there may be a significant degree of nonhomo-

geneity of deposition. For example, not only will the radium content of various major portions of the bone differ, but within a single major portion different cells or groups of cells may contain widely differing quantities of radionuclides. Likewise, colloidal thorium oxide in the liver may concentrate almost entirely in certain types of cells, leaving other cell types essentially free of contamination.

(3) The shape of the organ or whole body may differ from any simple geometric form. Few organs of the body are truly spherical, and the majority of body organs are not true simple geometric shapes, such as cylinders, cubes, and ellipsoids.

6.3 With highly penetrating radiation, such an energetic gamma rays, the lack of homogeneous distribution may introduce only a relatively small error. However, with radiations of very low penetrating power such as alpha emissions, nonhomogeneity can result in variations by several orders of magnitude (factors of ten) among different cells in the same organ. With regard to the shape of body organs or the whole body, calculations are most often made on the basis of an idealized geometry; this simplification does not introduce serious errors into the calculations. For example, the variations introduced by considering a body organ as a sphere or a cylinder do not introduce errors which are significant compared to the lack of quantitative knowledge concerning biological effects of irradiation.

6.4 Thus, for highly penetrating radiation the relatively straightforward and comparatively simple calculation relating body or organ burden to physical dose provides relatively accurate answers. For less penetrating radiations such as beta rays, the distribution pattern becomes more important, but, giving due regard to this problem, the calculations should ordinarily not err by orders of magnitude. With even less penetrating radiation such as alpha particles, however, the potential errors in the calculations are such as to make the answers clearly suspect.

6.5 As an additional complication, assessment of the biological significance of internally deposited radioactive materials emitting particles with high linear energy transfer, such as alphas, require

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the introduction of a factor for relative biological effectiveness. Thus, the computation of the body burden of beta or gamma emitting material which is biologically equivalent to a given amount of alpha emitting material is fraught with many pitfalls and inaccuracies.

RADIOACTIVITY CONCENTRATION GUIDES

6.6 The measurement of body burdens provides information regarding the extent to which an individual has accumulated radio-

active materials. However, it is not always practical to monitor the body burdens resulting from environmental contamination solely by the use of direct measurements on the human body, its tissues, or excreta. Although certain supplemental information can be obtained by monitoring the organ and body burdens of animals, this approach also has significant practical limitations. Furthermore, it is usually desirable to predict the significance of environmental contamination without waiting until it has accumulated in humans or animals.

6.7 For these reasons, direct data on the levels of environmental contamination are being collected, and it is necessary to have guides or benchmarks against which these environmental contamination levels can be evaluated. The National Committee on Radiation Protection and Measurements and its international counterpart have been publishing, for many years, tables of "maximum permissible concentrations" of radionuclides in air and in water for radiation workers.

6.8 Our understanding of the basis used in the derivation of these values is:

For the majority of radionuclides, the body burden which would result in a specified average annual dose is calculated. The doses used for this purpose are 15 rems for most individual organs of the body, 30 rems when the critical organ is the thyroid or the skin, and 5 rems when the gonads or the whole body is the critical organ. For bone seekers, the estimation is based on the deposition of radioactive material, the relative biological effectiveness, and a comparison of the effective energy release in the bone with the effective energy release from a body burden of 0.1 microgram of radium-226 plus daughters. According to certain calculations, this bone limit may correspond to approximately 30 rems per year. However, the difficulties inherent in estimating the physical dose to organs from alpha emitting isotopes, together with the relatively large amount of direct information on the biological effects of various body burdens of radium, have led the NCRP to use this basis for its recommendations. Once the "permissible body burden" has been decided upon, calculations are made as to the daily intake which, continued over a 50-year period, would not result in an accumulation greater than the permissible body or organ burden. (COMMENT: It is to be noted that the limiting factor is a maximum annual dose rate by the end of the period of exposure. Within this limitation there can be differences in the total accumulated dose depending upon the time taken for the isotope to reach an equilibrium concentration in the body. For example, with the same maximum dose rate, the total accumulated dose with a short half-life bone-seeker could be approximately twice the accumulated dose from a long half-life bone-seeker.) While biological data are introduced where available, the basis of much of these calculations is the so-called "standard man" which provides representative constants for the many variables involved. With regard to the determination of permissible intake by ingestion, among the variables involved are:

(1) The fraction of the ingested material which is absorbed into the blood from the gastro-intestinal tract. (COMMENT: Even for a given radionuclide, this may be quite variable depending upon the individual, the

chemical form in which the radionuclide is present and its relative solubility, and the influence of other materials also present in the gastro-intestinal tract.)

(2) The fraction of material present in the blood which becomes deposited in the critical organ. (COMMENT: Here again, there will be appreciable individual variations and, of course, major differences with various isotopes.)

(3) Rate of uptake and the time of retention of the material in the critical organ.

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6.9 Available biological data were utilized in the NCRP-ICRP computations whenever available. In many cases, the available data are extremely meager, and for certain isotopes, essentially nonexistent. Thus, there is a rather high degree of uncertainty in the calculation of permissible daily intakes, especially for the less adequately studied radionuclides. Even ignoring individual variability, estimates of permissible intakes of ingested radionuclides might vary by factors of 10 to 100 if all of the errors worked in one direction. This, however, is a rather unlikely situation and it appears from the rather meager direct data that, for ingestion, the estimates may be correct within a factor of less than 10.

6.10 Similar considerations are also involved for inhaled radioactive material, except that an estimate of the fraction of inhaled material which reaches the lungs and becomes absorbed into the blood stream is used, instead of the fraction absorbed from the gastro-intestinal tract for ingested material. Estimates and calculations of permissible intakes for inhalation appear much less reliable than for those for ingestion. This results primarily from our rather poor understanding of absorption from the lungs and such added complexities as the effect of particle size. The possible errors with regard to inhaled radionuclides being greater than for ingested radionuclides, it is possible that these intake values could be incorrect by even several orders of magnitude, especially if allowance is made for the existence of variations between individuals.

6.11 Once the NCRP has determined "permissible daily intake" by ingestion or inhalation, "maximum permissible concentrations" in air and water are derived by assuming that the total daily intake of water is 2.2 liters and that the water is uniformly contaminated; and that the total breathing rate is 2×10^7 milliliters per 24 hours and the air is likewise uniformly contaminated. These give values for the "168-hour week" which are then adjusted upward by a factor of 3 for ingestion and a factor of 3 for inhalation to allow for the shorter time exposure involved in a 40-hour week.

6.12 When lower Radiation Protection Guides are selected for the whole population as compared to the worker, this includes allowances for differential sensitivity between children and adults. However, in establishing Radioactivity Concentration Guides, consideration must also be given to the possibly different ratios of intake to uptake for adults and children. Whether this additional difference is sufficiently great to alter the final recommendation cannot be decided without thorough consideration of the specific radionuclide at hand.

6.13 It is also important to note that guides for continuous exposure are not readily converted to guides for short-term exposure by any simple mathematical relationship appropriate to all radionuclides. It is essential that detailed study of this problem be conducted as expeditiously and thoroughly as possible.

6.14 Taking the above factors into account, attention is being given to the establishment of numerical values for Radiation Concentration Guides applicable to the general population for the radionuclides of immediate practical importance to whole population exposure.

DETERMINATION OF BODY BURDENS IN THE INTACT HUMAN

6.15 Because of the many complications inherent in attempts to establish Radioactive Contamination Guides for the environment, attempts to determine body burden in the intact human have been made both as a control measure and as a technique for refinement of our knowledge regarding the relationship of intake to body or organ burdens. Historically, the quantitative determination of the radon content of the exhaled air has been used for decades as a technique for estimating the body burden of radium, the radioactive parent of radon. This particular technique has proved to be an extremely valuable one and the relationship has been substantiated by direct determination of the radium content of the skeleton of a few individuals. There are, however, relatively few radioactive materials which are deposited in body organs in a solid form and which decay to radioactive gaseous daughter products.

6.16 An additional approach has been to determine the radioactive content of the urine and feces in order to provide data to estimate the body or organ burden. This approach eliminates many of the uncertainties involved in converting intake to uptake. It does not, however, provide a direct answer as the excretion rate of any given radioactive material will vary between individ-

uals and within the same individual from time to time. An

important limitation in this technique arises from the fact that the excreta will contain not only a portion of the radioactive material which truly represents the organ burden, but also additional amounts may be present as a result of excretion of radioactivity which is not fixed in the tissues. Thus, measurements of excreta are particularly unreliable at relatively short times after an exposure, or during a continuing exposure. Additionally, the amounts in the excreta will usually be only a very small fraction of the body burden, and thus the quantities involved at levels of interest may be so small as to require extremely sophisticated radiochemical analytical techniques. In spite of these limitations, the relative directness of this approach as compared to the estimation of human exposure by analysis of environmental samples has led to its practical application in certain installations. It is to be noted, however, that the difficulties in the conduct of the procedures and interpretation of the data suggest that this method is not likely to be immediately useful for the study of problems related to exposure of large population groups.

6.17 One other approach to the determination of body or organ burdens is the use of "whole-body counters." This method can provide extremely useful information, but has several important limitations:

(1) The emissions of the radionuclide under consideration must have sufficient penetrating power to pass through intervening body tissues.

(2) The quantities involved must be sufficiently great to yield significant data in a reasonable period of time.

(3) For detection of very low levels, the equipment needed and the capabilities required for its operation can result in practical limitations when attempts are made to apply this technique to large numbers of people.

SUITABILITY AND MEASURABILITY

6.18 At the present time the serious gaps in knowledge which exist with regard to factors involved in the establishment of derived standards make them unsuitable as exact standards. Occasional short-term excesses should not be cause for undue concern. Meanwhile, major effort should be expended to determine the various unknowns, particularly those which relate intake to uptake in the body, with greater accuracy.

6.19 It appears that techniques are available to detect and measure, with adequate accuracy, environmental contamination near the levels currently recommended by the NCRP at least for several of the more important radionuclides. Such measurements are not necessarily simple or inexpensive, but should be within the competence of routine laboratories. However, the procedures in-

volved may be sufficiently complicated that sampling on only a representative portion of the environment is indicated.

ATMOSPHERIC CONTAMINATION IN URANIUM MINES

6.20 In addition to the current recommendations of the NCRP, the American Standards Association (ASA) has been active in the establishment of recommendations in this field concerning air contamination from radon and its daughter products. It appears that quite different approaches are used by these two groups, and the apparent differences are not readily explainable on a simple basis. Rather, there are differences as to whether primary emphasis is placed on dose calculations or on direct biological evidence and operational considerations. These recommendations are expressed in terms of different radionuclides, so that direct numerical comparison is not easily done. It is not immediately apparent that the measurements actually taken in the mines are directly applicable to the NCRP standard. It does appear prudent to assume, however, that significant numbers of individuals are being exposed to radiation in the mines that are in excess of the recommendations of either group. It is desirable, therefore, to make every reasonable attempt, on a continuing basis, to keep the exposures as low as practical. Reduction of the contamination to the recommended levels would be difficult and even unfeasible in some cases.

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6.21 In the meantime, the exposed group is being kept under close medical surveillance. This program should be continued, and expanded if there appears to be any probability of securing additional significant information. In addition, major efforts should be made to better define the radionuclide of principal significance to this problem.

SUMMARY

6.22 Reasonably accurate estimates can usually be made of the amount of internally deposited radioactive material equivalent to any given dose to a critical organ of the body. However, the establishment of guides as to the amount of material which, when taken into the body, will yield such organ burdens is fraught with many uncertainties. Further extension of the estimation to indicate the equivalent amount of environmental contamination is even more uncertain. The potential errors are greater with inhaled contamination than with ingested materials. Extension to individual portions of the environment further compounds the possible errors.

The possibility of multiple radionuclides in the same critical organ must be considered, and appropriate allowances made to be certain that the total dose to that organ is not excessive. At the present time, it therefore does not seem appropriate to consider Radioactive Concentration Guides or other derived standards as anything more than guidance levels, to be applied with judgment and discretion.

6.23 It is critical to note that no single standard is applicable to all situations. For example, the level at which the release of radioactivity from normal operations of a nuclear energy plant should be restricted might be quite different from the levels at which a food or milk supply is destroyed or discarded.

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SECTION VII.—SUMMARY AND RECOMMENDATIONS

7.1 To provide a Federal policy on human radiation exposure, the Federal Radiation Council was formed in 1959 (Public Law 86–373) to "... advise the President with respect to radiation matters, directly or indirectly affecting health, including guidance for all Federal agencies in the formulation of radiation standards and in the establishment and execution of programs of cooperation with States. . . ." The present staff report is a first step in carrying out this responsibility.

7.2 The scope of this staff report is limited to provide some basic radiation protection recommendations which are required. Some of these recommendations should be considered only of an interim nature. Periodic review will be necessary to incorporate new information as it develops. Only peacetime uses of radiation which affect the exposure of the civilian population are considered at this time. A further limitation of the staff report is that it does not consider the effects on the population arising from major nuclear accidents. Certain of the classes of radiation sources are now regulated by various Federal agencies. However, there are some which are not so regulated but which should be considered when dealing with the overall exposure of the population to radiation. Therefore, this staff report considers exposure of the population from all sources except those excluded above.

7.3 Only that portion of the knowledge of the biological effects of radiation that is significant for setting radiation protection standards is considered. Published information is summarized in this report; details may be obtained from reading the original doc-

uments. Among the items of most immediate interest to the establishment of radiation protection standards are the following:

1. Acute doses of radiation may produce immediate or delayed effects, or both.

2. As acute whole body doses increase above approximately 25 rems (units of radiation dose), immediately observable effects increase in severity with dose, beginning from barely detectable changes, to biological signs clearly indicating damage, to death, at levels of a few hundred rems.

3. Delayed effects produced either by acute irradiation or by chronic irradiation are similar in kind, but the ability of the body to repair radiation is usually more effective in the case of chronic than acute irradiation.

4. The delayed effects from radiation are in general indistinguishable from familiar pathological conditions usually present in the population.

5. Delayed effects include genetic effects (effects transmitted to succeeding generations), increased incidence of tumors, life span shortening, and growth and development changes.

6. The child, the infant, and the unborn infant appear to be more sensitive to radiation than the adult.

7. The various organs of the body differ in their sensitivity to radiation.

8. Although ionizing radiation can induce genetic and somatic effects (effects on the individual during his lifetime other than genetic effects), the evidence at the present time is insufficient to justify precise conclusions on the nature of the dose-effect relationship especially at low doses and dose rates. Moreover, the evidence is insufficient to prove either the hypothesis of a "damage threshold" (a point below which no damage occurs) or the hypothesis of "no threshold" in man at low doses.

9. If one assumes a direct linear relation between biological effect and the amount of dose, it then becomes possible to relate very low dose to an assumed

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biological effect even though it is not detectable. It is generally agreed that the effect that may actually occur will not exceed the amount predicted by this assumption.

7.4 To clarify the most critical problem areas concerning quantitative relationships of the effects of irradiation on man, it is recommended that special attention be given to the following research efforts:

1. Increasing epidemiological studies on humans who have been exposed to radiation especially in doses sufficient to offer some probability that deleterious effects can be found.

2. Continuing studies on the mechanism of radiation damage and of interaction of radiation with matter at the cellular level and at the molecular level.

3. Studies designed to determine more adequately the relationship between damage and dose at low total dose and low dose rates. Included should be more precise information at higher levels from which the relationships at lower levels may be inferred.

7.5 The various current sources of radiation exposure to the U. S. population are discussed in Section III. It should be noted that the radiation exposure to patients by practitioners of the healing arts is in the same order as natural background, when averaged over the population. The average exposure to the U. S.

population from activities of the nuclear energy industry, under current practices, is less than that from background by a substantial factor.

7.6 If the presence of a threshold for radiation damage could be established by adequate scientific evidence, and if this threshold were above the background level and sufficiently high to represent a reasonable working level, it would serve as a relatively simple basis for the establishment of radiation protection standards. However, with the accumulation of quantitative information concerning radiation effects in both animals and humans, and some increased understanding of the mechanisms of radiation injury, the possibility that somatic effects as well as genetic effects might have no threshold appeared acceptable, as a conservative assumption, to increasing numbers of scientists. On the basis of this conservative assumption, radiation protection standards must be established by a process of balancing biological risk and the benefits derived from radiation use. Such a balance cannot be made on the basis of a precise mathematical formula but must be a matter of informed judgment. Several approaches towards the evaluation of the risk are discussed in Section IV. These approaches, together with the evaluation of benefits and useful applications by the agences, have been used in the formulation of the recommendations in this staff report.

7.7 Under the working assumptions used, there can be no single "permissible" or "acceptable" level of exposure, without regard to the reasons for permitting the exposure. The radiation dose to the population which is appropriate to the benefits derived will vary widely depending upon the importance of the reason for exposing the population to a radiation dose. For example, once weapons testing in the atmosphere has taken place, the dose to be permitted in lieu of such alternatives as depriving the population of essential foodstuffs might also be quite different from levels used in the planning phases. As another example, for radiation workers, emergency situations will almost certainly arise which make exposures in excess of those applicable to normal operations desirable.

7.8 Also, under the assumptions used, it is noted that all exposures should be kept as far below any arbitrarily selected levels as practicable. There should not be any man-made radiation exposure without the expectation of benefit resulting from such exposure. Activities resulting in man-made radiation exposure should be authorized for useful applications provided the recommendations set forth in this staff report are followed. Within this context, any numerical recommendations should be considered as

guides, and the need is for a series of levels, each of which might be appropriate to a particular action under certain circumstances.

7.9 The term "maximum permissible dose" is used by the NCRP and ICRP for the radiation worker. However, this term is often misunderstood. The words "maximum" and "permissible" both have unfortunate connotations not intended by either the NCRP or the ICRP. This report introduces the use of the term Radiation Protection Guide (RPG). This term is defined as, the radiation dose which should not be exceeded without careful consideration of the reasons for doing so; every effort should be made to encourage the maintenance of radiation doses as far below this guide as practicable.

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7.10 There can, of course, be quite different numerical values for the Radiation Protection Guide, depending upon the circumstances. It seems useful, however, to recommend Guides which appear appropriate for normal peacetime operations. It is recognized that our present knowledge does not provide a firm basis within a factor of two or three for the selection of any particular numerical value in preference to another value. Nevertheless, on the basis set forth in Section V, the following Radiation Protection Guides are recommended for normal peacetime operations:

Type of exposure	*Condition*	*Dose* [1] *(rem)*
Radiation worker:		
(a) Whole body, head and trunk, active blood forming organs, gonads, or lens of eye.	Accumulated dose	5 times number of years beyond age 18
	13 weeks	3
(b) Skin of whole body and thyroid	Year	30
	13 weeks	10
(c) Hands and forearms, feet and ankles.	Year	75
	13 weeks	25
(d) Bone	Body burden	0.1 microgram of radium–226 or its biological equivalent
(e) Other organs	Year	15
	13 weeks	5
Population [2]		
(a) Individual [3]	Year	0.5 (whole body)
(b) Average [3]	30 years	5 (gonads)

[1] Minor variations here from certain other recommendations are not considered significant in light of present uncertainties.

[2] See Section V for reasons why these values differ from those applicable to radiation workers.

[3] See Paragraph 5.4 for applicability of these levels.

7.11 Recommendations are not made concerning the Radiation Protection Guides for individual organ doses to the population, other than the gonads. Unfortunately, the complexities of establishing guides applicable to radiation exposure of all body organs preclude their inclusion in the report at this time. However, current protection guides used by the agencies appear appropriate on an interim basis.

7.12 These guides are not intended to apply to radiation exposure resulting from natural background or the purposeful exposure of patients by practitioners of the healing arts.

7.13 The Federal agencies should apply these Radiation Protection Guides with judgment and discretion, to assure that reasonable probability is achieved in the attainment of the desired goal of protecting man from the undesirable effects of radiation. The Guides may be exceeded only after the Federal agency having jurisdiction over the matter has carefully considered the reason for doing so in light of the recommendations in this staff report.

7.14 This staff report also introduces the term Radioactivity Concentration Guide (RCG) defined as: the concentration of radioactivity in the environment which is determined to result in organ doses equal to the Radiation Protection Guide. Within this definition, Radioactivity Concentration Guide can be established only after the Radiation Protection Guide is decided upon. Any given Radioactivity Concentration Guide is applicable only for the circumstances under which use of its corresponding Radiation Protection Guide is appropriate.

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7.15 As discussed in Section VI, reasonably accurate estimates can be made of the amount of internally deposited radioactive material resulting in any particular organ dose. However, the establishment of guides as to the amount of material which, when taken into the body, will yield such organ doses is fraught with many uncertainties. Further extension of the estimation to indicate the equivalent amount of environmental contamination is even more uncertain. The potential errors are even greater with inhaled contamination than with ingested materials. Extension to individual portions of the environment further compounds the possible errors.

7.16 This staff report, therefore, does not contain specific numerical recommendations for Radioactivity Concentration Guides. However, concentration guides now used by the agencies appear appropriate on an interim basis. Where appropriate radioactivity concentration guides are not available, and where Radiation Protection Guides for specific organs are provided in this staff report,

the latter Guides can be used by the Federal agencies as a starting point for the derivation of radioactivity concentration guides applicable to their particular problems. The Federal Radiation Council has also initiated action directed towards the development of additional Guides for radiation protection.

7.17 Particular attention is directed to the possibly different ratios of intake to uptake for adults and children. There is no simple numerical relationship between Radioactivity Concentration Guides for the worker and for the general population, even if such a simple relationship is adopted for Radiation Protection Guides.

7.18 With particular relationship to the establishment of Radioactivity Concentration Guides, the following research needs (in addition to those listed in paragraph 7.4) are pointed out:

1. Efforts to design better and less expensive radiation monitoring instruments and methods.
2. Extensive studies to determine the relationship between concentration of radioactivity in food, air and water, and the ultimate disposition of these by the body.
3. Studies designed to elucidate the relationship between the intake of radionuclides in various chemical forms and their subsequent uptake. Presently, many compounds of a given radionuclide are treated as though they were the same compound.
4. Studies to elucidate the difference between children and adults in their uptake and disposition of radioactivity and their radiation sensitivity.

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4.1a(1) RADIATION PROTECTION GUIDANCE FOR FEDERAL AGENCIES (MEMORANDUM FOR THE PRESIDENT), FEDERAL RADIATION COUNCIL

May 18, 1960, 25 Fed. Reg. 4402 (1960)

MEMORANDUM FOR THE PRESIDENT

Pursuant to Executive Order 10831 and Public Law 86–373, the Federal Radiation Council has made a study of the hazards and use of radiation. We herewith transmit our first report to you concerning our findings and our recommendations for the guidance of Federal agencies in the conduct of their radiation protection activities.

It is the statutory responsibility of the Council to "* * * advise the President with respect to radiation matters, directly or indirectly affecting health, including guidance for all Federal agencies in the formulation of radiation standards and in the

establishment and execution of programs of cooperation with States * * *"

Fundamentally, setting basic radiation protection standards involves passing judgment on the extent of the possible health hazard society is willing to accept in order to realize the known benefits of radiation. It involves inevitably a balancing between total health protection, which might require foregoing any activities increasing exposure to radiation, and the vigorous promotion of the use of radiation and atomic energy in order to achieve optimum benefits.

The Federal Radiation Council has reviewed available knowledge on radiation effects and consulted with scientists within and outside the Government. Each member has also examined the guidance recommended in this memorandum in light of his statutory responsibilities. Although the guidance does not cover all phases of radiation protection, such as internal emitters, we find that the guidance which we recommend that you provide for the use of Federal agencies gives appropriate consideration to the requirements of health protection and the beneficial uses of radiation and atomic energy. Our further findings and recommendations follow.

Discussion. The fundamental problem in establishing radiation protection guides is to allow as much of the beneficial uses of ionizing radiation as possible while assuring that man is not exposed to undue hazard. To get a true insight into the scope of the problem and the impact of the decisions involved, a review of the benefits and the hazards is necessary.

It is important in considering both the benefits and hazards of radiation to appreciate that man has existed throughout his history in a bath of natural radiation. This background radiation, which varies over the earth, provides a partial basis for understanding the effects of radiation on man and serves as an indicator of the ranges of radiation exposures within which the human population has developed and increased.

The benefits of ionizing radiation. Radiation properly controlled is a boon to mankind. It has been of inestimable value in the diagnosis and treatment of diseases. It can provide sources of energy greater than any the world has yet had available. In industry, it is used as a tool to measure thickness, quantity or quality, to discover hidden flaws, to trace liquid flow, and for other purposes. So many research uses for ionizing radiation have been found that scientists in many diverse fields now rank radiation with the microscope in value as a working tool.

The hazards of ionizing radiation. Ionizing radiation involves

health hazards just as do many other useful tools. Scientific findings concerning the biological effects of radiation of most immediate interest to the establishment of radiation protection standards are the following:

1. Acute doses of radiation may produce immediate or delayed effects, or both.

2. As acute whole body doses increase above approximately 25 rems (units of radiation dose), immediately observable effects increase in severity with dose, beginning from barely detectable changes, to biological signs clearly indicating damage, to death at levels of a few hundred rems.

3. Delayed effects produced either by acute irradiation or by chronic irradiation are similar in kind, but the ability of the body to repair radiation damage is usually more effective in the case of chronic than acute irradiation.

4. The delayed effects from radiation are in general indistinguishable from familiar pathological conditions usually present in the population.

5. Delayed effects include genetic effects (effects transmitted to succeeding generations), increased incidence of tumors, life-span shortening, and growth and development changes.

6. The child, the infant, and the unborn infant appear to be more sensitive to radiation than the adult.

7. The various organs of the body differ in their sensitivity to radiation.

8. Although ionizing radiation can induce genetic and somatic effects (effects on the individual during his lifetime other than genetic effects), the evidence at the present time is insufficient to justify precise conclusions on the nature of the dose-effect relationship at low doses and dose rates. Moreover, the evidence is insufficient to prove either the hypothesis of a "damage threshold" (a point below which no damage occurs) or the hypothesis of "no threshold" in man at low doses.

9. If one assumes a direct linear relation between biological effect and the amount of dose, it then becomes possible to relate very low dose to an assumed biological effect even though it is not detectable. It is generally agreed that the effect that may actually occur will not exceed the amount predicted by this assumption.

Basic biological assumptions. There are insufficient data to provide a firm basis for evaluating radiation effects for all types and levels of irradiation. There is particular uncertainty with respect to the biological effects at very low doses and low-dose rates. It is not prudent therefore to assume that there is a level of radiation exposure below which there is absolute certainty that

no effect may occur. This consideration, in addition to the adoption of the conservative hypothesis of a linear relation between biological effect and the amount of dose, determines our basic approach to the formulation of radiation protection guides.

The lack of adequate scientific information makes it urgent that additional research be undertaken and new data developed to provide a firmer basis for evaluating biological risk. Appropriate member agencies of the Federal Radiation Council are sponsoring and encouraging research in these areas.

Recommendations. In view of the findings summarized above the following recommendations are made:

It is recommended that:

1. There should not be any man-made radiation exposure without the expectation of benefit resulting from such exposure. Activities resulting in man-made radiation exposure should be authorized for useful applications provided in recommendations set forth herein are followed.

It is recommended that:

2. The term "Radiation Protection Guide" be adopted for Federal use. This term is defined as the radiation dose which should not be exceeded without careful consideration of the reasons for doing so; every effort should be made to encourage the maintenance of radiation doses as far below this guide as practicable.

It is recommended that:

3. The following Radiation Protection Guides be adopted for normal peacetime operations:

Type of exposure	Condition	Dose (rem)
Radiation worker:		
(a) Whole body, head and trunk, active blood forming organs, gonads, or lens of eye.	Accumulated dose ..	5 times the number of years beyond age 18.
	13 weeks	3.
(b) Skin of whole body and thyroid	Year	30.
	13 weeks	10.
(c) Hands and forearms, feet and ankles	Year	75.
	13 weeks	25.
(d) Bone	Body burden	0.1 microgram of radium-226 or its biological equivalent.
(e) Other organs	Year	15.
	13 weeks	5.
Population:		
(a) Individual	Year	0.5 (whole body).
(b) Average	30 year	5 (gonads).

The following points are made in relation to the Radiation Protection Guides herein provided:

(1) For the individual in the population, the basic Guide for annual whole body dose is 0.5 rem. This Guide applies when the individual whole body doses are known. As an operational technique, where the individual whole body doses are not known, a suitable sample of the exposed population should be developed whose protection guide for annual whole body dose will be 0.17 rem per capita per year. It is emphasized that this is an operational technique which should be modified to meet special situations.

(2) Considerations of population genetics impose a per capita dose limitation for the gonads of 5 rems in 30 years. The operational mechanism described above for the annual individual whole body dose of 0.5 rem is likely in the immediate future to assure that the gonadal exposure Guide (5 rem in 30 years) is not exceeded.

(3) These Guides do not differ substantially from certain other recommendations such as those made by the National Committee on Radiation Protection and Measurements, the National Academy of Sciences, and the International Commission on Radiological Protection.

(4) The term "maximum permissible dose" is used by the National Committee on Radiation Protection (NCRP) and the International Commission on Radiological Protection (ICRP). However, this term is often misunderstood. The words "maximum" and "permissible" both have unfortunate connotations not intended by either the NCRP or the ICRP.

(5) There can be no single permissible or acceptable level of exposure without regard to the reason for permitting the exposure. It should be general practice to reduce exposure to radiation, and positive effort should be carried out to fulfill the sense of these recommendations. It is basic that exposure to radiation should result from a real determination of its necessity.

(6) There can be different Radiation Protection Guides with different numerical values, depending upon the circumstances. The Guides herein recommended are appropriate for normal peacetime operations.

(7) These Guides are not intended to apply to radiation exposure resulting from natural background or the purposeful exposure of patients by practitioners of the healing arts.

(8) It is recognized that our present scientific knowledge does not provide a firm foundation within a factor of two or three for selection of any particular numerical value in preference to another value. It should be recognized that the Radiation Protection Guides recommended in this paper are well below the level where biological damage has been observed in humans.

It is recommended that:

4. Current protection guides used by the agencies be continued on an interim basis for organ doses to the population.

Recommendations are not made concerning the Radiation Protection Guides on individual organ doses to the population, other than the gonads. Unfortunately, the complexities of establishing guides applicable to radiation exposure of all body organs preclude the Council from making recommendations concerning them at this time. However, current protection guides used by the agencies appear appropriate on an interim basis.

It is recommended that:

5. The term "Radioactivity Concentration Guide" be adopted for Federal use. This term is defined as the concentration of radioactivity in the environment which is determined to result in whole body or organ doses equal to the Radiation Protection Guide.

Within this definition, Radioactivity Concentration Guides can be determined after the Radiation Protection Guides are decided upon. Any given Radioactivity Concentration Guide is applicable only for the circumstances under which the use of its corresponding Radiation Protection Guide is appropriate.

It is recommended that:

6. The Federal agencies, as an interim measure, use radioactivity concentration guides which are consistent with the recommended Radiation Protection Guides. Where no Radiation Protection Guides are provided, Federal agencies continue present practices.

No specific numerical recommendations for Radioactivity Concentration Guides are provided at this time. However, concentration guides now used by the agencies appear appropriate on an interim basis. Where appropriate radioactivity concentration guides are not available, and where Radiation Protection Guides for specific organs are provided herein, the latter Guides can be used by the Federal agencies as a starting point for the derivation of radioactivity concentration guides applicable to their particular problems. The Federal Radiation Council has also initiated action directed towards the development of additional Guides for radiation protection.

It is recommended that:

7. The Federal agencies apply these Radiation Protection Guides with judgment and discretion, to assure that reasonable probability is achieved in the attainment of the desired goal of protecting man from the undesirable effects of radiation. The Guides may be exceeded only after the Federal agency having jurisdiction over the matter has carefully considered the reason for doing so in light of the recommendations in this paper.

The Radiation Protection Guides provide a general framework for the radiation protection requirements. It is expected that each Federal agency, by virtue of its immediate knowledge of its operating problems, will use these Guides as a basis upon which to develop detailed standards tailored to meet its particular requirements. The Council will follow the activities of the Federal agencies in this area and will promote the necessary coordination to achieve an effective Federal program.

If the foregoing recommendations are approved by you for the guidance of Federal agencies in the conduct of their radiation protection activities, it is further recommended that this memorandum be published in the FEDERAL REGISTER.

Chairman,
ARTHUR S. FLEMMING,
Federal Radiation Council.

The recommendations numbered "1" through "7" contained in the above memorandum are approved for the guidance of Federal agencies, and the memorandum shall be published in the FEDERAL REGISTER.

DWIGHT D. EISENHOWER

4.1b BACKGROUND MATERIAL FOR THE DEVELOPMENT OF RADIATION PROTECTION STANDARDS, REPORT NO. 2, STAFF REPORT OF THE FEDERAL RADIATION COUNCIL, SEPTEMBER 1961

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SECTION I.—INTRODUCTION

SCOPE

1.1 Report No. 1 of the Federal Radiation Council provided a general philosophy or radiation protection for Federal agencies. It introduced and defined the term "Radiation Protection Guide (RPG)." It provided numerical values for Radiation Protection Guides for the whole body and certain organs of radiation workers and for the whole body of individuals in the general population, as well as an average population gonadal dose. It introduced as an

operational technique where individual whole body doses are not known, the use of a "suitable sample" of the exposed population in which the guide for the average exposure of the sample should be one-third the RPG for individual members of the group. It emphasized that this operational technique should be modified to meet special situations. In selecting a suitable sample, particular care should be taken to assure that a disproportionate fraction of the average dose is not received by the most sensitive population elements. The observations, assumptions, and comments set out in the memorandum published in the Federal Register on May 18, 1960, are equally applicable to this report.

1.2 This report is concerned with the problem of providing guidance for Federal agencies in activities designed to limit exposure of members of population groups to radiation from radioactive materials deposited in the body as a result of their occurrence in the environment. Included are the following: (1) Radiation Protection Guides for certain organs of individuals in the general population, as well as averages over suitable samples of exposed groups, (2) guidance on general principles of control applicable to all radionuclides occurring in the environment, (3) some general principles by which Federal agencies may establish appropriate concentration values, and (4) specific guidance in connection with exposure of population groups to radium-226, iodine-131, strontium-90, and strontium-89.

1.3 In Report No. 1, the RPG's for radiation workers apply to individuals. Similarly, the whole body RPG for the general population of 0.5 rem per year applies to individual members of the general population. As this report is concerned with radioactive materials in the environment, individual whole body or organ doses will usually not be known. Therefore, this report provides Radiation Protection Guides not only for individuals in the general population, but also, using the operational technique referred to in paragraph 1.1, for the average of suitable samples of exposed population groups. In the development of the guidance on intake, the Radiation Protection Guides for averages have been used.

1.4 For radionuclides not considered in this report, Federal agencies should use concentration values in air, water, or items of food which are consistent with recommended Radiation Protection Guides and the general guidance on intake.

1.5 In the future, the Council will direct attention to the development of appropriate radiation protection guidance for those radionuclides for which such consideration appears appropriate or necessary. In particular, the Council will study any radionuclides for which useful applications of radiation or nuclear en-

ergy require release to the environment of significant amounts of these nuclides. Federal agencies are urged to inform the Council of such situations.

1.6 Radiation Protection Guide has been defined in FRC Report No. 1 (see paragraph 1.18). For convenience, it is repeated here.

> "Radiation Protection Guide (RPG) is the radiation dose which should not be exceeded without careful consideration of the reasons for doing so; every effort should be made to encourage the maintenance of radiation doses as far below this guide as practicable."

1.7 Report No. 1 also introduced and defined the term "Radioactivity Concentration Guide." This term is not used in this report. The guidance in this report is concerned with total daily [p. 1] intake from all sources of radionuclides rather than concentration values in air, water, or individual items of food. Agencies, however, may find the term "Radioactivity Concentration Guide" useful in some of their programs.

PREPARATION OF THE STAFF REPORT

1.8 The preparation of this report followed a pattern similar to that for Report No. 1. The Federal Radiation Council has received written comments from, and consulted with: (1) members of various Federal agencies responsible for the administration of radiation protection programs, (2) governmental and non-governmental scientists in many related disciplines, and (3) other individuals and groups who are interested in the subject.

1.9 In developing the recommendations given in this report, the staff of the Council considered the extensive studies made by the National Committee on Radiation Protection and Measurements (NCRP) and the International Commission on Radiological Protection (ICRP) of the behavior and effects of the radionuclides under discussion. The Council staff consulted scientists from the many disciplines involved in the studies such as physicians, radiobiologists, health physicists, radiochemists, and physicists. Many of the scientists consulted were, or had been, affiliated with NCRP, ICRP, the National Academy of Sciences (NAS), the American Standards Association (ASA), and other scientific groups. The staff also studied available literature and publications of the above groups as well as those of the Medical Research Council and the Agricultural Research Council of the United Kingdom and the United Nations Scientific Committee on the Effects of Atomic Radiation. In some consultations the Council staff had the opportunity to review current unpublished biological data.

1.10 In order to consider as completely as possible the many factors involved in establishing radiation protection standards for the general population, the Council solicited comments from interested organizations and individuals. For this purpose, the Council prepared and transmitted widely a paper stating major policy issues involved in the development of radiation protection guidance in connection with the radionuclides considered in this report. Among these policy issues is the question as to the appropriateness of specific radiation protection standards from the point of view of their social and economic impact. Questions of this sort do not lend themselves to exact quantitative treatment. They are matters of judgment on which the best available information is brought to bear.

RADIATION PROTECTION GUIDES

1.11 It has been emphasized in Report No. 1 of the Federal Radiation Council that the establishment of radiation protection standards involves a balancing of the benefits to be derived from the controlled use of radiation and atomic energy against the risk of radiation exposure. This principle is based upon the position adopted by the Federal Radiation Council that any radiation exposure of the population involves some risk; the magnitude of which increases with the exposure. As stated in "Radiation Protection Guidance for Federal Agencies," approved by the President, May 13, 1960, "There should not be any man-made radiation exposure without the expectation of benefit resulting from such exposure." In recommending use of the term, "Radiation Protection Guide" it was stated that "This term is defined as the radiation dose which should not be exceeded without careful consideration of the reasons for doing so; every effort should be made to encourage the maintenance of radiation doses as far below this guide as practicable." Consistent with these principles, no exposure to radiation should be permitted unless it satisfies two criteria:

(1) The various benefits to be expected as a result of the exposure, as evaluated by the appropriate responsible group, must outweigh the potential hazard or risk, and

(2) the reasons for accepting or permitting a particular level of exposure rather than reducing the exposure to a lower level must outweigh the decrease in risk to be expected from reducing the exposure.

1.12 In view of the considerations discussed above, ideally, an individual radiation protection guide should be developed for each activity or set of circumstances involving exposure to radiation. Recognizing the impracticability of establishing an individual

guide for each application, the Council, in its Report No. 1, pointed out the need for a compromise between this ideal and the applica-

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tion of a single guide to widely differing sets of conditions. The following is taken from the Council's recommendations approved by the President:

"There can be no single permissible or acceptable level of exposure without regard to the reasons for permitting the exposure . . . It is basic that exposure to radiation should result from a real determination of its necessity.
There can be different Radiation Protection Guides with different numerical values, depending upon the circumstances. The guides recommended herein are appropriate for normal peacetime operations."

1.13 On the basis of extensive consultation, the Council has recommended to the President a set of Radiation Protection Guides which represent a generalized balance between the considerations discussed above. Despite wide differences in the assignment of relative values to the various factors involved, the Council believes that the overall benefits from useful activities involving exposures to radiation at levels within those specified in these guides will outweigh the risks associated with such exposures. There is also sufficient experience in limiting radiation exposures to levels similar to these to demonstrate the general feasibility, with few exceptions, of operating at or below the levels specified in these guides in normal peacetime operations.

1.14 The Federal agencies, when applying these Radiation Protection Guides should recognize that they represent generalized and not specific guidance. Because the reasons for accepting or permitting exposure to radiation vary so widely from one situation to another, the guides cannot represent the most appropriate ones for some situations without being inappropriately high or low for others. Each agency should determine, in any specific application, the extent to which the generalized guides apply in the specific situation. For example, certain applications may be able to be conducted at a guide specifying a lower dose than the RPG recommended by the Council. On the other hand, some applications which are not practicable under existing guides and for which the needs are very great may require a guide specifying a higher dose. The possibility of certain situations, such as accidents, may require the development of guides to be used when an agency considers such drastic actions as exclusion of persons from a specified area, evacuation, or condemnation of supplies of food.

1.15 "Radiation Protection Guidance for Federal Agencies" published in the Federal Register May 18, 1960, recognized that in certain instances the balance of benefit versus risk might neces-

sitate an RPG higher than specified for normal peacetime operations. This was expressed in the following language:

"The guides may be exceeded only after the Federal agency having jurisdiction over the matter has carefully considered the reason for doing so in light of the recommendations in this paper."

Arrangements have been made for the Council to follow the activities of the Federal agencies in this area and to promote the necessary coordination to achieve an effective Federal program. These have been described in a memorandum from the Chairman of the Council to the President, made public on October 13, 1960.

CONTROL OF ENVIRONMENTAL RADIOACTIVITY

1.16 The objective of the control of population exposure from radionuclides occurring in the environment is to assure that appropriate RPG's are not exceeded. This control is accomplished in general either by restrictions on the entry of radioactive materials into the environment or through measures designed to limit the intake of such materials by members of the population. The most direct means of evaluating the effectiveness of control measures is the determination of the amount of radioactive material in the bodies of the members of exposed population groups. Although the determination of such body burdens may at times be indicated, in routine practice potential exposures will generally be assessed on the basis of either one or a combination of two general approaches: (1) calculations based upon known amounts of radioactive material released to the environment, and assumptions as to the fraction of this material reaching exposed population groups, or (2) environmental measurements of the amount of radioactive material in various environmental media.

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1.17 Both of these general approaches involve the calculation or determination of actual or potential concentrations of radioactive material in air, water, or food. As stated above, controls should be based upon an evaluation of population exposure with respect to the RPG. For this purpose, the average total daily intake of radioactive materials by exposed population groups, averaged over periods of the order of a year, constitutes an appropriate criterion.

1.18 There is for any radioactive material a daily intake which is calculated to result, under specified conditions, in whole body or organ doses equal to a Radiation Protection Guide. The resulting value represents either the continuous or the average daily intake which would meet an RPG stated in terms of an annual dose. It is evident that the daily intake of radioactive material might

fluctuate very widely around the average and still result in an annual dose which would not exceed the associated RPG.

1.19 The control of the intake of radioactive materials from the environment can involve many different actions. The character and import of these actions vary widely from those which entail little interference with usual activities, such as monitoring and surveillance, to those which involve a major disruption, such as condemnation of food supplies. Some control actions would require prolonged lead times before becoming effective, e.g., major changes in water supplies. For these reasons, control programs developed by the agencies should be based upon appropriate actions taken at different levels of intake. In order to provide guidance to the agencies in developing appropriate programs, this report describes a graded approach for the radionuclides considered, involving three ranges of transient rates of daily intake applicable to different degrees or kinds of action.

1.20 The objective of the graded scale of actions is to limit intake of radioactive materials so that specified RPG's will not be exceeded. Daily intakes varying within the total extent of all three ranges of intake might result in annual doses not exceeding a single RPG. However, in instances in which the daily intake is fluctuating above the average which would meet the RPG, it may not be possible to be assured that this will be the case. The actions outlined below would be appropriate, not only when intakes are fluctuating so as not to exceed a given RPG, but also in those situations in which valid reasons exist for the responsible agency to permit the possibility of doses which would exceed the RPG.

1.21 A suggested graded system of actions is outlined below. For each of the three ranges of transient rates of daily intake, specific values for which are given in the sections devoted to the specific radionuclides, the general type of action appropriate for the range is outlined.

RANGE I

Intakes falling into this range would not under normal cond
tions be expected to result in any appreciable number of indi
uals in the population reaching a large fraction of the
Therefore, if calculations based upon a knowledge of the sou
release of radioactive materials to the environment indic
intakes of the population are in this range, the only
quired is surveillance adequate to provide reasonable c
of calculations.

RANGE II

Intakes falling into this range would be expected to result in average exposures to population groups not exceeding the RPG. Therefore such intakes call for active surveillance and routine control.

SURVEILLANCE

Surveillance must be adequate to provide reasonable assurance that efforts being made to limit the release of radioactive materials to the environment are effective. Surveillance must be adequate to provide estimates of the probable variation in average daily intake in time and location. Detection of sharply rising trends is very important. In some cases, because of the complexities of the environment, surveillance data may have to be sufficiently reliable to be used as a rough check on whether radioactive materials in the environment are behaving as expected. Not only the radioactive material in question, but also the environment must be

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studied. Appropriate efforts might be made to obtain measurements in man as well as to study physical, chemical, and metabolic factors affecting uptake. Appropriate consideration should be given to other independent sources of exposure to the body (the same organs or different ones) to avoid exceeding RPG's.

CONTROL

Routine control of useful applications of radiation and atomic energy should be such that expected average exposures of suitable samples of an exposed population group will not exceed the upper value of Range II. The sample should be taken with due regard for the most sensitive population elements. Control actions for intakes in Range II would give primary emphasis to three things: (1) assuring by actions primarily directed at any trend sharply upward that average levels do not rise above Range II, (2) assuring by actions primarily directed either at specific causes of the environmental exposure levels encountered or at the environment that a limit is placed on any tendencies of specific population segments to rise above the RPG, and (3) reducing the levels of exposure to segments of the population furthest above the average or tending to exceed Range II.

RANGE III

Intakes within this range would be presumed to result in exsures exceeding the RPG if continued for a sufficient period of

combinations. Consequently, concentration values applying to the different sources of intake must take into account the relative contribution of each source to total intake. Even in those situations where food is the only source of intake of radioactive material, widely varying concentration values applying to different items in the diet may be appropriate. For example, in the case of intakes in Range III the necessity may arise for removal of a particular radionuclide from certain major contributors in the diet, or even elimination of certain dietary items containing high concentrations of the nuclide. The following are some of the considerations which may be involved in the determination of specific levels at which action such as the condemnation of certain food supplies would take place:

(1) Relative proportion of the total diet by weight represented by the item in question.

(2) The importance of the particular item in nutrition and the availability of substitutes having the same nutritional properties, or perhaps stockpiles of uncontaminated food.

(3) The availability of other possible control methods such as the removal of the radioactive material from the particular dietary item without affecting its quality.

(4) The half-life of the radioactive material.

(5) Other internal or external sources of radiation exposure to the same organ.

(6) Relative contribution of other dietary items to the total daily intake of the nuclide.

(7) Physical, chemical, and other factors affecting the relationship between intake and uptake of the nuclide.

(8) The time and effort required to effect corrective action.

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In this connection, it is important to emphasize a point made in paragraph 1.18 in connection with guidance on intake. The agencies should bear in mind in establishing concentration values that it is possible to have wide fluctuations in daily intake which might still result in an annual average dose within the RPG. It can be readily seen that, since fluctuations in concentration guides can occur within a given intake value, even wider fluctuations can occur in concentrations in various foods and still result in an annual average dose that does not exceed the associated RPG. In any specific instance the greater the variation in concentrations, the more difficult it will be to estimate average intakes.

1.28 Because of the wide difference possible in concentration values applying to different environmental media and depending upon specified circumstances, the Federal Radiation Council has not made any specific recommendations on such values. The responsible Federal agencies should develop specific concentration values to apply to appropriate control actions as part of their operating criteria. The Federal Radiation Council will follow de-

velopments in this area and will promote the necessary coordination to achieve an effective Federal program.

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SECTION II.—THE THYROID GLAND AND IODINE-131

INTRODUCTION

2.1 This section is concerned with the development of an RPG for the thyroid gland and guidance in connection with exposure of the general population to radioactive iodine. Currently, the major concern is environmental contamination resulting from fallout from the explosion of nuclear devices and the release of radioiodine during the use and processing of fuel for reactors. Fission products so formed may contain iodine-131, -132, -133, -134, and -135. The dose rate from the shorter-lived radionuclides (iodine-132, -133, -134, and -135 with half-lives ranging from approximately 53 minutes to 21 hours) will decrease rapidly with time in comparison with iodine-131 (half-life approximately 8 days). Consequently, guidance on intake of iodine-131 only is considered in this section. However, when the shorter-lived iodine nuclides are present and contribute significantly to the radiation dose received, they should be taken into account in accordance with the principles for summation of dose.

2.2 Like the naturally occurring stable isotope of iodine, iodine-131 when ingested or inhaled concentrates in the thyroid gland. Thus the thyroid gland receives a far larger radiation dose from iodine-131 than any other organ in the body. Radiation protection guidance to be used in connection with iodine-131, therefore, involves the determination of RPG's for the thyroid gland.

RPG FOR THE THYROID GLAND

2.3 Report No. 1 specifies a Radiation Protection Guide for the thyroid gland of radiation workers of 30 rem per year. It specifies an annual whole body dose to individuals in the general population of 0.5 rem. The whole body guide is a factor of 10 below that specified for radiation workers. If one were to assume that the thyroid gland of individuals in the general population is no more sensitive when compared with the whole body than is the case in radiation workers, it might, from the point of view of the risk factor, be reasonable to use a value of 3 rem per year as an RPG for the thyroid of individuals in the general population.

2.4 This, however, may not be the case. Evidence is summarized below which has led the Council to the conclusion that in the

development of RPG's for the thyroid gland it is necessary to take the position that a child's thyroid gland, relative to other organs of the child, is more sensitive to the carcinogenic effect of radiation than the adult thyroid gland compared to other organs of the adult. In the development of guidance on intake there is an additional factor which must be considered, i.e., the ratio between size of thyroid and intake of radioiodine in children is different from the ratio in adults.

2.5 In Report No. 1 (paragraph 2.19) it is noted that the child's thyroid is more sensitive to the carcinogenic effects of radiation than the adult thyroid. This conclusion is based upon several studies in recent years of the occurrence of thyroid carcinoma in children who had previously received therapeutic x-irradiation in the neck region for enlarged thymus or for other benign head and neck conditions. The incidence of thyroid carcinoma in these children was significantly higher than in control groups who had not been previously irradiated.

2.6 In these studies cancer of the thyroid was observed in children after exposures as low as approximately 150 rem. Similar effects have been observed in adults only at much higher dosages. Although these data do not provide a quantitative relationship, they do indicate that the child's thyroid is more sensitive to the carcinogenic effects of radiation than is that of the adult.

2.7 The RPG for the thyroid gland of radiation workers of 30 rem per year is twice the dose specified for other organs. This difference is based on two factors: (1) the evidence that the thyroid gland in adults is a particularly radioresistant organ, and (2) the needs for exposure of radiation workers to radioactive iodine

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in useful applications of radiation and atomic energy. If it were not for these considerations, no individual treatment would have been given the thyroid gland of radiation workers and it would have fallen into the category of other organs with and RPG of 15 rem per year.

2.8 From the point of view of the biological risk, therefore, the RPG for the thyroid of individuals in the general population, including children, should be less than 1/10 of 30 rem per year. On the other hand, it is logical to assume that the risk associated with a given radiation dose to the child's thyroid gland must be less than that associated with the same dose to his whole body. Thus the RPG for the thyroid of individuals in a population group could be higher than the 0.5 rem per year whole body dose without resulting in a greater biological risk.

2.9 The Council has reviewed data and studied atomic energy

operations involving exposure of the thyroid gland of members of the general population. As noted in paragraph 2.1, such operations usually involve iodine-131. It finds that in general these operations can be conducted without undue difficulty in such a manner that the dose to the thyroid of individuals in the general population will not exceed 1.5 rem per year. It has been stated above that, since in the situation of environmental contamination individual doses are not usually known, this report will specify both individual doses and average doses to population groups. Therefore, the Council recommends RPG's for the thyroid gland of 1.5 rem per year for individuals and 0.5 rem per year to be applied to the average of suitable samples of an exposed group in the general population as representing a reasonable balance between biological risk and benefit to be derived from useful applications of radiation and atomic energy. If specific applications should be contemplated which cannot be conducted without exceeding the dose specified in the RPG, an individual assessment of benefit and risk must be made by the responsible agency in accordance with the principles previously outlined by the Council.

GUIDANCE ON INTAKE OF IODINE-131

2.10 As a step in the development of guidance on intake of iodine-131 it is necessary to determine the average daily intake which would meet the RPG for averages in the general population. Among the factors to be considered are: (1) the weight of the thyroid gland, (2) the percent of the iodine intake which reaches the gland, and (3) the average retention time.

2.11 There is wide variation from one individual to another in the percent of an ingested or inhaled quantity of iodine-131 which appears in the thyroid gland. This percentage uptake is dependent upon such factors as the amount of stable iodine in the diet and the physiological state of the thyroid gland. In point of fact, certain pathological conditions in humans are manifest by an increase or decrease in the ability of the thyroid gland to concentrate iodine. A review of the data in the United States indicates that the normally functioning thyroid gland concentrates at 24 hours on the average approximately 30% of the initial quantity of iodine-131 taken into the body. The data also indicate that, while, as stated above, there is wide variation from individual to individual, there is no significant difference in the average between children and adults.

2.12 There is some evidence that suggests that iodine is metabolized more rapidly in the child than in the adult. This suggests the possibility of a somewhat shorter biological half-life. How-

ever, adequate information concerning the effective half-life of iodine-131 in younger children is not presently available. It is assumed, therefore that an effective half-life of 7.6 days is applicable for all age groups.

2.13 The average mass of the thyroid gland in adults is generally taken to be 20 grams. The mass of the gland in the child is, of course, less and depends upon the specific age. Since, as discussed above under the consideration of the RPG, the child is taken as the limiting case, the weight of the child's thyroid is considered as the limiting factor in the determination of guidance on intake. In calculating the average daily intake which would meet the RPG, the mass of the thyroid gland is taken as 2 grams. The resulting guidance on intake should, theoretically, be applied only to children and is subject to adjustment upward when applied only to adults. In many practical situations this adjustment will not be feasible. However, when agencies develop appropriate concentration values to refer to specific modes of intake (as between inhalation and

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ingestion) or to different dietary elements, this consideration should be kept in mind.

2.14 Using the known factors and the assumptions enumerated above, it can be calculated that an average daily intake of 80 micromicrocuries of iodine-131 per day would meet the RPG for the thyroid for averages of suitable samples of an exposed population group of 0.5 rem per year. As stated in Section I, it is appropriate to specify three ranges of transient rates of daily intake in order to provide guidance for the Federal agencies in the establishment of operating criteria. For this purpose, the value of 80 micromicrocuries per day has been rounded off to 100 micromicrocuries per day as being more in keeping with the precision of the data. Therefore, the following guidance on intake of iodine-131 to be applied to suitable samples of an exposed population group is recommended:

Range I	0 to	10 micromicrocuries per day
Range II	10 to	100 micromicrocuries per day
Range III	100 to	1,000 micromicrocuries per day

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SECTION III.—BONE AND RADIUM-226

INTRODUCTION

3.1 Human experience with comparatively large quantities of radium in the skeleton was discussed in Report No. 1 (particularly

pages 13–15) and the general practice of establishing radiation protection guides for occupational exposure to various radionuclides in the skeleton by relating them to radium-226 was endorsed. For this purpose, 0.1 microgram of radium-226 in the skeleton was adopted as a Radiation Protection Guide for radiation workers. This value has been in general use since 1941. The discussion in this section is concerned with the development of an appropriate Radiation Protection Guide for bone and of corresponding guidance on daily intake for control of exposures of the general population to radium-226.

3.2 The critical organ for radium in the body is the skeleton. It is assumed in this section that, except for radiation from natural sources other than radium and from medical x-rays, the total radiation dose to the skeleton is from radium-226 and its radioactive decay products. If other sources of radiation contribute significantly to the radiation dose to the skeleton, it is expected that they will be taken into account.

CONSIDERATIONS IN THE DEVELOPMENT OF RPG'S

3.3 In the consideration of the risk side of the risk-benefit balance in the development of RPG's, Report No. 1 indicated several approaches to aid in the evaluation of the risk. Comparisons with occupational exposure guides and with exposures from natural background were discussed. Although neither provides a quantitative basis for the determination of population RPG's, each is useful. This is particularly true in the case of radium-226 because some data are available on both occupational and whole population environmental exposure.

3.4 The Radiation Protection Guide recommended by the Council for the whole body of individuals in the general population is a factor of 10 below the whole body guide for radiation workers. There are certain considerations, however, which indicate that the application of the same factor to the RPG for occupational exposure to radium-226 to obtain population RPG's may not provide the same degree of protection as in the case of the whole body. Some of these considerations are the following:

(1) The skeletal content required to give a particular radiation dose to the bone of a child is less than for the adult. Fortunately (from the point of view of simplicity of treatment of the problem), available data suggest that in an environment in which the average concentration of radium in the total diet, including water, is constant, concentrations of radium-226 in the skeletons of humans who have lived their entire lives in the environment are found to be relatively independent of age.

(2) The distribution of radium-226 in the skeleton of an individual who has lived his entire life in an environment constant with respect to small quantities

of radium in his diet will be much more uniform than that of radium deposited in the skeleton as the result of occupational exposure. How the degree of hazard from radium in the skeleton might depend upon nonuniformity of distribution is not known.

(3) The radiation dose to the bone from radium deposited in the skeleton under constant environmental conditions is relatively constant throughout life. On the other hand, the dose resulting from deposition under controlled occupational exposure increases with length of exposure. Constant environmental exposure, therefore, results in a larger lifetime dose per unit quantity of radium-226 in the skeleton than occupational exposure in which the specified quantity is assumed to be reached only near the end of life. Furthermore, because of the long latent periods characteristic of carcinogenesis at low dose [p. 11]

levels, it appears reasonable to assume that the earlier in life the radiation dose from radium is received the more likely the individual will live until any carcinogenic effect can become manifest.

3.5 Turning to the second approach, that of comparing the radiation doses to the skeleton from radium-226 with radiation doses normally received from all natural sources of radiation, it is immediately apparent that bases for comparisons are, at best, uncertain. In physical units of radiation dose (e.g., rads) the dose to the skeleton from all natural sources of radiation averages between 0.1 and 0.15 rads per year. The quantities of radium-226 in the adult skeleton which, with its radioactive decay products, are required to give corresponding physical doses range from about 0.003 to 0.005 micrograms. There is insufficient information on the relative biological effectiveness of the radiation from radium to attempt a realistic conversion of this dose in rads to the skeleton from radium and its decay products into rems.

3.6 Because of the uncertainties involved in comparing radiation from radium with total radiation to the skeleton from natural sources, it is useful to consider the natural occurrence of radium in the skeleton. In most areas of the United States, the radium content of the adult human skeleton is found to range from about 0.0001 microgram of radium-226 to some two or three times this amount. In such areas, the radium content of drinking water is generally so low that the skeletal content is believed to be almost entirely due to the occurrence of sufficient radium-226 in food to result in a daily intake of from 1 to 2 micrograms. In some areas, however, concentrations of radium-226 in drinking water are sufficiently high to result in much larger daily intakes and correspondingly higher amounts in the skeleton. There are communities in which unusually high radium concentrations in supplies of drinking water result in adult skeletal levels which range upward to amounts of the order of 0.001 microgram. A program is underway to determine whether any biological effects of such amounts

of radium can be detected by epidemiological studies with methods currently available. However, it is expected that a number of years will be required to reach any useful conclusions.

3.7 These approaches give two reference points for use in comparison of biological risk with reasons for acceptance of risk. In the case of radium, reasons for acceptance of risk involve consideration of the difficulty of meeting possible RPG's and the impact of this difficulty on industry and the community. Before this comparison can be made it is necessary to consider the relationship between environmental levels and body content of radium since this relationship vitally affects the difficulty of meeting any RPG.

3.8 The data which are most relevant to the determination of the relationship between environmental levels and body content are the observations of the relationships between concentrations of radium-226 in community water supplies and corresponding quantities in the skeleton of persons using the water. Estimates of average concentrations in normal United States diets and corresponding average skeletal contents, while less firmly supported, are reasonably consistent with these observations. These data indicate that on the average the concentration of radium-226 in the skeleton of individuals of any age does not exceed a value corresponding to a total quantity in the adult skeleton of about fifty times the daily intake.

3.9 The Council has considered operations involving the release of radium-226 to the environment. These can be conducted, in the opinion of the Council, without undue difficulty in such a manner that average daily intake of radium-226 in an exposed population group will not exceed 20 micromicrograms. The Council has also reviewed available data on radium-226 concentrations in public water supplies in the United States. The overwhelming majority of the population consumes water from supplies corresponding to daily intakes of radium-226 well below this level. In those situations where this may not be the case, the extremely small risk associated with intakes above this level should be considered by the appropriate authorities in light of difficulties which may be associated with any modifications in the water supply.

3.10 In view of the above considerations, the Council recommends as an alternate RPG for bone for individuals in the general population a skeletal concentration of radium-226 corresponding to 0.003 microgram in the adult skeleton. The RPG to be applied to the average of suitable samples of an exposed population group is a skeletal concentration of radium-226 corresponding to 0.001 microgram in the adult skeleton. These values are considered by

the Council to represent an appropriate balance between biological risk and reasons for acceptance of risk.

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GUIDANCE ON INTAKE

3.11 The relationship between environmental levels and body content referred to in paragraph 3.8 indicates that an average daily intake of 20 micromicrograms of radium-226 corresponds to the RPG for suitable samples of exposed population groups. Therefore, the Council recommends the following guidance on transient rates of daily intake of radium-226 to be applied to the average of suitable samples of an exposed population group:

Range I	0 to 2 micromicrograms per day
Range II	2 to 20 micromicrograms per day
Range III	20 to 200 micromicrograms per day

It is important to emphasize that the risk associated with this intake guidance is, in the opinion of the Council, much lower than has generally been considered. The skeletal content associated with a daily intake of 20 micromicrograms is about an order of magnitude lower than that which would be implied by extrapolation from current occupational standards for radium. The Council considers, however, that the data from the environmental studies, though limited, represent a more valid basis for derivation of the relationship between continuous exposure and body content.

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SECTION IV.—BONE MARROW, BONE AND RADIOISOTOPES OF STRONTIUM

INTRODUCTION

4.1 In this section, RPG's for bone marrow and bone and guidance for the protection of individuals in the general population against excessive exposure to radioisotopes of strontium are developed. The chemical and physical characteristics are such that, for this purpose, our principal interest is in the irradiation of bone and bone marrow as the result of deposition of strontium-90 and strontium-89 in the skeleton. Because such deposition results from the occurrence of the radioisotopes in ingested food and water and in inhaled air, protection is achieved by limiting average concentrations in food, water, and air used by humans. Thus, while the hazard to the individual results from radiation emitted over long periods of time by material actually in his skeleton, for purposes of control it is necessary to specify guidance on intake of the isotopes which will not result in excessive irradiation of

body tissues. In applying such guidance to actual environmental situations, it is necessary to convert intake values to concentration values applicable to specific items in the total diet (both food and water) and in inhaled air according to the general principles in Section I.

DERIVATION OF RPG'S FOR BONE MARROW AND BONE

4.2 Report No. 1 recommended an RPG for the whole body of individuals in the general population of 0.5 rem per year as representing an appropriate balance between the requirements of health protection and of the beneficial uses of radiation and atomic energy. Basic to the considerations involved in a guide for whole body dose were the factors associated with exposure of bone marrow. Thus RPG's for the bone marrow of 0.5 rem per year for individuals in the general population and 0.17 rem per year as an average to be applied to suitable samples of an exposed population group are considered by the Council to represent a similarly appropriate balance of benefit and risk.

4.3 Experience indicates that bone is relatively insensitive to X and gamma radiation when compared with bone marrow. Groups exposed to X and gamma radiation in which a higher than normal incidence of leukemia has been observed have not shown corresponding increases in bone tumors. Although these data do not provide a quantitative basis for relating the sensitivity of bone and bone marrow they do indicate that from the point of view of the risk it is reasonable to permit a larger dose to bone than to bone marrow.

4.4 In the case of strontium-90, the dose rate to bone from a given skeletal content is three times the average dose rate to bone marrow. Other beta emitters of similar distribution in bone and comparable energy would yield similar factors. The Council considers that Radiation Protection Guides for the bone of 1.5 rem per year for individuals in the general population and 0.5 rem per year as an average to be applied to suitable samples of an exposed population group represent an appropriate balance between the requirements of health protection and of the beneficial uses of radiation and atomic energy.

THE DEVELOPMENT OF GUIDANCE ON INTAKE OF STRONTIUM-89 AND STRONTIUM-90

4.5 The considerations involved in the development of guidance on intake of strontium-89 and strontium-90 are summarized in the following paragraphs. The guidance is applicable only under the

conditions specified in their derivation, i.e. continuous exposure to radioactive strontium in food, water, and air throughout the lifetimes of the individuals involved and under normal peacetime operations. The guidance is based on the assumption that the exposure source it covers is the only source of exposure of the skeleton to radiation other than natural background and medical and dental exposures. Where actual exposure involves both strontium-89 and strontium-90, or where the skeleton is also exposed to significant amounts of radiation from other sources, such as

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barium-140 or abnormal quantities of radium-226, it is expected that these will be taken into account. Likewise, where there is significant intake through both ingestion and inhalation, it is expected that the total deposition in the skeleton will be considered.

BIOLOGICAL EFFECTS

4.6 No effects in humans attributable to the ingestion or inhalation of radioactive strontium have been observed from the levels of radioactive strontium which have occurred in the environment nor does it appear from our present knowledge that it would be possible to observe any. Consequently, evaluation of the hazard to humans is primarily dependent upon extrapolation and dose interpolation from the effects on experimental animals exposed to far greater quantities of radioactive strontium, or from the effects of other sources of radiation on humans.

4.7 Experimental animals given large doses of radioactive strontium have developed osteogenic sarcomas, and it might be expected that this would occur in a human group under similar circumstances.

4.8 Some small laboratory animals have developed leukemia following large injected doses of radioactive strontium, presumably from irradiation of the bone marrow, although the causative relationship is not clear. Extrapolating animal experience to humans is very uncertain. Data obtained as a result of exposure of humans to external radiation indicate that at levels of exposure much higher than those under consideration here, the bone marrow is significantly more radiosensitive than the bone.

METABOLIC FACTORS

4.9 Ingested strontium is concentrated in the mineral skeleton, as is calcium and several other alkaline earth elements. Under equilibrium conditions, essentially all strontium in the body is in the skeleton. The mineral skeleton appears during intra-uterine

life, and increase in mass until about age twenty years. Another process of bone metabolism is the continuous replacement of the mineral portion at a low rate on a microscopic scale throughout life. Thus, there is a continuous exchange of mineral elements between the environment and the blood, and a continuous exchange between the blood and the skeleton.

4.10 Strontium is similar but not identical biochemically to calcium. Therefore, although some ingested strontium is deposited in bone in a manner similar to calcium, there are metabolic mechanisms which perform some discrimination between the two elements, so that their relative concentration when deposited in bone is different from their relative concentration in the diet. The similarities in metabolic pathways of strontium and calcium make it meaningful and convenient to use ratios of the two elements in evaluating the deposition of radioactive strontium.

4.11 Newly formed bone has about the same strontium to calcium ratio as is in the blood circulating at the time of formation. There is some discrimination against strontium between ingested material and blood, which results primarily from preferential renal excretion of strontium, but which may also be influenced by preferential absorption of calcium through the gut.

4.12 Data on humans and laboratory animals indicate rather well that there is a discrimination factor against strontium of about four in the strontium to calcium ratio between diet and bone. Although some experimental evidence suggests that there may be periods during infancy and adolescence in which the discrimination factor is less than four, observations of the ratio of natural strontium to calcium in the human skeleton as a function of age indicate no practical difference. The strontium to calcium ratio of the embryo and fetus is affected not only by the maternal discrimination factor of four between diet and blood, but by a placental discrimination factor of about two. The resultant discrimination between maternal diet and fetal bone would therefore be about eight under conditions of equilibrium. Presently, the observed occurrence of strontium-90 in fetal bone is somewhat less than predicated for conditions of equilibrium, probably because of a calcium contribution from the maternal skeleton, which is not now in equilibrium with the strontium-90 in the diet.

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4.13 Under constant intake conditions throughout life, and with the exception of the infant, whose skeletal level of strontium would be in transition from the prenatal to the postnatal equilibrium values, evidence indicates that the distribution of strontium in bone mineral would be reasonably uniform both throughout the

bone and throughout life. For example, measurements of the ratio of natural strontium to calcium in over 200 skeletons of persons ranging in age from stillbirths to eighty years, reported by the Medical Research Council of the United Kingdom, November 14, 1960, indicate that the mean ratio of strontium to calcium in humans does not increase more than about 25 percent after the age of two years.

RADIATION DOSE FACTORS

4.14 Strontium-90 in the skeleton exists in secular equilibrium with its daughter, yttrium-90. These nuclides emit beta radiation with a maximum range of about six millimeters in bone and one centimeter in soft tissue. For a non-uniform distribution of the nuclides in bone, they would deliver a substantially more uniform radiation dose than a similarly distributed alpha-emitting material. When the macroscopic distribution of strontium-90 in bone is reasonably even, the radiation dose can be considered as essentially uniform.

4.15 Because of the greater range of beta radiation, bone marrow would receive a greater portion of the radiation dose from strontium-90 than from an alpha-emitting material in bone. The dose to a small bit of bone marrow surrounded by a large mass of dense bone would approach the dose to the bone. However, the average bone marrow dose from strontium-90 would be substantially less than the bone dose. Similar considerations apply to strontium-89.

APPLICATION OF RPG'S TO STRONTIUM-90

4.16 The Council has considered the basis for evaluation of the biological risk associated with exposure of population groups to strontium-90 under the conditions stated in paragraph 4.5. This consideration included comparison with the RPG for bone marrow and bone recommended in paragraphs 4.2 and 4.4 and comparison with the alternate guide for bone in Section III.

4.17 For those radionuclides for which the skeleton is considered to be the critical organ, occupational standards commonly have been derived by estimating body burdens considered to be no more hazardous than 0.1 microgram of radium. Two of the reasons for adopting this approach were: (1) experience with radiation injury to the human skeleton is largely limited to cases in which relatively large quantities of radium have been introduced into the skeletons of adults, whether as a result of occupational exposure or for medical reasons; and (2) it is considered that, in general, the distribution of radionuclides deposited in the skeleton under occupational

conditions of exposure may be of such a nature as to make direct comparison with X and gamma radiation uncertain.

4.18 In addition to the considerations which normally arise in making comparisons between exposures of population groups and exposures for occupational reasons, the manner in which occupational standards for strontium-90 have been derived appears to make them less appropriate as a basis for comparison than the RPG's for bone marrow and bone given in paragraphs 4.2 and 4.4. Basically, derivation of occupational standards for strontium-90 has involved experimental determination of relative quantities of strontium-89 and radium-226 in small laboratory animals required to produce biological damage considered to be comparable. It was then assumed (for lack of more certain information) that, except for an adjustment to allow for the higher retention of radon in the human skeleton, the same ratio would hold for man. The corresponding ratio for strontium-90 and radium-226 was estimated to be twice as large as that for strontium-89 and radium-226 because the combined energy emitted by strontium-90 and yttrium-90 per disintegration of strontium-90 is approximately twice that emitted per disintegration by strontium-89.

4.19 This estimate of the relative quantities of strontium-90 and radium-226 required to produce radiation hazards or effects considered to be equivalent for purposes of radiation protection to those of radium was found to depend upon the conditions of the experiment, particularly dose rate, and upon the effect chosen as a measure of injury. The ratios chosen as representing the relative hazards of strontium with respect to radium were those corresponding to massive acute doses. The experimental observations indicated that for chronic exposure at lower dose rates the relative

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hazards of radiostrontium are smaller by factors which range downward to less than one-tenth and perhaps to one-hundreth of those observed for acute doses.

4.20 Studies of individual and relative radiotoxicities of radium-226 and strontium-90 using large laboratory animals are now in progress. It is expected that such studies will not only provide better comparisons of the relative hazards of strontium and radium to experimental animals under conditions more nearly approaching those of interest, but will provide better independent data on the nature and degree of hazard from radioactive strontium. In addition, the use of larger animals and several species of animals is expected to reduce the uncertainties inherent in extrapolation to man. However, the nature of such investigations is such that periods of time comparable to the normal lifetimes of the animals

are required to obtain a sufficient amount of useful information on which to base sound conclusions.

4.21 It appears that comparisons with the bone marrow and bone RPG's given in paragraphs 4.2 and 4.4 can be made with less uncertainty and are more meaningful than comparisons with occupational standards for strontium-90 which have been, in turn, based upon comparisons with radium-226. It is assumed that the total intake of strontium-90 by individuals is such that the average ratio of strontium-90 to calcium in the blood is constant throughout life. This is considered to be approximately true if the ratio of strontium-90 to calcium in the total diet (that is, in the total amount of food and water ingested by the individual) remains constant. In line with the principles in Report No. 1 of control of exposure of members of the public to radiation, ratios may be averaged over periods of time of the order of one year.

4.22 Under the conditions assumed, experience with stable strontium in the normal diet as well as such data on the uptake of radioactive strontium from the diet indicate that the distribution of strontium-90 in the skeleton will be reasonably uniform. The ranges of the beta rays from strontium-90 and its radioactive decay product, yttrium-90, are sufficiently large that the microscopic distribution of radiation dose to the bone (except for losses of radiation near the surface) will be even more uniform. Under these conditions, the RBE (relative biological effectiveness) of the beta radiation does not differ markedly from that of X and gamma radiation of quantum energy in the range between two hundred and several hundred Kev.

4.23 It has been estimated that the average dose to bone marrow from strontium-90 and yttrium-90 in a skeleton of average density is about one-third of the dose to bone. Data on experimental animals indicate that the protection of a small portion of bone marrow from a high dose of radiation may markedly lower the incidence of leukemia. This suggests that in the case of non-uniformity of radiation dose to the bone marrow, the average dose is a more meaningful index of hazard than the maximum local dose and that, for a given average, a non-uniform distribution of dose may be less hazardous than a uniform distribution. Thus, the RPG's for bone marrow and bone recommended in paragraphs 4.2 and 4.4 appear appropriate as a basis for the evaluation of the risk associated with exposure of population groups to strontium-90.

4.24 *The Council has emphasized, however, that in the application* of general RPG's, both the risk and the reasons for accepting the exposure should be considered. The Council has, therefore, reviewed past and current activities resulting in release of stron-

tium-90 to the environment, and given some consideration to future developments. This review indicates that in general these activities can be conducted without undue difficulty at exposures lower than those corresponding to the RPG's. Therefore, in the development of the guidance on intake, doses corresponding to one-third the RPG's for bone marrow and bone to be applied to the average of suitable samples of an exposed population group have been used.

GUIDANCE ON INTAKE OF STRONTIUM-90

4.25 As a step in the development of guidance on intake of strontium-90, it is necessary to determine the average daily intake of strontium-90 which would correspond to doses of one-third the RPG's to be applied to suitable samples of an exposed population group. The nature of the relationship between the ratio of strontium and calcium in the human diet and in the human skeleton has been discussed in paragraphs 4.9–4.13. The data referred to in paragraph 4.13 not only indicate that the ratio of natural strontium to calcium in the skeleton does not increase significantly with age but they show that within a general geographical area natural

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differences in dietary habits do not result in a large spread in the values observed in the skeletons of individuals of all ages.

4.26 The average ratio of strontium to calcium in the human skeleton is estimated to be about one-fourth of the ratio in the diet. On this basis, a continuous dietary ratio of 200 micromicrocuries of strontium-90 per gram of calcium is estimated to result in a skeletal concentration of 50 micromicrocuries per gram of calcium and to produce radiation doses, averaged over any age group of a uniformly exposed population group, corresponding to approximately one-third of the appropriate RPG's. This level in the maternal diet would give about one-sixth the RPG to the prenatal individual.

4.27 The similarity between the chemical properties of strontium and those of calcium makes the average ratio of strontium-90 to calcium in the diet a useful device in the development of guidance on intake. In some situations, it may be desirable to consider concentrations of strontium-90 and calcium in individual items of diet. However, in general it is useful to use intake values based on average calcium content of the diet.

4.28 Appropriate intake values will depend upon the composition of the diet and the average consumption. The minimum calcium requirement in the American diet is considered to be of the order of one gram per day. The average intake may be consider-

ably in excess of this amount, although in some areas it is found to be somewhat less. For the derivation of intake guidance, the Council adopts the figure of one gram of calcium per day. On this basis, a continuous dietary intake of 200 micromicrocuries per day would generally correspond to the radiation doses discussed above.

4.29 It is therefore recommended that the following guidance on transient rates of daily intake of strontium-90 to be applied to the average of suitable samples of an exposed population group be adopted for normal peacetime operations:

Range I	0	to	20 micromicrocuries per day
Range II	20	to	200 micromicrocuries per day
Range III	200	to	2,000 micromicrocuries per day

STRONTIUM-89

4.30 Occupational standards have related body burdens of strontium-89 and strontium-90 in such a manner as to permit the same total absorption of energy by the skeleton from one as from the other. This results in a body burden for strontium-89 two times that for strontium-90. Because of the shorter half-life of strontium-89, 52 days as compared to 27 years, the corresponding ratio of permissible concentrations has been estimated to be about 100.

4.31 Because of the manner in which the Council has derived guides for exposures of population groups to strontium-90, it is not possible to relate the two on the basis of energy comparison alone with as high a degree of confidence as is involved in the development of the guide for strontium-90. The guides for strontium-90 depend upon the validity of the assumption of reasonable uniformity of concentration in the skeleton. Because of the relatively short half-life of strontium-89, and hence the relatively short time in which strontium-89 atoms exist in the body, the distribution of dose is necessarily much less uniform than that from strontium-90. It is, however, possible to derive, by comparison with strontium-90, guides which represent no greater hazards than those for strontium-90 and which are not excessively restrictive.

4.32 For this purpose, we take advantage of the current practice of permitting population exposures to be averaged over periods of up to one year. The maximum dose rate will be experienced in areas in which new bone is being formed. Our objective is to limit the dose in any one year to the value which would have been permitted if the radioactivity were strontium-90. For simplicity, consider a section of "bone" of reasonable size and suppose that it has been "formed" of calcium, strontium-89, and other appropriate elements by normal process of metabolism in a period

of time short in comparison with the half-life of strontium-89. It may be shown that the decay rate of strontium-89 is such that the average dose rate to the bone over a period of one year after formation will be only one-fifth of the initial dose rate. Because the

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average energy absorbed per disintegration of strontium-89 is only half that per disintegration of strontium-90 and its yttrium daughter, in this hypothetical case ten times as much strontium-89, measured in terms of activity, could be permitted as of strontium-90 without increasing the average dose in one year. In subsequent years, of course, the dose to this section of the bone would be essentially zero.

4.33 It is apparent that if such a section of bone were to be built up slowly instead of instantaneously, the average dose to this section of the bone during the ensuring year would be somewhat less. This may be demonstrated in the following manner. If the section of bone added is reduced in thickness, a larger fraction of the total radiation emitted by the strontium-89 in this section escapes to adjacent material. While this escape may be compensated for in part by absorption of radiation from adjacent material, if such adjacent material is older than the section under consideration, it must have a lower concentration of strontium-89 and, hence, the compensation cannot be complete.

4.34 On the basis of the above argument, since strontium-89 follows the same metabolic pattern as strontium-90, guidance on intake of ten times that used for strontium-90 will result in dose rates to bone marrow and bone which, in any area of the skeleton, will not exceed in any one year those permitted from strontium-90. While these dose rates represent hazards which, over a period of years, are certainly much less than those from continuous exposure to strontium-90 at one-third the RPG, the reasons for accepting comparable risks from strontium-89 are generally less.

4.35 Therefore the following guidance on transient rates of daily intake of strontium-89 to be applied to the average of suitable samples of an exposed population group is recommended for normal peacetime operations:

Range I	0	to	200 micromicrocuries per day
Range II	200	to	2,000 micromicrocuries per day
Range III	2,000	to	20,000 micromicrocuries per day

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4.1b(1) RADIATION PROTECTION GUIDANCE FOR FEDERAL AGENCIES (MEMORANDUM FOR THE PRESIDENT), FEDERAL RADIATION COUNCIL

September 26, 1961, 26 Fed. Reg. 9057 (1961)

MEMORANDUM FOR THE PRESIDENT

SEPTEMBER 13, 1961.

Pursuant to Executive Order 10831 and Public Law 86–373, the Federal Radiation Council herewith transmits its second report to you concerning findings and recommendations for guidance for Federal agencies in the conduct of their radiation protection activities.

Background. On May 13, 1960, the first recommendations of the Council were approved by the President and the memorandum containing these recommendations was published in the FEDERAL REGISTER on May 18, 1960. There was also released at the same time, Staff Report No. 1 of the Federal Radiation Council, entitled, "Background Material for the Development of Radiation Protection Standards," dated May 13, 1960.

The first report of the Council provided a general philosophy of radiation protection to be used by Federal agencies in the conduct of their specific programs and responsibilities. It introduced and outlined the term "Radiation Protection Guide" (RPG). It provided numerical values for Radiation Protection Guides for the whole body and certain organs of radiation workers and for the whole body of individuals in the general population, as well as an average population gonadal dose. It introduced as an operational technique, where individual whole body doses are not known, the use of a "suitable sample" of the exposed population in which the guide for the average exposure of the sample should be one-third the RPG for the individual members of the group. It emphasized that this operational technique should be modified to meet special situations. In selecting a suitable sample particular care should be taken to assure that a disproportionate fraction of the average dose is not received by the most sensitive population elements. The observations, assumptions, and comments set out in the memorandum published in the FEDERAL REGISTER, May 18, 1960, are equally applicable to this memorandum.

This memorandum contains recommendations for the guidance of Federal agencies in activities designed to limit exposure of members of population groups to radiation from radioactive materials deposited in the body as a result of their occurrence in the environment. These recommendations include: (1) Radiation Protection Guides for certain organs of individuals in the general population, as well as averages over suitable samples of exposed

groups; (2) guidance on general principles of control applicable to all radionuclides occurring in the environment; and (3) specific guidance in connection with exposure of population groups to radium–226, iodine–131, strontium–90, and strontium–89. It is the intention of the Council to release the background material leading to these recommendations as Staff Report No. 2 when the recommendations contained herein are approved.

Specific attention was directed to problems associated with radium–226, iodine–131, strontium–90, and strontium–89. Radium–226 is an important naturally occurring radioactive material. The other three were present in fallout from nuclear weapons testing. They could, under certain circumstances, also be major constituents of radioactive materials released to the environment from large scale atomic energy installations used for peaceful purposes. Available data suggest that effective control of these nuclides, in cases of mixed fission product contamination of the environment, would provide reasonable assurance of at least comparable limitation of hazard from other fission products in the body.

Establishment of the Federal Radiation Council followed a period of public concern incident to discussions of fallout. While strontium–90 received the greatest popular attention, exposures to cesium–137, iodine–131, strontium–89 and, in still lesser degrees to other radionuclides, are involved in the evaluation of over-all effects. The characteristics of cesium–137 lead to direct comparison with whole body exposures for which recommendations by the Council have already been made.

Studies by the staff of the Council indicate that observed concentrations of radioactive strontium in food and water do not result in concentrations in the skeleton (and consequently in radiation doses) as large as have been assumed in the past. However, concentrations of iodine–131 in the diets of small children, particularly in milk, equal to those permitted under current standards would lead to radiation doses to the child's thyroid which, in comparison with the general structure of current radiation protection standards, would be too high. This is because current concentration guides for exposure of population groups to radioactive materials in air, food, and water have been derived by application of a single fraction to corresponding occupational guides. In the case of iodine–131 in milk, consumption of milk and retention of iodine by the child may be at least as great as by the adult, while the relatively small size of the thyroid makes the radiation dose to the thyroid much larger than in the case of the adult. In addition, there is evidence that irradiation of the thyroid involves

greater risk to children than to adults.

Recommendations as to Radiation Protection Guides. The Federal Radiation Council has previously emphasized that establishment of radiation protection standards involves a balancing of the benefits to be derived from the controlled use of radiation and atomic energy against the risk of radiation exposure. In the development of the Radiation Protection Guides contained herein, the Council has considered both sides of this balance. The Council has reviewed available knowledge, consulted with scientists within and outside the Government, and solicited views of interested individuals and groups from the general public. In particular, the Council has not only drawn heavily upon reports published by the International Commission on Radiological Protection (ICRP), the National Committee on Radiation Protection and Measurements (NCRP), and the National Academy of Sciences (NAS), but has had during the development of the report the benefit of consultation with, and comments and suggestions by, individuals from NCRP and NAS and of their subcommittees. The Radiation Protection Guides recommended below are considered by the Council to represent an appropriate balance between the requirements of health protection and of the beneficial uses of radiation and atomic energy.

It is recommended that:

1. The following Radiation Protection Guides be adopted for normal peacetime operations.

TABLE I—RADIATION PROTECTION GUIDES FOR CERTAIN BODY ORGANS IN RELATION TO EXPOSURE OF POPULATION GROUPS

Organ	RPG for individuals	RPG for average of suitable sample of exposed population group
Thyroid	0.5 rem per year.	1.5 rem per year
Bone marrow	0.17 rem per year.	0.5 rem per year
Bone	0.5 rem per year.	1.5 rem per year
Bone (alternate guide).	0 001 micrograms of Ra-226 in the adult skeleton or the biological equivalent of this amount of Ra-226.	0.003 micrograms of Ra-226 in the adult skeleton or the biological equivalent of this amount of Ra-226.

It will be noted that the preceding table provides Radiation Protection Guides to be applied to the average of a suitable sample of an exposed population group which are one-third of those applying to individuals. This is in accordance with the recommendations in the first report of the Council concerning operational techniques for controlling population exposure. Since in the case of exposure of a population group to radionuclides the radiation doses to individuals are not usually known, the organ dose to be

used as a guide for the average of suitable samples of an exposed population group is also given as an RPG.

Recommendations as to general principles. Control of population exposure from radionuclides occurring in the environment is accomplished in general either by restriction on the entry of such materials into the environment or through measures designed to limit the intake by members of the population of radionuclides already in the environment. Both approaches involve the consideration of actual or potential concentrations of radioactive material in air, water, or food. Controls should be based upon an evaluation of population exposure with respect to the RPG. For this purpose, the total daily intake of such materials, averaged over periods of the order of a year, constitutes an appropriate criterion.

The control of the intake by members of the general population of radioactive materials from the environment can appropriately involve many different kinds of actions. The character and import of these actions may vary widely, from those which entail little interference with usual activities, such as monitoring and surveillance, to those which involve a major disruption, such as condemnation of food supplies. Some control actions may require prolonged lead times before becoming effective, e.g., major changes in processing facilities or water supplies. The magnitude of control measures should be related to the degree of likelihood that the RPG may be exceeded. The use of a single numerical intake value, which in part has been the practice until now, does not in many instances provide adequate guidance for taking actions appropriate to the risk involved. For planning purposes, it is desirable that insofar as possible control actions to meet contingencies be known in advance.

It is recommended that:

2. The radiological health activities of Federal agencies in connection with environmental contamination with radioactive materials be based, within the limits of the agency's statutory responsibilities, on a graded series of appropriate actions related to ranges of intake of radioactive materials by exposed population groups.

In order to provide guidance to the agencies in adapting the graded approach to their own programs, the recommendations pertaining to the specific radionuclides in this memorandum consider three transient daily rates of intake by suitable samples of exposed population groups. For the other radionuclides, the agencies can use the same general approach, the details of which are considered in Staff Report No. 2. The general types of action appropriate when these transient rates of intake fall into the

different ranges are also discussed in Staff Report No. 2. The purpose of these actions is to provide reasonable assurance that average rates of intake by a suitable sample of an exposed population group, averaged over the sample and averaged over periods of time of the order of one year, do not exceed the upper value of Range II. The general character of these actions is suggested in the following table.

TABLE II—GRADED SCALES OF ACTION

Ranges of transient rates of daily intake	Graded scale of action
Range I	Periodic confirmatory surveillance as necessary.
Range II	Quantitative surveillance and routine control.
Range III	Evaluation and application of additional control measures as necessary.

Recommendations on Ra–226, I–131, Sr–90, and Sr–89. The Council has given specific consideration to the effects on man of rates of intake of radium–226, iodine–131, strontium–90 and strontium–89 resulting in radiation doses equal to those specified in the appropriate RPG's. The Council has also reviewed past and current activities resulting in the release of these radionuclides to the environment and has given consideration to future developments. For each of the nuclides three ranges of transient daily intake are given which correspond to the guidance contained in Recommendation 2, above. Routine control of useful applications of radiation and atomic energy should be such that expected average exposures of suitable samples of an exposed population group will not exceed the upper value of Range II. For iodine–131 and radium–226, this value corresponds to the RPG for the average of a suitable sample of an exposed population group. In the cases of strontium–90 and strontium–89, the Council's study indicated that there is currently no known operational requirement for an intake value as high as the one corresponding the RPG. Hence, a value estimated to correspond to doses to the critical organ not greater than one-third of the RPG has been used.

The guidance recommended below is given in terms of transient rates of (radioactivity) intake in micromicrocuries per day. The upper limit of Range II is based on an annual RPG (or lower, in case of radioactive strontium) considered as an acceptable risk for a lifetime. However, it is necessary to use averages over periods much shorter than a lifetime for both radiation dose rates and rates of intake for administrative and regulatory purposes. It is recommended that such periods should be of the order of one year. It is to be noted that values listed in the tables are

much smaller than any single intake from which an individual might be expected to sustain injury.

It is recommended that:

3. (a) The following guidance on daily intake be adopted for normal peacetime operations to be applied to the average of suitable samples of an exposed population group:

TABLE III—RANGES OF TRANSIENT RATES OF INTAKE (MICROMICROCURIES PER DAY) FOR USE IN GRADED SCALE OF ACTIONS SUMMARIZED IN TABLE II.

Radionuclides	Range I	Range II	Range III
Radium-226	0–2	2–20	20–200
Iodine-131[1]	0–10	10–100	100–1,000
Strontium-90	0–20	20–200	200–2,000
Strontium-89	0–200	200–2,000	2,000–20,000

[1] In the case of iodine-131, the suitable sample would inc ude only small children. For adults, the RPG for the thyroid would not be exceeded by rates of intake higher by a factor of 10 than those applicable to small children.

(b) Federal agencies determine concentrations of these radionuclides in air, water, or items of food applicable to their particular programs which are consistent with the guidance contained herein on average daily intake for the radionuclides radium—226, iodine–131, strontium–90, and strontium–89. Some of the general considerations involved in the derivation of concentration values from intake values are given in Staff Report No. 2.

It is recommended that:

4. For radionuclides not considered in this report, agencies use concentration values in air, water, or items of food which are consistent with recommended Radiation Protection Guides and the general guidance on intake.

In the future, the Council will direct attention to the development of appropriate radiation protection guidance for those radionuclides for which such consideration appears appropriate or necessary. In particular, the Council will study any radionuclides for which useful applications of radiation or atomic energy require release to the environment of significant amounts of these nuclides. Federal agencies are urged to inform the Council of such situations.

ABRAHAM RIBICOFF,
Chairman,
Federal Radiation Council.

The recommendations numbered "1" through "4" contained in the above memorandum are approved for the guidance of Federal agencies, and the memorandum shall be published in the FEDERAL REGISTER.

JOHN F. KENNEDY.

4.1c HEALTH IMPLICATIONS OF FALLOUT FROM NUCLEAR WEAPONS TESTING THROUGH 1961, REPORT NO. 3 OF THE FEDERAL RADIATION COUNCIL, MAY 1962

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REPORT OF THE FEDERAL RADIATION COUNCIL

HEALTH IMPLICATIONS OF FALLOUT FROM NUCLEAR WEAPONS TESTING THROUGH 1961

The Federal Radiation Council has considered available information on radiation doses and possible health effects of atmospheric nuclear weapons testing. Before discussing the estimates made in this report in detail, it is appropriate to point out the difficulties of being precise in this field.

Although a large and expanding program for measuring radiation levels at a number of locations throughout the United States has been in effect for a number of years, the application of such data to the whole country, to an extended time period, or to the entire population involves assumptions than can not be completely validated. Furthermore, while a considerable body of information has been accumulated on the effects of radiation on animals and man, the possible effects of low doses delivered at low dose rates are insufficiently known to permit firm conclusions about the extremely low exposures resulting from fallout. Current experimental techniques are not good enough to detect biological effects at the low levels of worldwide fallout from nuclear tests.

Any possible manifestations resulting from fallout radiation will not be unique, for all of the diseases and disabilities known to be caused by radiation also occur for other reasons. Whatever effects might be produced by fallout could only be reflected in statistical increases in the number of conditions already present in the population. Any individual effects would be so diluted by space and time that they would not be recognizable among the much larger number of identical effects arising from other causes, among which they would be interspersed.

Finally, any proper understanding of estimates in this field must take into account the many different ways in which similar or

even identical data can be expressed. Many of the apparent differences among scientists arise from different forms of presentation. Two approaches have been used. One estimates the risk of damage to a single person. This risk is extremely small in comparison with others which people normally accept. The second approach considers possible effects on a large population for a year or a generation or for several generations totaling hundreds of years. Even a very small proportion of affected individuals will, in a very large population for a long period of time, amount to an impressive total number of individuals.

ESTIMATED RADIATION EXPOSURE FROM TESTING

Any consideration of possible health effects from fallout must begin with the radiation doses to which people are exposed as a result of such tests.

A sharp distinction must be made between the devastating effects of "local" fallout in a nuclear attack on an unshielded population and the effects of fallout from weapons testing. Weapons testing creates far smaller total amounts of fission products so that its fallout is far less than that which would result from nuclear war. Furthermore, the tests are planned to avoid local fallout or to confine it to locations where it will have minimal effects. Hence, in weapons testing the problem is largely confined to delayed fallout which decays greatly in the upper atmosphere and is dispersed at low concentrations over the earth's surface. This report is concerned primarily with the effects of such delayed fallout.

Dose estimations must take into account exposure from all sources; external, and internal through ingestion of food and water and inhalation. Some radioactive elements may concentrate to different extents in various parts of the body. Those which tend to concentrate in a certain organ will selectively irradiate that organ. Thus a thyroid dose, for example, represents the sum of the whole-body dose from a variety of substances plus the extra dose from iodine-131, an element which tends to concentrate in the thyroid gland. In addition, some elements are taken up more effectively at one age than another. For example, the proportion of strontium-90 retained in the growing bones of children is greater than that retained in the bones of adults ingesting the same foods. Furthermore, different sources of radiation give off different kinds of radiation having different biological effects, so that doses cannot be directly compared. These points should indicate the difficulty of referring to any one exposure level from a

particular source without identifying what kind of a dose and what part of the body is involved.

Estimates of doses from fallout from tests through 1961 in millirems, a unit of ionizing radiation dose, are given in Table I and discussed further in Appendix "A". Because of uncertainties and the variety of necessary assumptions, these estimates are expressed as ranges of values within which the average exposure over the United States is expected to lie. The values given apply to the United States, and are somewhat higher than those for most of the rest of the world. Doses to the whole-body and reproductive cells represent an average for all age groups in the entire population. Doses to bone and bone marrow are average values for those who were infants at the time of highest concentrations of the particular isotopes irradiating these organs; values averaged for all age groups will be lower.

[p. 1]

The half-life of radioactive iodine, the principal source of the thyroid dose, is only 8 days and the peak dose rates persist for a relatively short period of time. For this reason thyroid doses are not included in the table. Doses to the thyroid from the major past tests were estimated to have ranged from 100 to 200 millirems per year during and immediately following periods of testing. These values apply only to individuals who were infants at the time of highest concentration of radioactive iodine. The average value for all age groups was about a tenth as much. Although data from which thyroid doses during 1957–58 can be estimated are limited, it is likely that there was much geographic variation, and in some limited areas of the United States the average thyroid doses were probably many times the national average.

The whole-body dose due to the carbon-14 produced by all tests through 1961 has been included but not separately listed in Table I. It is estimated to total from 10 to 15 millirems during the first thirty-year period. The dose rate will decrease much more rapidly than would be predicted on the basis of the carbon-14 radioactive half-life of 5,700 years because of the absorption of the radioactive carbon dioxide from the atmosphere into the ocean. After about 200 years the dose rate from carbon-14 will have been reduced to a total of about 0.75 millirem during a thirty-year period.

To put these dose levels in some perspective, Table I compares them with exposures from natural background and with the Radiation Protection Guides of the Federal Radiation Council. The comparisons indicate that doses from fallout have generally been a small fraction of the Guides for population groups.

Background radiation arises from naturally radioactive mate-

rials such as carbon-14 and potassium-40 in the human body, radium in the earth's crust, and cosmic radiation from outer space. Man has always been exposed to these radiations. Natural background radiation varies from place to place, both with elevation and with radioactive content of local materials. In the United States these values have been observed to range from 70 to 200 millirems per year. The value for background radiation given in Table I is a weighted average for the entire United States population.

The estimated values given in Table I for whole-body exposures from fallout are considerably less than the exposures from natural sources. Over a period of 30 years the average whole-body dose from all testing through 1961 will be between 60 and 130 millirems compared to 3,000 millirems from background. Thus testing through 1961, including the contribution from carbon-14, will, over this thirty-year period, increase exposures over natural background by less than five percent. Seventy-year average bone doses, when similarly compared, are increased less than ten percent. Any further testing will of course, increase the exposure.

The fact that exposure from some sources is generally accepted without question should not in itself be a reason for accepting exposure to added levels of man-made radiation. However, comparison of exposure levels with those of natural background does provide some indication of the significance of increases from fallout. One normally considers variation in exposure from natural sources to be of little significance. For example, a resident of the East Coast contemplating a move to a high-altitude location in the West is unlikely to know or attach any importance to the fact that his exposure to background radiation will be appreciably increased —more than twenty-five percent at elevations above one mile.

Another basis of comparison is the radiation exposure received from medical diagnostic procedures in the United States. It has been estimated that a person in the United States will accumulate a genetically effective dose of the order of 1,000 millirems over a thirty-year period. There are, however, wide fluctuations in the exposures to the reproductive cells from the diagnostic procedures.

ESTIMATES OF BIOLOGICAL EFFECTS

Much available evidence indicates that any radiation is potentially harmful. However, effects become increasingly difficult to demonstrate below 10,000 millirems, and impossible to detect by present techniques at the very low dose levels from fallout. Nevertheless, it is virtually certain that genetic effects can be produced by even the lowest doses. These effects in the children of

exposed parents and all future generations may be of many kinds, ranging from minor defects too small to be noticed to severe disease and death.

In the case of somatic effects, i.e., effects directly on the persons exposed, the evidence is insufficient to prove either that there is a dosage level below which no damage occurs (the "damage threshold" hypothesis) or that there is some risk of damage at any dosage level, no matter how low (the "no threshold" hypothesis). It may well be that some effects are of one kind, some of the other. Dose rate is important; a protracted dose is much less effective than the same total dose given in a short time.

Estimates have been made by national and international groups of scientists of the number of possible adverse health effects that might occur from various exposure levels. Tables II and III apply

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some of these estimates to the exposure levels from all testing through 1961 to indicate the possible adverse health effects in the United States population that might result from this testing. United States figures have been used because knowledge of dose levels and of health effects occurring in the absence of testing is more complete for this country than on a worldwide basis. For convenience in expressing the concepts and calculations in this report, the population of the United States has been taken as approximately one-tenth of the population in the same latitudes of the northern hemisphere, and as one-twentieth of the population of the entire world. The figures in Table II on the possible number of adverse health effects from testing through 1961 may be multiplied by 10 to provide a rough estimate of comparable worldwide effects with the exception of carbon-14, for which a factor of approximately 20 must be applied.

Table II and Appendix "B" give numerical estimates of the effects of fallout on one category of genetic effects—severe physical and mental defects. This category includes the hereditary component of such things as congenital malformations, blindness, deafness, feeblemindedness, muscular dystrophy, hemophilia and mental diseases.

In Table II the estimated numbers of radiation effects are given as three values. The upper figure is the best estimate based on radiation-induced mutation rates in mice, and on the spontaneous incidence of these defects in man. The other figures represent the range within which the true value may reasonably be expected to lie.

As shown in the table, about ten percent of the number that may result in all time from weapons tests through 1961 are estimated

to occur in the first generation—the children of parents exposed to this fallout. The remaining ninety percent occur in decreasing numbers in succeeding generations. Somatic effects appear only in the irradiated individual himself, and not in his offspring. The manifestations of particular concern are leukemia and other types of cancer.

The radiation dose from carbon-14 is spread over an enormous period of time extending through many thousands of years. The number of mutations from carbon-14, when exposure over all time is considered, is estimated to be greater than from other radioactive elements produced in nuclear detonations. These mutations will, however, be distributed over a much longer time with a much smaller number in any one generation.

In addition to the gross defects listed in Table II, there may be an unknown but probably a considerably larger number of mutations with less obvious effects such as minor physical abnormalities, mild diseases, impairment of physiological functions, and reduced resistance to infection or other stresses of life. Part of this damage will result in a lowered probability of survival at various ages.

Reduced viability of this kind has been consistently found in mouse experiments. The best data on mice are for the infant and embryonic deaths. To the extent that mouse data can be applied to man, the results indicate that the radiation-induced mortality of embryos and infants in the first generation after irradiation is probably larger, perhaps five times larger, than the number of induced defects of the type estimated in Table II. Numerical estimates are not given for such effects because of uncertainties as to the comparability of these effects in mice and humans. This is the viewpoint of those who have done much of the experimental work in this field.

Mutations which have a mild effect on the individual may cause substantial damage in the aggregate. This is because the mildness permits these mutations, such as slight reductions in viability and other less obvious effects, to persist in the population longer than mutations with severe effects, and thus to affect a correspondingly greater number of persons. There are no data which would permit these effects to be assessed with sufficient accuracy to permit numerical estimates.

If, however, numerical estimates are made of all these genetic effects, both those which are likely and those which are more speculative, the aggregate of these estimates when counted as the total number of individuals affected throughout the world in future generations leads to very large numbers. Likewise, large num-

bers can be obtained when other effects or deaths from any cause are totaled over large populations and many generations. On the other hand, it must be emphasized again that whatever the genetic effects of fallout radiation from weapons testing through 1961 may be, the total effect will certainly be considered less than that occurring inescapably from background radiation. This, in turn, is considerably less than the effects from other factors which determine the total natural mutation rate.

Estimates for two kinds of somatic effects, leukemia and bone cancer, are given in Table III. As mentioned earlier, it is not known whether or not there is a threshold dose below which these diseases are not produced. If a threshold exists, fallout radiation may produce no additional cases, and the lower limits of zero reflect this possibility.

The upper estimates in Table III are made by assuming the effect of a low dose, delivered at a low dose rate, to be proportional to the effect of a high dose delivered at a higher dose rate. The estimates for the upper limits are probably too high because no allowance had been made for the possibility that a given dose is [p. 3] less effective when received slowly over a long period of time. Thus the range of numbers given in Table III is reasonably certain to bracket the correct value.

There are other possible somatic effects of radiation such as malignancies (other than leukemia and bone cancer) and general effects such as life shortening. Among these malignancies is cancer of the thyroid, a possible effect from exposure to radioiodine. Table III includes no data on the possible incidence of this effect because estimates, like those recognized by national and international groups of scientists for possible leukemia and bone cancer effects, have not been made for cancer of the thyroid. However, from what little is known about the effect of radioiodine, including data obtained from human exposures at very high levels, the likelihood of any possible thyroid effects has been considered to be about the same as other malignancies for comparable exposures. Even less information is available as to possible increases in all these other effects than is available for leukemia and bone cancer.

To put these estimates of possible adverse health effects in some perspective, Tables II and III also include the total number of these same effects occurring in the United States from all causes.

CONCLUSIONS

We cannot say with certainty what health hazards are caused by fallout from nuclear testing. We expect there will be some

genetic effects; other effects such as leukemia and cancer are more speculative and may not occur at all. We can observe that, compared to the number of these same adverse biological effects occurring wholly apart from testing, the additional cases that might be caused by testing are a very small quantity. We conclude that nuclear testing through 1961 has increased by small amounts the normal risks of adverse health effects.

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4.1d ESTIMATES AND EVALUATION OF FALLOUT IN THE UNITED STATES FROM NUCLEAR WEAPONS TESTING CONDUCTED THROUGH 1962, REPORT NO. 4 OF THE FEDERAL RADIATION COUNCIL, MAY 1963

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SUMMARY

As a sequel to a similar report last spring, the Federal Radiation Council has again made a full study and analysis of fallout expected in the current year from nuclear tests in the past. In this case the report covers fallout expected in the next few years from Soviet and United States tests conducted to date.

Although absolute fallout levels in the U.S. in 1963 will probably be substantially increased over 1962 if rainfall is normal, they will still be, in relative terms far short of figures which would cause concern or justify counter-measures. Cumulative whole-body radiation doses from all past tests is estimated to be 110 millirems in 30 years, which is about one-thirtieth the exposure from natural sources such as soil, rocks, and building materials. The special cases of iodine-131 and strontium-90, the two radionuclides of most concern to the public, have been thoroughly reviewed and specifically included in the general conclusion. The Council concludes that the health risks from radioactivity in foods, now and over the next several years, are too small to justify countermeasures to limit intake of radionuclides by diet modifications or altering the normal distribution and use of food, particularly milk and dairy products.

The substantial increase in absolute amounts of fallout is due primarily to Soviet nuclear tests. The amount of fission yield in the thermonuclear test explosions is a measure of the quantity of strontium-90 and other fission products produced by the tests. The total yield of thermonuclear explosions is a measure of the carbon-14 produced. Since the Soviet Union ended the three-year moratorium by resuming nuclear tests in 1961. Soviet testing has produced 85 megatons of fission yield, and U.S. testing 16 megatons.

This report updates weapons testing information to include all tests conducted through 1962. The USSR conducted atmospheric tests at levels of 120 megatons (MT) total yield and 25 MT fission yield in 1961; 180 MT total yield and 60 MT fission yield in 1962.

A few of the underground tests conducted by the U.S. in 1961 resulted in some venting to the atmosphere. The U.S. conducted a series of atmospheric tests in the Pacific at a level of 37 MT total yield and 16 MT fission yield in 1962 plus a few low yield tests at the Nevada Test Site.

Measurements of strontium-90 in food supplies and the total diet in the U.S. show that the levels rose from a value of 4–8 strontium units (SU) in 1961 to 8–13 SU in 1962, and may rise to a peak value of 50 SU in 1963. The predicted concentrations of strontium-90 in milk for 1963 are twice the value observed in 1962 and about 4 times the values observed in 1961. The strontium-90 concentrations in human bone are expected to rise from an observed value of 2.6 SU in 1961 to 7 SU in 1964. The presently estimated radiation dose to bone from all past tests is about 465 millirems in 70 years, which is about one-twentieth the exposure from natural sources. It should be noted that these presently predicted values are no greater than those which were predicted in the FRC Report No. 3 as likely to result from all tests conducted prior to 1962. This is because the measured levels are lower than originally predicted.

It was estimated in 1962 that carbon-14 resulting from tests conducted through 1961 would give an average per capita radiation dose to the whole-body including the reproductive cells of 10 to 15 millirems in the first 30 years. It is now estimated that the carbon-14 produced by testing conducted in 1962 will produce a comparable radiation dose in the first 30 years. When the carbon-14 now in the atmosphere has equilibrated with the oceans, the natural levels will be increased by about 4 percent instead of the 2 percent previously reported.

As an addition, FRC Report No. 3, "Health Implications of Fallout from Nuclear Weapons Testing through 1961," is attached for reference.

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SECTION I

INTRODUCTION

1.1 The Federal Radiation Council evaluated the health implications of fallout from nuclear weapons testing conducted through 1961 in its Report No. 3 issued in May 1962. Since that report was prepared, additional atmospheric testing of nuclear weapons has been conducted by the USSR and U.S. governments. The purpose of the present is to:

(a) Update the information concerning the scale of weapons testing programs conducted by all nations;

(b) Summarize the radiation doses experienced in the past and expected in the future;

(c) Evaluate the change in the inventories of long-lived radionuclides in the stratosphere and on the ground resulting from these tests;

(d) Predict the probable levels of fallout that may be expected in 1963 and subsequent years in the food supplies of the nation; and

(e) Draw conclusions about the suitability of food products for human consumption in view of the predicted levels of radionuclides.

1.2 The predictions of future fallout levels from testing conducted through 1962 are based on the information available through March 1963. The estimates of doses received in 1962 are based on extensive measurements of the radionuclide concentrations in air, rain, soil, water supplies, food supplies, and people.

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SECTION II

HISTORY OF NUCLEAR WEAPONS TESTING

2.1 The atmospheric testing of nuclear devices inevitably introduces radioactive nuclides into man's environment. The existence of many of these products is transitory due to the process of radioactive decay. Other species, notably carbon-14, are so long-lived that they can be considered as a permanent man-made modification of the environment. Historically, major attention has been focused on the production and distribution of strontium-90 and cesium-137, both of which can lead to radiation exposure over the full lifetime of persons now living. Of the shorter-lived radionuclides, iodine-131 has been emphasized.

2.2 The production of strontium-90 and other fission products depends on the fission yields of the devices. The production of carbon-14 depends on the total fission plus fusion yields of the devices.

2.3 Table 1 summarizes the fission and total yields of atmospheric testing conducted by all nations through December 1962. As of January 1959, the strontium-90 inventory was estimated to be 9.2 megacuries produced by the detonation of 92 megatons of fission yield, 40 megatons of which had been detonated in 1957 and 1958.[1] Of this inventory, it was estimated that 3 megacuries had deposited as "close in" fallout near the test sites. Of the 6 megacuries then available for worldwide deposition, 3 megacuries had been deposited as worldwide deposition, and 3 megacuries were still in the atmosphere. The available inventory as of May 1961, taking into account the decrease of 2.5 percent per year for the radioactive decay of strontium-90, was estimated as 5.2 to 5.3

[1] 10 megatons of fission yield produce approximately 1 megacurie of strontium-90.

megacuries strontium-90. Of that quantity, 4.2 megacuries had deposited on the ground and 1 megacurie was still in the atmosphere. Less than one-quarter of this atmospheric burden was in the lower stratosphere in the northern hemisphere.

2.4 The USSR detonated an estimated 120 megatons of total yield in 1961 of which about 25 megatons were due to fission yield. The estimated radiation doses from this series were presented in FRC Report No. 3, "Health Implications of Fallout from Nuclear Weapons Testing through 1961."

2.5 The United States and the Soviet Union conducted tests in 1962 at levels shown in Table 2. U.S. and Soviet tests do not contribute equally to fallout exposures in the U.S. not only because of the difference in fission yields, but also because the distribution and rate of deposition vary with the geographic location of the tests and the altitude to which the weapon debris is carried. The amounts of fission yield injected into the stratosphere by the U.S. and the USSR in 1961 and 1962 are shown in Table 3. The total of 57 megatons fission yield injected into the lower stratosphere in 1961 and 1962 dominates the inventory available for worldwide deposition in 1962, and in the next few years.

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TABLE 1.—APPROXIMATE FISSION AND TOTAL YIELDS OF NUCLEAR WEAPONS TESTS CONDUCTED IN THE ATMOSPHERE BY ALL NATIONS

Yield in megatons

Inclusive years	Fission yield		Total yield	
	Air	Surface	Air	Surface
1945–1951	.19	.52	.19	.57
1952–1954	1	37	1	59
1955–1956	5.6	7.5	11	17
1957–1958	31	9	57	28
Subtotal	37.8	54	69.2	104.6
1959–1960	Test		Moratorium	
1961	25 [1]		120	
Subtotal	63	54	189	105
1962	76 [1]		217	
Total	139	54	406	105

[1] The small yield tests conducted in Nevada do not contribute significantly to the worldwide distribution of strontium-90 to which this summary is related.

TABLE 2.—APPROXIMATE FISSION AND TOTAL YIELDS OF ATMOSPHERIC TESTS CONDUCTED IN 1962

Yield in megatons

	Fission yield	Total yield
U.S.	16	37
U.S.S.R.	60	180
Total	76	217

TABLE 3.—APPROXIMATE FISSION YIELDS INJECTED INTO THE STRATOSPHERE IN 1961 AND 1962

	Yield in megatons		
	Lower stratosphere [1] (MT)	Upper stratosphere [1] (MT)	Total (MT)
U.S.S.R. (1961)	17	8	25
U.S.S.R. (1962)	30	30	60
U.S. (1962)	10	1	11

[1] The lower stratosphere occupies the first few tens of thousands of feet above the tropopause and the upper stratosphere continues to about 150,000 feet. The tropopause, on the average, is located at 30–40,000 feet in the temperate and polar zones and 50–55,000 feet in the tropical and the equatorial zones. Debris injected above 150,000 feet is omitted from this table.

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SECTION III

ATMOSPHERIC TRANSPORT AND DISTRIBUTION OF FALLOUT

3.1 The future course of fission-product deposition in man's environment resulting from past nuclear detonations can be estimated either from a knowledge of the amount and distribution of these products in the atmosphere at some recent date or from an estimate of the time, place, and amount injected into the atmosphere by the various test series. These data can be utilized in conjunction with the experience and knowledge gained over the past decade in analyzing fallout phenomenology. Studies of the movement and deposition of debris from past test series, using short-lived isotopes and unique radioactive tracers to identify the sources of the debris, have added to our understanding of the role of the atmosphere in determining the ultimate distribution of fission products on the surface of the earth.

3.2 Although the exact mechanisms involved in the transfer of debris from the stratosphere to the surface of the earth are not completely understood, the general features of the distribution on the ground are known from the available fallout data. These data show that precipitation is the most important mechanism in depositing material on the surface, and that there are both a latitudinal variation, with most deposition in temperate latitudes, and a seasonal variation with maximum deposition in the spring.

3.3 On January 1, 1963, the accumulated levels of strontium-90 deposited over the United States varied from about 100 to 125 millicuries per square mile in the "wet" areas (areas of greatest annual precipitation) to 40 to 50 millicuries per square mile in the "dry" regions. Figure 1 shows the continental United States; the areas considered as "wet" are closely hatched, "dry" areas are unshaded, and intermediate precipitation regions have widely spaced hatching.

3.4 Utilizing sampling data obtained by the Defense Atomic Support Agency's STARDUST Program, it is possible to compare the burden of strontium-90 in the lower stratosphere in early 1963 with the burden approximately a year earlier. Experience indictates that debris present in January up to 55,000 feet will appear in the fallout of the coming year. Figure 2 shows the strontium-90 concentration up to 70,000 feet, the ceiling of the sampling aircraft, in early 1963. The stratosphere below 55,000 feet in the northern hemisphere contained about 2 megacuries of strontium-90 in early 1963, while about 1 megacurie was observed in the same region in early 1962. Thus, the 1963 fallout is expected to be about twice that of the stratospheric component in 1962, as shown in Table 4. About 80 percent of the stratospheric burden available for fallout in 1963 came from testing conducted in 1962. The apparent age of the 1963 spring fallout is expected to correspond to a mean production time of mid-September 1962. An independent analysis of the input of strontium-90 based on the fission yields given in Table 3 agrees with the estimates in Table 4.

3.5 In Table 4 the annual fallout estimates from weapons tests already conducted have been extended, with considerable uncertainty, to future years. Since the half-life of strontium-90 is 28 years, it decays at the rate of 2.5 percent per year. By 1966, radioactive decay of the accumulated strontium-90 should exceed deposition, resulting in a gradual lowering of the strontium-90 values in succeeding years.

3.6 The possibility exists that fallout estimates can be in error by a factor of two for the year 1963 and by more than a factor of two in subsequent years. The uncertainties in the estimates of fallout are largely due to data limitations, incomplete understanding of atmospheric behavior, and year to year weather differences.

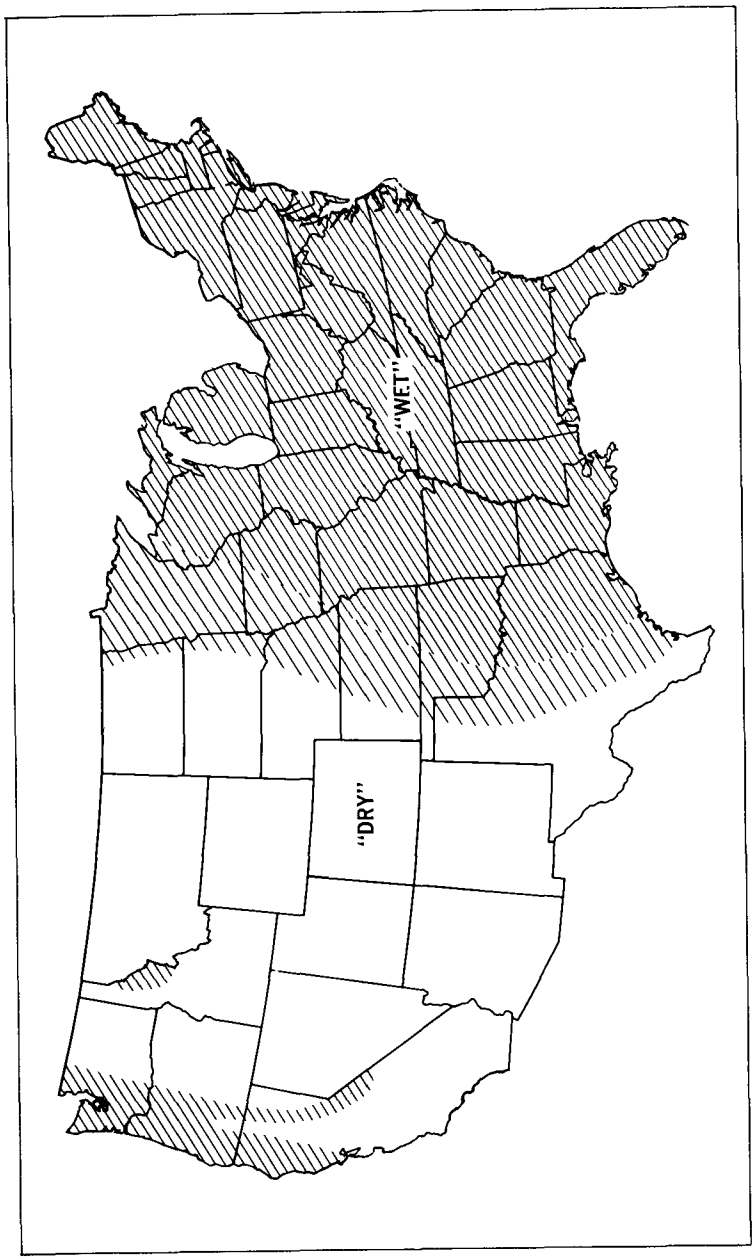

Figure 1.—*Schematic representation of "wet" and "dry" areas in the conterminal United States.*

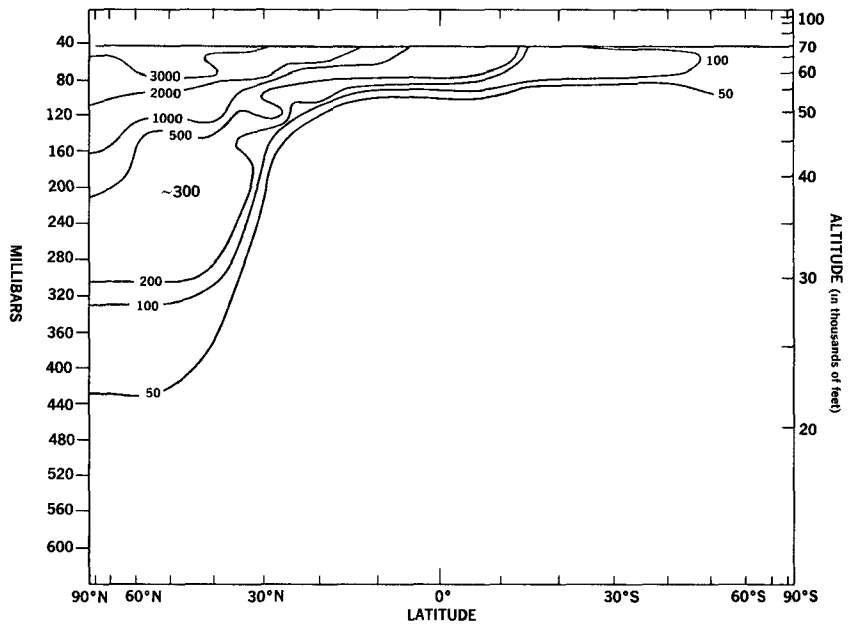

Figure 2.—*Mean distribution of strontium-90 (Disintegrations per minute per 1000 standard cubic feet of air) observed by the STARDUST Program December 1962 through January 1963 (Preliminary).*

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TABLE 4.—EXPECTED ANNUAL DEPOSITION OF STRONTIUM-90 IN THE UNITED STATES
MILLICURIES PER SQUARE MILE

	Most probable value	Variability within area
Deposition during 1962 (stratospheric component only)		
"Wet" area	25	15–35
"Dry" area	10	5–15
Accumulated deposition to January 1, 1963		
"Wet" area	110	100–125
"Dry" area	45	40–50
Expected deposition during 1963		
"Wet" area	50	30–60
"Dry" area	20	10–30
Expected deposition during 1964		
"Wet" area	20	10–25
"Dry" area	8	5–10
Expected deposition during 1965		
"Wet" area	10	5–15
"Dry" area	3	2–5

Note: In each year, it is expected that about 70 per cent of the annual fallout will occur in the first 6 months of the year.

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SECTION IV

RADIONUCLIDES IN THE DIET AND IN PEOPLE

4.1 Estimates of radiation doses received from fallout must take into account exposures from all sources including sources external to the body and those which enter the body by inhalation and ingestion. There is a special interest in those radionuclides that enter the body through the diet. This section considers that part of fallout debris which is found in the food supplies of the nation.

4.2 The most significant contributors to the internal dose to man from fallout radionuclides are strontium-90, cesium-137, iodine-131, strontium-89, and carbon-14. The shorter lived nuclides iodine-131 and strontium-89 are significant in fallout only over the first few months following a test; the others are of importance over many years. Information concerning the appearance of these nuclides in the diet and in man is provided in the following paragraphs.

STRONTIUM-90

4.3 Strontium-90 is a long-lived radionuclide (half-life of 28 years) with chemical properties similar to calcium. It deposits in bone where it has a long residence time. Its concentration in the human body is determined by radiochemical analyses of bone specimens obtained surgically or at autopsy. Since strontium-90 emits only beta particles, the skeletal content cannot be measured externally by instrumental methods. It enters the body in the total diet; milk, wheat products, and vegetables are the main contributors.

4.4 Historically, strontium-90 has been considered the most potentially hazardous component of radioactive fallout and has been the most widely studied. Measurements of its concentration in human bone specimen are the most direct approach to dose estimation, but the time lags in body uptake and in the collection and analyses of specimens are a handicap in maintaining knowledge of current concentrations in the skeleton. However, past experience allows reasonably reliable estimates of strontium-90 in new bone [1] from total dietary intake, from the strontium-90 content of milk, or from fallout deposition measurements.

4.5 The confidence with which estimates of strontium-90 concentrations in new bone can be made from a knowledge of the strontium-90 levels in the diet has increased since the 1959 Con-

[1] New bone is the bone being formed from the dietary components. In the adult it is only that bone being re-formed or exchanged metabolically, and is a small fraction of the skeleton. In the growing child new bone represents a much higher portion of the skeleton.

gressional Hearings on fallout. Prior to that time, diet information was largely derived from milk sampling and from a few other items, but the bone sampling was not correlated with diet samples.

4.6 Beginning in late 1959 the Atomic Energy Commission's Health and Safety Laboratory (HASL) established a quarterly survey in New York City, San Francisco, and Chicago based on food consumption. *Consumers Union* collected and analyzed complete diets of teen-agers for two weeks in 24 cities in November 1959 and similar collections have been made up to the present time. The U.S. Public Health Service (USPHS) monthly institutional diet sampling program involving the age groups 8 to 20 and now covering institutions in 22 states began in March 1961. The Food and Drug Administration (FDA) set up a total diet sampling program in May 1961, and continued regional sampling of major food items.

4.7 Because of these expanded programs, estimates of dietary strontium-90 levels have been greatly improved since 1958. Studies of the relationships between fallout deposition levels and the strontium-90 levels in diet and milk have provided a basis for predicting future levels of strontium-90 in several dietary components and in total intake. These prediction models take into account both the uptake by plant roots from the total accumulated deposition in the soil, and the foliar uptake of fallout deposited during the growth period. Other factors, such as the length of the growing season and differences in agricultural practices also lead to variations in radionuclide concentrations in man's food supplies even though the levels of fallout deposition appear to be similar. Thus, the observed radionuclide levels in milk and other foods per millicurie of strontium-90 deposited per square mile are somewhat higher in the southern part of the U.S., than they are in the north. Similarly, the food chain of lichen-caribou-man, which is characteristic of the Far North may sometimes lead to transient levels in food for a given level of fallout deposit many times higher than corresponding levels in the "wet" areas of the U.S.

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4.8 Studies of strontium and calcium metabolism show that the ratio of strontium-90 to calcium in new bone may be estimated as about one-fourth of the ratio in the diet, since the body uses calcium preferentially over strontium. This metabolic discrimination against strontium may be less in infants, but the strontium-90/calcium ratio in new bone will not be greater than that of the diet.

4.9 Based on these considerations and on fallout predictions for 1963, 1964, and 1965, as described in Section III, predictions of

strontium-90 levels in total diet, diet components, and bone have been made.

TOTAL DIET

4.10 Table 5 shows the strontium-90/calcium ratios in the U.S. total diet obtained by measurements made from 1959 through March 1963, and values predicted in the future for the total diet in the "wet" and "dry" areas of the U.S. Following the peaks of 13 to 18 SU (Strontium Unit—See Glossary) reached in 1959 as a result of 1958 weapons tests, the levels dropped by 1961 to 4 to 8 SU. The rise at the end of 1962 and early 1963 resulting from tests in 1961 and 1962 will continue to a predicted maximum of 50 SU in 1963.

4.11 These predicted values resulting from tests conducted through 1962 can be compared with measurements made since 1959 only on the basis of average levels for broad regions. Measurements made in the pasteurized milk network during 1961 and 1962 indicate that the average annual concentration of strontium-90 in milk produced in the "wet" area of the U.S. is about 1.5 times greater than the annual average for milk produced in the "dry" area. The maximum difference between the lowest station in the "dry" area and the highest station in the "wet" area in 1962 was about a factor of 10 for the radionuclides of interest. The average annual intake of radionuclides in some regions may be about 3 times higher or 3 times lower than the overall national average.[2] The data from Table 5 show that the annual intake of strontium-90 in a diet representative of a typical person in the U.S. dropped from about 15 SU in 1959 to a low of about 6 SU in 1961 before the resumption of nuclear testing. The large increase predicted for the year 1963 was not generally evident in measurements made through March. However, the maximum fallout rates are expected to have occurred during the months of April and May, so surveillance measurements of nuclides such as cesium-137 and strontium-89 should show sharp increases by June if these predictions are approximately correct. The decrease in subsequent years reflects the diminished fallout rates predicted for those years.

DIET COMPONENTS

4.12 The percentage contributions of four major diet categories to the diet weight, strontium-90 and calcium intakes for the tri-

[2] This information is of interest since previous estimates have presented the analyses in terms of the national average, whereas an attempt is being made to analyze the "wet" and "dry" regions separately in this report.

city diet studies of the Health Safety Laboratory are shown in Table 6. It is apparent that an attempt to substitute other diet items for milk would decrease calcium intake more sharply than strontium-90 and in fact increase the strontium-90/calcium ratio of the diet. A number of studies have shown that conservative estimates of the strontium-90/calcium ratio in the total diet may be made by multiplying the ratio of strontium-90/calcium in milk for a particular locality by 1.5. The strontium-90/calcium ratio in milk may be the same as that in the diet during periods of fresh fallout.

4.13 The levels of strontium-90 in milk measured in the past, and predicted for the future are shown in Table 7. The measured values of strontium-90 in the milk supply of New York City were about 9 picocuries per liter of milk in 1959 and dropped to a low of 8 picocuries in 1961. The concentration rose to a value of about 14 picocuries per liter of milk in 1962 and is projected to average about 30 picocuries per liter in 1963 and then drop to values of about 17 picocuries per liter by 1965. It should be recognized that Table 5 considers the total diet which contains food from several areas, while Table 7 is concerned with milk alone. The relationship that the strontium units in the total diet equal 1.5 times the strontium units in milk was derived when this relationship was stable. The predictions in Table 5 cannot be derived from Table 7 since, as already noted, the relationship changes during periods of fresh fallout.

4.14 The levels of strontium-90 in wheat and in white flour measured in the past and predicted for the future are shown in Table 8. Wheat levels are more dependent on the fallout rate component than are milk levels and thus they vary over a wider range.

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4.15 The levels of strontium-90 in wheat are among the highest found in important food items. The maximum level resulting from past weapons testing is expected in the 1963 wheat crop and may average as high as 250 picocuries of strontium-90/kilogram in harvested wheat. Milling, distribution, and storage practices bring about much lower levels in major dietary wheat products, and also make it unlikely that levels of strontium-90 ingestion through wheat products in any particular area will differ much from the national average.

4.16 From 70 to 80 percent of the wheat consumed by humans in the United States is in the form of bread made from white flour. This wheat is produced almost entirely on the Great Plains from Texas to North Dakota and Montana, and the concentration of

strontium-90 has differed little from the national average in any past year. Most of the remaining wheat is consumed in the form of other baked goods and is produced primarily east of the Mississippi River or in the Pacific Northwest. Less than five percent of the wheat consumed is in the form of whole wheat bread or cereals, and very little is in the form of bran. Although the latter products contain a higher concentration of strontium-90 than white flour or whole wheat, the relatively small quantities consumed prevent them from becoming major contributors of strontium-90 in the total diet.

4.17 Water, meat, fish, poultry, eggs, sugars and fats contribute negligible amounts of strontium-90 to the diet. Fruits and vegetables contribute about one-third of the total intake of strontium-90, which is quite comparable with their weight intake. These figures are based on the foods as prepared for eating; slightly higher values are found in the raw unwashed items.

4.18 The levels of strontium-90 measured in the past and predicted for new bone in the future are shown in Table 9. The predicted value for new bone is taken as one-fourth the predicted strontium-90/calcium ratio in the total diet in order to indicate the concentrations being deposited in the skeletons of the younger age groups. However, as pointed out in FRC Report No. 2, the mean bone dose is a better estimate of risk inasmuch as a larger volume of tissue is affected. Calcium and strontium-90 in new bone is continually redistributed as the result of normal bone metabolism, so the observed values in the skeleton would be expected to be lower than the maximum concentration in new bone during a relatively short period of time (i.e., one year). Thus the calculated concentrations of strontium-90 in new bone in 1963, 1964, and 1965 are 12, 8, and 5 SU respectively, whereas the values estimated in bone for the 0–4 age group are about 5, 7, and 7 SU respectively in the "wet" areas of the United States and 3, 5, and 5 SU respectively in the "dry" areas.

CESIUM-137

4.19 Cesium-137, another long-lived radionuclide (half-life 30 years), distributes itself throughout soft tissue and has a relatively short residence time in the body. Its gamma radiation allows direct measurement in the living body with a whole-body counter.

4.20 The distribution of cesium-137 in the diet is not well defined, but milk, meat, and vegetables are the main contributors. Trends in dietary cesium-137 have been similar to those for strontium-90, in that both tend to fluctuate with fallout rate. Because of this dependence on fallout rate and the rapid turnover rate of

cesium in the body, cesium-137 levels in foods and in the body increase and decrease more rapidly than levels of strontium-90. Peak concentrations of cesium-137 in milk have appeared about one month after peak fallout rates, and peaks in the balance of the diet have appeared about one year after peak fallout rates. Peak levels in people have been observed about seven months after peaks in fallout rates.

4.21 Because of the differences in the mechanisms by which cesium-137 moves through the environment, predictions for cesium-137 cannot be made on the same basis as those for strontium-90. About all that can be done is to make comparisons with previous test patterns and the corresponding observations for milk and man, and noting that a year by year comparison is not direct inasmuch as there are different time lags in the responses. Table 10 gives the observations on cesium-137 measured in pasteurized milk samples by the U.S. Public Health Service from 1959 through the first quarter of 1963. Table 11 gives measured and predicted concentrations of cesium-137 in milk and man.

4.22 Table 10 shows that the concentration of cesium-137 in milk in picocuries per liter, was about 4 to 5 times the corresponding strontium-90 concentration in 1959; it was essentially the same as strontium-90 in 1960 and 1961; it rose to 3 to 4 times the strontium-90 concentration in 1962 as the result of fresh fallout in that year. Although there is no uniform relationship between cesium-137 and strontium-90 concentrations in milk, estimates based on fallout rate lead to the conclusion that the average "wet"

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area concentrations of cesium-137 in milk may be about 140, 70, and 30 picocuries per liter respectively in 1963, 1964, and 1965. The anticipated concentration in man is expected to be about 150 picocuries per gram of potassium [3] in 1963 and then drop to a value below 100 by the end of 1965.

IODINE-131

4.23 Iodine-131 is a short-lived radionuclide (half-life 8 days) which concentrates in the thyroid gland. Its gamma radiation allows direct measurement in the body. The residence time in the body and the half-life are both short. Therefore iodine-131 disappears in a few weeks. The significant diet contributor is milk because the time lag between production, and distribution is only

[3] Potassium is essential to life and its naturally occurring radionuclide contributes a whole-body dose of about 20 millirems per year. It is chemically similar to cesium and is distributed through the soft tissues of the body. Therefore, cesium concentrations in people are usually reported as the cesium-137/potassium ratio.

a few days.

4.24 The U.S. Public Health Service measurements of iodine-131 in milk are summarized in Table 10. Iodine-131 levels from past testing are based on values observed from 1959 through March 1963. Radioactive decay has reduced the iodine-131 resulting from tests conducted in 1962 to insignificant levels. The presentation of iodine-131 levels by "wet" and "dry" areas is included only to keep the form of the information comparable. The deposition of iodine-131 is largely associated with material initially injected into the troposphere and hence is not systematically related to the mean annual rainfall.

4.25 Since November 1961, the Public Health Service with the cooperation of selected medical centers throughout the continental United States has collected and analyzed several hundred thyroid autopsy specimens. The thyroids were primarily from adults experiencing a traumatic death. Iodine-131 values ranged from 0–20 picocuries per gram of thyroid with a probable mean in the range of 5–7 picocuries per gram. Iodine-131 in the thyroid was found only where appreciable levels of iodine-131 were observed in the pasteurized milk network samples in the area from which the thyroid specimen was obtained.

4.26 The highest station for iodine-131 in milk in the continental U.S. in 1962 was in Utah. A large percentage of the observed iodine-131 occurred as the result of atmospheric tests in Nevada. Although the Utah State Health Department reported iodine-131 concentrations in excess of 1000 picocuries iodine-131 per liter of milk for about a week, the equivalent daily intake for a year for the population in the milk fed would have been 103 picocuries iodine-131 per liter. Milk from individual farms or from individual cows could, of course, be higher or lower than the measured average for the station.

STRONTIUM-89

4.27 Strontium-89 has a half-life of 50 days, and is similar chemically to strontium-90. It deposits preferentially in bone, and remains there until it is reduced to a negligible level through radioactive decay. Like strontium-90 it is a beta emitter and is measured in humans by the radiochemical analyses of bone samples obtained at autopsy. Milk is the important dietary contributor since time lags between deposition and the production and distribution of most other foods result in the radioactive decay of strontium-89. Strontium-89 appears in other foods attached to their surfaces.

4.28 The observed values for strontium-89 in milk since 1959 are given in Table 10. It can be seen that the annual average concentration for most stations was three to four times the corresponding concentration of strontium-90 for that station. Based on the apparent age of the fission debris in the stratosphere, the strontium-89/strontium-90 ratio in milk in 1963 may reach a maximum value of about 8 during the first part of the year, but due to the short half-life of strontium-89, the annual averages in 1963 should be comparable to those observed in 1962.

CARBON-14

4.29 Carbon-14 is a very long-lived radionuclide (half-life 5.760 years) produced by the interaction between neutrons and nitrogen in the atmosphere. It is produced naturally by cosmic radiation, and artificially by nuclear weapons. It follows non-radioactive carbon chemically and metabolically, and is part of all living matter. Carbon-14 in the body is essentially in equilibrium with carbon-14 in the environment. The environmental level tends to decrease slowly as carbon-14 enters the carbonates of the deep ocean waters and sediments. Carbon-14 emits only beta particles and cannot be measured directly in the body. All items of the diet contribute in proportion to their carbon content so that measurements made on atmospheric carbon dioxide, which is the source of plant carbon, can be substituted for measurements in the body.

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4.30 As a result of nuclear weapons tests conducted through 1958 the tropospheric level of carbon-14 was about 30 percent above the equilibrium inventory of naturally produced carbon-14 in the atmosphere due to its normal production by cosmic radiation.

4.31 The testing conducted in 1961 and 1962 probably produced about 100 times more carbon-14 than was produced naturally by cosmic rays during the same period. This should raise the artificially produced carbon-14 in the atmosphere to twice the natural levels over the next several years. This excess carbon-14 is expected to be removed from the atmosphere by exchange with the ocean with a rate corresponding to a half-time (See Glossary) of about 33 years. Ultimately, about 96 percent will be removed, leaving an atmospheric level about 4 percent higher than the natural level. This conclusion is consistent with preliminary data from the stratospheric sampling program.

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TABLE 5.—AVERAGE STRONTIUM-90 CONTENT OF U.S. TOTAL DIET

(pc Sr^{90}/g Ca)

	"Wet" area	Observed	"Dry" area
1959	13–18		9
1960	11		4
1961	4–8		3–6
1962	8–13		4–8
1963 (through March)	10		8
		Predicted	
1963	50		35
1964	30		20
1965	20		10

TABLE 6.—AVERAGE PERCENT CONTRIBUTIONS OF DIET CATEGORIES

			Approximate percent of annual strontium-90 intake		
	Diet Weight [1]	Diet Calcium	N.Y.	Chicago	S.F. [2]
Milk products	33	61	51	39	37
Grain products	14	15	16	26	24
Fruits and vegetables	36	13	30	30	32
Others	17	11	3	5	7
Total	100	100	100	100	100

[1] The diet weights do not include water, coffee, tea and other nonmilk beverages.
[2] S.F.—San Francisco.

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TABLE 7.—AVERAGE STRONTIUM-90 CONTENT IN MILK IN THE U.S.

[pc Sr^{90}/1. of milk]

	New York	"Wet" areas	San Francisco	"Dry" areas
		Observed (PHS values)		
1959 [1]	9	14	—	9
1960	9	9	4	5
1961	8	9	4	6
1962	14	15	5	10
1963 (First quarter)	16	18	8	11
		Predicted		
1963	31	—	11	—
1964	20	—	6	—
1965	17	—	4	—

[1] Based on raw milk data; dash (—) indicates no raw milk station.

TABLE 8.—STRONTIUM-90 CONTENT OF WHEAT AND FLOUR IN THE U.S.

[pc/kg]

Year of Harvest	Average from 9–15 states weighted for production (HASL) [1]		Average of pared samples (FDA) [2]		FDA sampling program
	Wheat	Flour	Wheat	Flour	Wheat
	Observed				
1959	48	9	—	—	—
1960	26	4	13	4	17
1961	23	7	19	4	18
1962	—	—	—	—	[3] 56
	Predicted				
1962 [3]	130	22			
1963	250	40			
1964	100	16			
1965	50	8			

[1] (HASL) Health and Safety Laboratory, USAEC, New York.

[2] (FDA) Food and Drug Administration, Department of Health, Education and Welfare. The "Paired Samples" indicates that the same sample of wheat was analyzed when made into flour.

[3] Incomplete—includes less than 50% of production. The 1962 predicted value is presented pending the availability of more complete data.

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TABLE 9.—AVERAGE STRONTIUM-90 CONTENT OF HUMAN BONE IN THE U.S.

[pc Sr^{90}/g Ca]

	"Wet" areas	"Dry" areas
	Observed (0–4 years old)	
1958 [1]	2.0	2.0
1959	2.7	2.2
1960	2.4	1.8
1961	2.6	0.9
1962 (6 months)	2.9	1.0
	Predicted (new bone) [2]	
1963	12	9
1964	8	5
1965	5	3

[1] Data for 1958–60 are from Lamont Geological Observatory, 1961–62 are from HASL.

[2] One-fourth the predicted total diet values in Table 5.

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TABLE 10.—RADIONUCLIDE CONCENTRATIONS IN PASTEURIZED MILK

[pc/1. of milk]

Year	Strontium-90				Strontium-89				Cesium-137				Iodine-131			
	"Wet"	"Dry"	A.[2]	H.[3]	"Wet"	"Dry"	A.[2]	H.[3]	"Wet"	"Dry"	A.[2]	H.[3]	"Wet"	"Dry"	A.[2]	H.[3]
1959 [1]																
Annual average level	14	9	—	—	30	20	—	—	65	55	—	—	<10	<10	—	—
1960:																
Annual average level	9	5	7	4	<5	<5	<5	<5	10	10	10	20	<10	<10	<10	<10
1961:																
Annual average level	9	6	8	5	15	5	15	<5	10	10	10	20	20	20	60	<10
1962:																
Annual average level	15	10	10	5	55	38	51	27	49	36	37	27	29	36	104	12
1st Quarter 1963:																
3-month average level	18	11	11	8	40	30	20	55	75	65	65	55	<10	<10	10	20

[1] Based on raw milk data; dash (—) indicates no raw milk station. (Table prepared from USPHS data.)
[2] Alaska.
[3] Hawaii.

TABLE 11.—AVERAGE CESIUM-137 MEASURED AND PREDICTED CONCENTRATIONS IN MAN AND MILK

	Measured			
	In Man [2]			In milk "wet" areas [3]
	Washington, D.C.	Los Alamos	Average	
1957	—	51	—	—
1958	[1] 69	62	—	—
1959	67	74	70	65
1960	51	67	60	10
1961	31	—	30	10
1962	—	—	—	49
			Predicted	Predicted
1963			150	140
1964			120	70
1965			80	30

[1] July-December only.
[2] Units, picocuries per gram of potassium.
[3] Units, picocuries per liter of milk. (USPHS Data.)

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SECTION V

RADIATION DOSE ESTIMATES

Exposure from Testing Conducted in 1962

5.1 Radiation doses that could affect present and future generations as the result of nuclear weapons testing conducted through 1961 were reported in FRC Report No. 3, "Health Implications of Fallout from Nuclear Weapons Testing through 1961." The present report considers doses attributable to the tests conducted *in* 1962 separately from the cumulative doses attributable to all tests conducted *through* 1962. The major interest is to isolate as much as possible the effects of the fallout rates expected from 1962 through 1965. Results from tests conducted *in* 1962 are shown in Table 12. Estimates of doses from short-lived nuclides, cesium-137, strontium-89, and strontium-90 were based on measurements made through March 1963 plus the predicted fallout deposition through 1965 in order to emphasize the information which is important in the immediate future. This procedure leaves a small percentage of the debris unaccounted for since it will still be in the stratosphere in 1965. However, the short-term carbon-14 estimates and the bone and bone marrow estimates would not be changed substantially. Estimates of radiation doses incurred in 1962 from tropospheric fallout were based on surveillance data as shown in Table 10.

5.2 Predictions shown in Table 12 of future doses from external

radiation from debris yet to be deposited are based on projected deposition rates for "wet" areas of the U.S. as given in Table 4. The levels of cesium-137 were taken to be 1.7 times the level of strontium-90. Estimates of the possible contributions from short-lived nuclides were based on an apparent age of fission debris in the stratosphere corresponding to a mean production time of mid-September 1962, and the estimated levels of these nuclides relative to strontium-90 at the time of deposition. The estimated doses were then calculated, making corrections for weathering, shielding, and the movement of different radionuclides through the environment to man.

5.3 The period of the test moratorium from 1959 to 1961 was sufficient for a peak level of radionuclides such as strontium-90 and cesium-137 to occur and for subsequent downward trends in levels of these radionuclides to be established. The period was not sufficient to define the effective rates of removal of these radionuclides from the biosphere in the absence of deposition of additional fallout. The effective half-times in the environment for these radionuclides and their biological availability are, therefore, subject to uncertainty, and dose estimates in this report should be considered in that light.

5.4 Whole body and reproductive cell doses from both short-lived and long-lived radionuclides from 1962 tests were considered to begin during 1962. External exposures from cesium-137 were assumed to diminish with an effective halftime of ten years. Exposures to external short-lived radionuclides and short-lived internal emitters such as strontium-89 and barium-140—lanthanum-140 were considered to be completed within about one year following the 1962 tests.

5.5 Strontium-90 is expected to be effectively removed from that part of the biosphere which is important to man with an effective half-time of ten years. Therefore, doses for bone and bone marrow from 1962 tests were predicted for infants born in 1963 since this is the most sensitive age group and is expected to have the maximum concentration of strontium-90 per gram of calcium as discussed in Section IV of this report. Similarly, this is the age group expected to receive the highest lifetime bone dose from tests conducted in 1962.

5.6 The whole-body and bone doses to people deriving their foodstuffs from "dry" areas of the U.S. are estimated to be somewhat less (possibly as much as one-third to one-half) than those deriving their food from "wet" areas. Individuals and population groups subsisting on diets differing greatly from the diet typical of the majority of the population in "wet" and "dry" areas of the

U.S. are expected to receive doses both higher and lower than the average dose for the "wet" area presented in Table 12. Although some individuals in the U.S. will receive doses higher than for "wet" areas and some will receive doses lower than for "dry" areas, it is expected that doses differing from these average values by more than a factor of 10 will not occur.

5.7 For calculations of 30-year and 70-year doses, exposure to carbon-14 from 1962 tests of 217 MT total yield (Table 2) was assumed to be reduced with a mean time of 48 years (see Glossary), or a half-time of 33 years. Since the total yields of tests conducted in 1962 are about two-thirds of the total yield from tests conducted through 1961, the long-term doses from carbon-14 from 1962 tests will be almost the same as the long-term doses from carbon-14 discussed in FRC Report No. 3.

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Doses from all Tests through 1962

5.8 Estimates of doses to people in the U.S. in "wet" areas from exposure to fallout radioactivity produced by all nuclear tests conducted through 1962 are presented in Table 13. These estimates are based upon observed levels of deposited radioactivity and observed levels of radioactivity in people for "wet" areas through 1962 and upon annual deposition levels of radioactivity expected to occur in "wet" areas through 1965.

5.9 Whole-body and reproductive cell doses from both short-lived and long-lived radionuclides produced by all tests were estimated for population in the U.S. born prior to beginning of nuclear testing. These doses are assumed to be independent of age groups within the population. Based primarily upon measurements of radioactivity in 1961 and 1962, 30-year and 70-year doses related to tests through 1961 are now estimated to closely approximate the lower number of the range of estimated values for whole-body and reproductive cells presented in Table I of FRC Report No. 3 (30-year, whole body and reproductive cells both 60 millirems; 70-year, whole-body and reproductive cells both 70 millirems;). The estimates of whole-body and reproductive cell doses for all tests through 1962 in Table 13 of the current report will be found to be the sum of whole-body doses from all tests through 1961 (shown in Col. 1 of Table 13), plus the estimated whole-body and reproductive cell doses from 1962 tests presented in Table 12, and repeated as Col. 2 in Table 13.

5.10 The doses to bone and bone marrow from all tests through 1962, presented in Table 13, will not be the sum of estimated bone doses in FRC Report No. 3 (Col. 1 of Table 13) plus doses from

1962 tests in Table 12 of this report. The doses to bone and bone marrow were estimated for the age group in the population expected to receive the highest doses from all tests through 1962. The age group considered was infants born in 1963. This determination was based upon a review of measured values of strontium-90 in human bone samples obtained from the beginning of testing through the first six months in 1962, predicted levels in new bone and bone being re-formed or exchanged metabolically from 1963 through 1965, the whole body doses for infants born during various years since testing began.

5.11 Doses to bone and bone marrow in Table 13 are very little higher than those estimated for tests through 1961 and presented in Table I of FRC Report No. 3. The reason for such results is that measured levels of strontium-90 deposition were less in 1962 than had been predicted.

5.12 Doses to bone and bone marrow for the adult population in the U.S. are expected to be smaller than the doses to the most sensitive age group of children.

5.13 Doses to people in "dry" areas of the U.S. from all tests through 1962 are estimated to be about one-third to one-half those for people in "wet" areas. The lower deposition levels in the "dry" areas reduce the exposure from sources external to the body, and lower the concentrations of radionuclides in locally produced food.

5.14 Thirty-year and 70-year carbon-14 doses from tests through 1962 were estimated using a total yield of 459 MT [1], a production rate of 2×10^{26} atoms carbon-14 per MT total yield, and a dose rate of 1 millirem per year for naturally occurring carbon-14. The exposure from carbon-14 was assumed to be reduced with a mean time of 48 years, the time calculated for exchange between the atmosphere and the vast carbon reservoir in the oceans.

5.15 It was estimated in FRC Report No. 3 that carbon-14 from weapons testing conducted through 1961 would lead to an average per capita whole-body and reproductive cell dose of 10 to 15 millirems in the first thirty years. This was estimated to equilibrate eventually at a level of about 0.75 millirem per generation, and this would continue for hundreds of generations. Since testing conducted in 1962 contributed almost an equal amount of carbon-14, the above values may be doubled to arrive at the long-term doses that are now predicted.

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[1] Based on the sum of the total yields for air detonations and one-half the total yields of surface detonations from Table 1 of this report.

Thyroid Doses from Iodine-131

5.16 Doses to the thyroid due to iodine-131 in fallout have occurred during and immediately following periods of nuclear testing. The Public Health Service's Pasteurized Milk Network reported no iodine-131 at detectable levels in the interval from 1959 through August 1961. Table 10 shows that following resumption of nuclear testing in September 1961, iodine-131 was found generally throughout the nation in zones of both high and low precipitation. Limited *in vivo* measurements in the fall of 1961 and in 1962 support a conclusion that fresh milk is the principal source of iodine-131 exposure to the thyroid gland in a large proportion of the population.

5.17 The relationship between iodine-131 intake and thyroid dose is based on the biological model derived in FRC Report No. 2. An estimated annual average daily intake of 80 [2] picocuries of iodine-131 would result in an average dose of 500 millirems in one year to a suitable sample of exposed infants in which the thyroid weight is taken as two grams. This condition applied approximately to the age group from 6 to 18 months. With children above approximately 18 months of age the dose to the thyroid would become progressively smaller with the increase in size of the thyroid to a value in the adult of approximately one-tenth the value in infants.

5.18 Estimates of iodine-131 dose to the thyroid developed for infants 6 to 18 months of age on the basis of the above relationship between intake and dose, assuming one liter of fresh milk consumption per day, ranged from 30 to 440 millirems in 1961 and from 30 to 650 millirems in 1962. These values are estimates of thyroid dose for high and low individual stations in the pasteurized milk network for the years indicated. It has been estimated that a small number of infants in localized areas conceivably could receive doses from 10 to 30 times the average.

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[2] "Using the known factors and the assumptions enumerated above, it can be calculated that an average daily intake of 80 micromicrocuries of iodine-131 per day would meet the RPG for the thyroid for averages of suitable samples of an exposed population group of 0.5 rem per year. As stated in Section I, it is appropriate to specify three ranges of transient rates of daily intake in order to provide guidance for the Federal agencies in the establishment of operating criteria. For this purpose, the value of 80 micromicrocuries per day has been rounded off to 100 micromicrocuries per day as being more in keeping with the precision of the data." (Paragraph 2.14, FRC Report No. 2).

TABLE 12.—ESTIMATED RADIATION DOSES IN THE "WET" AREAS FROM TESTING CONDUCTED IN 1962

[Doses expressed in millirem.]

Tissue or organ	Radiation doses	
	30-year	70-year
Whole body and reproductive cells:		
Cesium-137 external	9	10
Cesium-137 internal	9	10
Short-lived nuclides	18	18
Carbon-14	11	18
Total	47	56
Bone:		
Strontium-90		180
Strontium-89		39
Whole body		56
Total		275
Bone marrow:		
Strontium-90		60
Strontium-89		13
Whole body		56
Total		129

TABLE 13.—ESTIMATED RADIATION DOSES IN THE "WET" AREAS OF THE U.S. FROM ALL NUCLEAR WEAPONS TESTING CONDUCTED THROUGH 1962

[Doses expressed in millirem.]

Tissue or organ	From tests conducted through 1961 [1]	From tests conducted in 1962	From all tests conducted through 1962	From natural background
Whole body and reproductive cells:				
1 year	10–25	24		
30 years	60–130	47	[2] 110	3,000
70 years	70–150	56	[2] 130	7,000
Bone:				
1 year	30–80	83		
70 years	400–900	275	[3] [4] 465	9,100
Bone marrow:				
1 year	20–40	44		
70 years	150–350	130	[3] [4] 215	7,000

[1] Taken from Table 1, FRC No. 3. Based on surveillance measurements made in 1962, the actual exposures are expected to correspond to the low end of the reported range. Actual exposures to bone and bone marrow are now expected to be even lower than the reported range.

[2] The whole body dose is based on the average person receiving the highest exposure assuming that the person was born prior to the beginning of testing. Current estimates indicate that from tests conducted through 1961, the whole body and reproductive cell doses for 30 and 70 years will be 63 and 74 millirems respectively.

[3] The bone and bone marrow doses are calculated for the average person born in 1963 since it is believed that this person might receive the highest bone dose of any age group.

[4] Doses in previous columns are not additive; see paragraph 5.10.

SECTION VI

EVALUATION

6.1 The Federal Radiation Council reported on the health implications of fallout from nuclear weapons testing through 1961 in FRC Report No. 3, issued in May 1962. (Copy attached) The doses were evaluated by comparison with the doses due to naturally occurring sources of radiation following the procedures developed over the past several years through studies conducted by the National Academy of Sciences, the United Nations Scientific Committee on the Effects of Atomic Radiation, the National Committee on Radiation Protection and Measurements, the International Commission on Radiological Protection, and the fallout prediction panels convened by the Joint Committee on Atomic Energy in 1957, 1959, and 1962. Two types of biological effects are of concern; effects induced by exposure of the reproductive cells (genetic effects), and possible effects on persons now living (somatic effects) resulting from the exposure. Both types of effects have been considered and evaluated by the National Academy of Sciences Committee on the Biological Effects of Atomic Radiation and the conclusions of this committee have been accepted by the Federal Radiation Council as the basis for the scientific aspects of the present evaluation.

6.2 The genetics subcommittee of the National Academy of Sciences Committee on the Biological Effects of Atomic Radiation has recommended that the genetically effective per capita dose during the first thirty years of life be limited to 10 Roentgens (equivalent to 10,000 millirems as used in this report) from all man-made sources, including medical exposures.

6.3 The revised estimates of the short-term per capita effective dose to the reproductive cells show that weapons tests conducted during 1962 will be about 47 millirems. All tests conducted through December 1962 will result in a per capita 30-year dose of about 110 millirems. This is about one-hundredth of the amount recommended by the National Academy of Sciences. These values are considerably less than the corresponding 30-year dose of 3,000 millirems from naturally occurring sources during the same period. Similarly, the variations in dose-rate from worldwide fallout in different parts of the country are less than the variations in dose-rate from naturally occurring sources in the inhabited parts of the world. Further, comparison with the 5,000 millirems per generation proposed previously by the Federal Radiation Council as a level of genetic risk that would be acceptable to gain the benefits of nuclear energy from normal peacetime operations and

the 10,000 millirems per generation recommended by the NAS Subcommittee on Genetics as a "reasonable quota" for man-made radiation exposure of the general public indicates that present and anticipated levels of fallout do not constitute an undue risk to the genetic future of the nation.

6.4 The genetically significant dose per generation attributable to tests conducted through 1962 will be greatly reduced in later generations. The total dose which may come eventually from material still in the stratosphere in 1966 plus the long-term effects from carbon-14 may be somewhat larger than the estimates reported. Thus, the ultimate genetic effects attributable to weapons tests conducted in 1962 are expected to be nearly as much as that from all tests conducted prior to 1962.

6.5 In addition to the possible influence of weapons testing on heredity, the possibility of adverse health effects on persons now living is of concern to the Council. The estimates in Table 13 show that testing conducted through 1962 is expected to result in cumulative whole-body doses over a 70-year period from radionuclides external to the body and radionuclides in the body of about 130 millirems. The biological effect of concern is the induction of serious diseases such as cancer that might result from irradiation of the whole body.

6.6 The Subcommittee on Pathological Effects of the National Academy of Sciences Committees on the Biological Effects of Atomic Radiation (1960) concluded that as long as the criteria for the effective genetic exposure were met, any possible effects on the health of the persons exposed would be much too small to be perceptible. However, the special cases of iodine-131 and strontium-90 which deposit preferentially in the thyroid and bone respectively were pointed out as possible exceptions to the evaluation. The Council, therefore, concludes that except for iodine-131 and strontium-90, the estimated whole-body doses from present and anticipated levels of fallout do not constitute an undue risk in terms of direct effects on the individuals exposed.

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Evaluation of Iodine-131

6.7 The special case of iodine-131 has been recognized by the Federal Radiation Council. The known experience in the U.S. related to iodine-131 in milk from 1959 to the present is summarized in Table 10. The data are reported in terms of the average daily intake of iodine-131 over a 12-month period assuming a consumption of 1 liter of milk per day to correspond to the cumulative levels

of iodine-131 actually observed at the regular milk sampling stations. The corresponding radiation dose for the average infant thyroid in the highest region has a calculated value of 620 millirems. In the special case where nearly all of the annual intake could come from exposure to abnormally high concentrations in a local area, resulting from a single nuclear explosion of low yield, the Council recognized that some small number of individual infants could conceivably receive doses 10 to 30 times the average for the area as a whole.

6.8 Based on the advice of a special panel convened by the Council in the summer of 1962, it was concluded that radiation doses to the thyroid many times higher than those provided in FRC Report No. 2 would not result in a detectable increase in diseases such as thyroid cancer. No case of thyroid cancer in man ascribable to radioactive iodine used in the medical diagnosis and treatment of thyroid disease has yet been established. The radiation doses administered for diagnosis and treatment of thyroid disorders have ranged up to thousands of times higher than the 1.5 rems per year recommended as a Radiation Protection Guide in FRC Report No. 2 for exposure to individuals due to iodine-131 released to the environment from normal peacetime operations.

6.9 The Council concluded in September 1962 that iodine-131 exposures at the levels existing then, involve health risks so slight that countermeasures applied to the food industries might have an adverse, rather than favorable effect on public well-being. It is similarly concluded in this report that iodine-131 doses from weapons testing conducted through 1962 have not caused an undue risk to health.

Evaluation of Strontium-90

6.10 The health risk from strontium-90 arises from the fact that it is taken into the body with calcium and is deposited in the skeleton. Once incorporated into the skeleton, it causes radiation doses to the skeleton at a continuously decreasing rate during the entire life of the individual. The lifetime doses to the age group receiving the highest doses from radionuclides in fallout are expected to be about 465 millirems for bone and 215 millirems for bone marrow. Of this exposure, it is estimated that the average concentration of strontium-90 in new bone at its maximum value from fallout associated with all weapons testing conducted through 1962 may reach about 12 picocuries strontium-90 per gram of calcium, although by metabolic activity this would soon drop to an average concentration in the whole skeleton of about 7 picocuries per gram of calcium. This would give an initial dose rate to new bone of

36 millirems per year and to bone marrow of 12 millirems per year. When redistributed, the dose rates would be 21 millirems per year to bone, and 7 millirems per year to bone marrow.

6.11 The Council has evaluated the possible need and desirability of instituting national programs for modifying the diet, removing strontium-90 from food supplies such as milk, or otherwise limiting the annual intake of strontium-90. A general appreciation of the contribution of strontium-90 to health risks can be gained by comparing the lifetime radiation dose of 465 millirems to bone with the corresponding dose of 9,100 millirems from natural sources; the radiation dose of 215 millirems to bone marrow with the corresponding dose of 7,000 millirems from natural sources.

6.12 With specific reference to strontium-90, the Council has reexamined its recommendations for skeletal burdens of strontium-90 which have been judged to be an acceptable risk to gain the benefits of normal peacetime operations. The selection of these skeletal burdens reflect the simultaneous judgment that the corresponding risks to health are too small to warrant actions that would interfere with or disrupt the normal utilization of food. The skeletal burden of strontium-90 corresponding to the Radiation Protection Guide recommended in FRC Report No. 2 for limiting the exposure of the skeleton is 150 picocuries of strontium-90 per gram of calcium. However, since no operating need for exposures this high was foreseen, the recommended level was reduced to 50 picocuries of strontium-90 per gram of calcium, corresponding to a sustained dietary intake of 200 picocuries of strontium-90 per day. The skeletal burdens of strontium-90 from present and anticipated levels of fallout are well below these values.

6.13 On the basis of the preceding considerations, it is concluded that the health risks from present and anticipated levels of strontium-90 from fallout due to testing through 1962 are too small to justify measures to limit the intake by modification of the diet or altering the normal distribution and use of food. It is further concluded that since milk and dairy products are the major sources of calcium in the U.S. diet and since these products have a lower concentration of strontium-90 in relation to calcium than the total diet, restriction or reduction in the normal use of these food products would be unwise.

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Future Indications

6.14 Looking into the future, the Council notes that the highest

annual dose rates have been associated with the short-lived radionuclides and tropospheric fallout. How much these annual transients contribute to the cumulative lifetime exposures depends, of course, on the frequency with which test programs occur. This review has shown that the testing programs of 1961 and 1962 reached higher levels of fission and total yields than any previous comparable period, and the radionuclides associated with tropospheric fallout were correspondingly evident.

6.15 Renewed attention has been directed to the special case of iodine-131, and the pathways by which it passes through the environment to man. Studies conducted by the Department of Agriculture and the U.S. Public Health Service in 1962 have demonstrated the effectiveness of reducing the iodine-131 levels in milk by adjusting the source of feed used by the dairy cattle if such action is needed. Also, the Atomic Energy Commission has recently initiated a program at the Livermore Radiation Laboratory to gain a better understanding of the processes affecting the distribution of fallout and its movement through the environment. Iodine-131 is included among the nuclides of interest to this program.

6.16 As to long-lived radionuclides such as strontium-90 the Council notes that processes for the removal of radionuclides from milk developed jointly by the Department of Agriculture, the Public Health Service, and the Atomic Energy Commission are now being evaluated for the feasibility of full-scale production for possible use in an emergency.

6.17 However, in the Council's judgment, major national programs directed at removing strontium-90 from food supplies would not contribute to the national welfare at present or projected levels of strontium-90. Even if the strontium-90 levels in human bone reached those corresponding to the Radiation Protection Guide established for the control of normal peacetime operations, the removal of strontium-90 from foods would not necessarily be in the best interests of the nation. The Council would have to consider whether the health risk would be great enough to justify the total impact of such a program on the economy and the necessary allocation of national resources in relation to the health benefits that might be achieved through feasible reduction in strontium-90 intake.

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GLOSSARY OF TERMS

Absorbed Dose.—The energy imparted to matter by ionizing radiation per unit mass of irradiated material at the place of interest.

Activity. The number of disintegrations of a quantity of radionuclide per unit time.

Average Dose. The arithmetic mean radiation dose. The average may be taken with respect to time, number of people, location, or the dose distribution in tissue.

Beta Radiation. Swiftly moving electrons emitted by radioactive substances. Strontium-90, strontium-89, and carbon-14 all emit beta particles.

Biological Half-life. The time taken for the body burden of a radionuclide to be reduced by biological removal processes to one-half its initial value. Radioactive decay is not involved.

Body Burden. The amount of a specified radioactive material or the summation of the amounts of various radioactive materials in a person's body at the time of interest.

Critical Organ. An organ or tissue most affected by ionizing radiations from the deposition of a specified internal emitter or from external sources. The reproductive cells are considered the critical tissue for genetic effects. The thyroid is considered the critical organ for the effects from radioactive iodine. Bone and bone marrow are considered the critical organs for the effects from strontium-90.

Curie. A measure of the activity (rate of disintegration or decay) of a radioactive substance. One curie equals 3.7×10^{10} nuclear disintegrations per second, or 2.2×10^{12} per minute.

Megacurie (MC).—One million curies. A fission yield of 10 megatons creates approximately 1 megacurie of strontium-90.

Millicurie (mc). One-thousandth of a curie. Also one thousand microcuries.

Microcurie (μc). One-millionth of a curie.

Picocurie (pc). One micromicrocurie (μμc). This is one-millionth of a microcurie or one-millionth-millionth of a curie. It corresponds to a rate of radioactive decay equivalent to 2.2 disintegrations per minute.

Dose. A measure of the energy absorbed in tissue by the action of ionizing radiation on tissue. As used in radiation protection, definitive practice requires that the term be used in such combining forms as radiation dose, absorbed dose, whole-body dose, and partial-body dose.

Dose-effect Relationship. The magnitude of a specific biological effect, expressed as a function of the radiation dose producing it. It is frequently represented as a curve described as a dose-effect curve, dose-effect response curve, or dose response curve.

Dose Equivalent. A concept used in radiation-protection work to permit the summation of doses from radiations having varying linear energy transfers, distributions of dose, etc. It is equal numerically to the product of absorbed dose in rads and arbitrarily defined quality factors, dose distribution factors and other necessary modifying factors. In the case of mixed radiations, the dose equivalent is assumed to be equal to the sum of the products of the absorbed dose of each radiation and its factors.

Effective Half-life or Half-time. The time taken for the total number of atoms of a radioactive nuclide to be reduced to one-half of its initial value by combined radioactive decay and biological removal processes.

Environment. The physical environment of the world we live in consisting of the atmosphere, the hydrosphere, and the lithosphere. The biosphere is that part of the environment supporting life and which is important to man.

Exposure. A measure of x and gamma radiation at a point. However, it is often used in the sense of being made subject to the action of radiation.

External Exposure. The exposure of body tissues to ionizing radiation originating from sources outside the body.

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Fallout. The process of phenomenon of the fallback to the earth's surface of particles contaminated with radioactive material from the radioactive cloud. The term is also applied in a collective sense to the contaminated particulate matter itself. The early (or local) fallout is defined, somewhat arbitrarily, as those particles which reach the earth within 24 hours after a nuclear explosion. The delayed (or worldwide) fallout consists of the smaller particles which ascend into the upper troposphere and into the stratosphere and are carried by the winds to all parts of the earth. The delayed fallout is brought to earth, mainly by rain and snow, over extended periods ranging from months to years.

Internal Exposure. The exposure of body tissue to ionizing radiations originating from radionuclides contained within the body.

Whole-body Exposure. Literally, the exposure of the whole body.

Fission. The process whereby the nucleus of the particular heavy element splits into (generally) 2 nuclei of lighter elements, with the release of substantial amounts of energy. The most important fissionable materials are uranium-235 and plutonium-239.

Fission Products. A general term for the complex mixture of substances produced as the result of nuclear fission. Something like 80 different fission fragments result from approximately 40 different modes of fission of a given nuclear species. The fission fragments, being radioactive, immediately begin to decay, forming additional radioactive products with the result that the complex mixture of fission products so formed contains about 200 different isotopes of 36 elements. For example, iodine-131, being a daughter element with several preceding radioactive parents, reaches its maximum production approximately 7 hours after the detonation of a fission device.

Fission Yield. The equivalent energy released as the result of nuclear fission. The production of fission products is proportional to the fission yield.

Fusion. The process whereby the nuclei of light elements, especially those of the isotopes of hydrogen, combine to form the nucleus of a heavier element with the release of substantial amounts of energy. These are so called thermonuclear reactions because very high temperatures are used to bring about the fusion of the light nuclei. Neutrons, leading to the production of carbon-14, are produced by this reaction; however, fission products are not.

Gamma Rays. Electromagnetic waves of very short wave lengths produced during the disintegration of radioactive elements. Like x-rays, they readily penetrate body tissues.

Genetic Effect. A change in a reproductive cell which would alter the characteristics of an individual produced from the affected cell or which causes a mutation that may be inheritable by subsequent generations.

Half-life. The time required for the activity (the disintegration rate) of a radioactive nuclide to decay to one-half of the initial value.

Internal Emitters. Radionuclides contained within the human body.

Isotopes. Atoms of the same element, i.e., having the same atomic number, but of differing atomic weights. The isotopes of an element have closely similar chemical and physical properties, but different in atomic mass (due to different numbers of neutrons in the atomic nuclei) and in their nuclear properties (e.g., stable, radioactive, fissionable, etc.). Nearly all elements found in nature are mixtures of several isotopes. (See nuclide)

Mean or Average-lifetime. A particular radioactive atom can decay now, later, or never. However, the average or mean-life expectancy of a number of the same radionuclides is a definite quantity and is equal to 1.4 times the half-life. Analogous terms are often used to express changes in radionuclide concentrations in different compartments of the environment as a function of time. For example, the rate of disappearance of carbon-14 from the atmosphere as the result of diffusion into the ocean, the biosphere, and other environmental compartments has been expressed in terms of a half-time of 33 years and a meantime of 48 years.

Megaton Yield. A nuclear detonation which releases a total energy equivalent to one million tons of TNT.

Natural Background Radiation. Ionizing radiations from naturally occurring radionuclides as they exist in nature plus cosmic radiation.

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Normal Peacetime Operations. The peaceful applications of nuclear technology where the primary radiation protection control is placed on the design and use of the source.

Nuclide. An atom of a particular species or element; that is, characterized by an atomic number and an atomic weight. Carbon-14 is a nuclide. Carbon as it occurs naturally consists of 3 nuclides; carbon-12, carbon-13, and carbon-14, which together bear the relationship of isotopes.

Organ or Tissue Dose. The radiation dose received by a particular body organ or tissue. The radiation may be from an external or an internal source.

Population Dose.—The radiation dose received by members of a population. It is usually estimated as that dose which would be received by the average member of the population under consideration.

Radiation Effect.—A response or change induced by exposure to ionizing radiation.

Radiation (Ionizing). Radiation capable of producing ions in a medium, particularly tissues of the human body. Examples are x-radiation and gamma radiation, beta radiation, and cosmic radiation.

Radiation Protection Guide (RPG). The radiation dose which should not be exceeded without careful consideration of the reasons for doing so; every effort should be made to encourage the maintenance of radiation doses as far below this guide as practicable.

Radioactivity. The property or process whereby certain isotopes or nuclides spontaneously disintegrate emitting particles and/or gamma rays by the disintegration of the atomic nuclei. (See activity)

Radionuclide. A radioactive nuclide.

Rem. A special unit of dose equivalent. It is that quantity of any type of ionizing radiation which, when absorbed in the human body, produces an effect equivalent to the absorption of 1 roentgen of x or gamma radiation at a given energy.

Seventy-year Somatic Dose. That whole-body dose received by tissues other than the reproductive cells over a period of 70 years. When calculated for exposures from fallout this dose includes contributions from whole-body radiation from external sources, cesium-137 taken internally, and carbon-14.

Somatic Effect. A change (other than genetic) produced in any tissue which alters the normal body processes of the irradiated individual.

Stratosphere. A relatively stable layer of the atmosphere lying above the tropopause. For the purpose of this document, the lower stratosphere is

defined as the first few tens of thousands of feet above the tropopause and the upper stratosphere as the layer to about 150,000 feet.

Stratospheric Fallout. Fallout associated with weapon debris which was initially injected above the troposphere into the stratosphere. This is the component that results in world-wide distribution of fallout from the testing of nuclear weapons.

Strontium Unit (SU). One picocurie of strontium-90 per gram of calcium, usually in bone but now extended to items of food and milk.

Thirty-year Genetic Dose. The dose estimated to be received from all sources by the reproductive tissues for a period of 30 years. When computed for fallout exposures this includes whole-body doses from external sources, gamma radiation from cesium-137 in the body, and carbon-14. Recent reports indicate that strontium-90 may also be a minor contributor.

Tropopause. The boundary between the troposphere and the stratosphere. It normally occurs at an altitude of about 30,000 to 40,000 feet in polar and temperature regions and about 55,000 feet in the tropical and equatorial regions.

Troposphere. That portion of the atmosphere below the stratosphere. It is that portion in which temperature generally decreases rapidly with altitude, clouds form, and which is associated with all of what we generally know as "weather." The altitude of the troposphere varies from the equator to the poles and from winter to summer.

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Tropospheric Fallout. The deposition of radioactive weapons debris which was initially injected into the troposphere and not deposited as local fallout.

Yield. The total effective energy released in the nuclear explosion. It is usually expressed in terms of the equivalent tonnage of TNT required to produce the same energy release in an explosion.

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4.1e BACKGROUND MATERIAL FOR THE DEVELOPMENT OF RADIATION PROTECTION STANDARDS, REPORT NO. 5, STAFF REPORT OF THE FEDERAL RADIATION COUNCIL, JULY, 1964.

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SECTION I

INTRODUCTION

This report contains background material used in the development of guidance for Federal agencies in respect to: (1) plan-

ning protective actions to reduce potential doses to the population from radioactive fisson products which may gain access to food, and (2) doses at which implementation of protective actions may be appropriate.

The material is directed to guidance concerned with protective actions affecting the normal production, processing, distribution, and use of food for human consumption when the action is taken because of the radioactive content of the food.

The first two reports of the Federal Radiation Council contained background material used in the development of guidance given in the Memorandums approved by the President on May 13, 1960, and September 13, 1961. These reports provided a general philosophy of radiation protection and general principles of control based on the annual intake of radioactive materials. The recommendations contained therein were intended to provide the basis for the control and regulation of normal peacetime operations in which exposure to radiation is a factor. Numerical values for the Radiation Protection Guides designed to limit the exposure of the whole body and certain organs as the result of normal peacetime operations were provided.

During the period of atmospheric testing of nuclear weapons in 1961 and 1962 the question arose as to the possible need for protective actions and the use of existing Radiation Protection Guides for determining the conditions under which the production, processing, distribution, and use of food, particularly fresh fluid milk, should be altered to reduce human intake of radioactive materials from fallout.

In September 1962 the Federal Radiation Council stated, in effect, that the Radiation Protection Guides provided for the conduct of normal peacetime operations are not intended to set a limit at which protective action affecting the normal production, processing, distribution, and use of food should be taken, nor to indicate what kind of action should be taken. In the 1963 hearings, "Fallout, Radiation Standards, and Countermeasures," conducted by the Joint Committee on Atomic Energy, the Council reiterated that position and noted that it would recommend to the President guidance for the appropriate Federal agencies applicable to a determination of the need for protective actions.

Scope

Limiting the exposure of members of the population to manmade radioactive material can be accomplished by controlling the release of such material from its place of origin or use, or by protecting the population after the material is released to the environ-

ment. This report is directed to guidance for protecting the

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population from radioactive material after it has been released to the environment in concentrations which justify action.

Situations justifying protective action could occur from such events as: (1) an industrial accident, possibly involving a nuclear reactor or a nuclear fuel processing plant, and (2) release of radioactive materials from the detonation of nuclear weapons or other nuclear devices.

The guidance concerns protective actions which might be applied to the production, processing, distribution, or use of food to reduce the potential human intake of such radioactive material. This guidance is confined in application to those conditions under which the hazard of concern is that associated with the ingestion of radioactive materials. Conditions requiring protection from external gamma radiation or protection when inhalation may also be a significant mode of entry for radioactive material into the human body involve different considerations.

This report includes guidance as to the general principles concerned with protective actions and specific guidance applicable to iodine-131.

Preparation of the Staff Report

In the development of this report, the Staff has reviewed the literature on the origin, distribution, mechanisms of transmission through the environment, and potential biological effects of radioactive materials. In particular, the Staff has studied the transcripts of the hearings conducted by the Joint Committee on Atomic Energy; the reports by the National Committee on Radiation Protection and Measurements, the World Health Organization and Food and Agricultural Organization of the United Nations, the United Kingdom Medical Research Council's Committee on Protection against Ionizing Radiations, the National Advisory Committee on Radiation—an advisory committee to the Surgeon General, United States Public Health Service; and the "Proceedings of the Hanford Symposium on the Biology of Radioiodine."

The Staff also has had considerable assistance from many individual scientists and technical experts.

Definitions

The *absorbed dose* is the energy imparted to a volume of irradiated material per unit mass of that volume.

The *rad* is a unit of absorbed dose equal to 100 ergs per gram.

The *projected dose* is the dose that would be received in the future by individuals in the population group from the contaminating event if no protective action were taken.

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The *Protective Action Guide (PAG)* is the projected absorbed dose to individuals in the general population which warrants protective action following a contaminating event.

The *curie* is a unit of radioactivity defined as 3.7×10^{10} transformations per second. Commonly used multiples of the curie are the following:

1 millicurie = 1×10^{-3} curie
1 microcurie = 1×10^{-6} curie
1 nanocurie = 1×10^{-9} curie
1 picocurie = 1 micromicrocurie = 1×10^{-12} curie

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SECTION II

ORIGIN AND DISTRIBUTION OF RADIOACTIVE CONTAMINATION

The origin and distribution of radioactive material injected into the atmosphere and its transport mechanisms through the environment to man have been studied intensively both nationally and internationally for the past decade in connection with the atmospheric testing of nuclear weapons. The past and anticipated concentrations of radioactive materials in the environment from weapons testing through 1962 have been studied and evaluated by the Council in its Reports No. 3 and No. 4.

Material injected into the stratosphere by nuclear weapons tests eventually descends to the troposphere from which it is deposited on the earth's surface. During storage in the stratosphere, short-lived radionuclides decay essentially to zero. Long-lived radionuclides which find their way to the troposphere deposit relatively uniformly on a regional basis, although the quantities vary with latitude and with rainfall. A somewhat similar distribution pattern of short-lived radioactive material such as iodine-131 has been observed in the U.S. for the tropospheric distribution of debris from tests conducted outside the U.S.

When radioactive material is released to the atmosphere at ground level, as would generally be the case in an industrial accident, diffusion in the troposphere is limited and the passage of the radioactive cloud over an area takes a relatively short time. However, the concentrations in the cloud can be high. The deposition of radioactive materials in this case can lead to possible radiation doses that warrant protective action.

Radioactive Nuclides of Interest

Although nuclear fission results in many nuclides, most of which are radioactive, their chemical and physical properties are such that few of them are of interest as potential radioactive contaminants of food. Some of these radionuclides have such short radioactive half-lives that their radioactive decay to stable nuclides is complete before the food is consumed. Those of principal interest are isotopes of chemical elements readily utilized by vegetation or animals, and of sufficiently long radioactive half-lives that much of their radioactivity will not have disappeared before they have reached the human diet.

The relative importance of different radionuclides may depend on many factors such as the time that elapses between fission and the release of fission products to the environment, chemical or physical separation or fractionation, conditions of release, and season of year. For example, in unseparated fission products only a few days of age, the properties of iodine make it the critical radionuclide, while a few weeks later the disappearance of iodine-131 will leave the longer-lived strontium-89, strontium-90, and

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cesium-137 as the nuclides of interest. Many studies of possible types of release important to this report have led to the conclusion that events requiring protective actions are most likely to involve iodine-131 as the critical nuclide.

The Transmission Chain

The path of radioactive material from the atmosphere through the food chain to man is shown in Figure I. The material is scavenged from the atmosphere by meteorological processes, particularly rain. If the air mass containing the radioactive material is at ground level the radionuclides may be directly removed from the air by vegetation. Following the initial deposition, the radioactive contamination tends to be removed by various processes, such as being washed off by subsequent rainfall or being blown off by the wind. The extent to which such removal occurs varies widely depending on the particle size and chemical properties of the material deposited. Although radionuclides may be incorporated subsequently into plants through absorption by the root system, their concentration on the surfaces of vegetation will be the dominant factor leading to a possible need for protective action.

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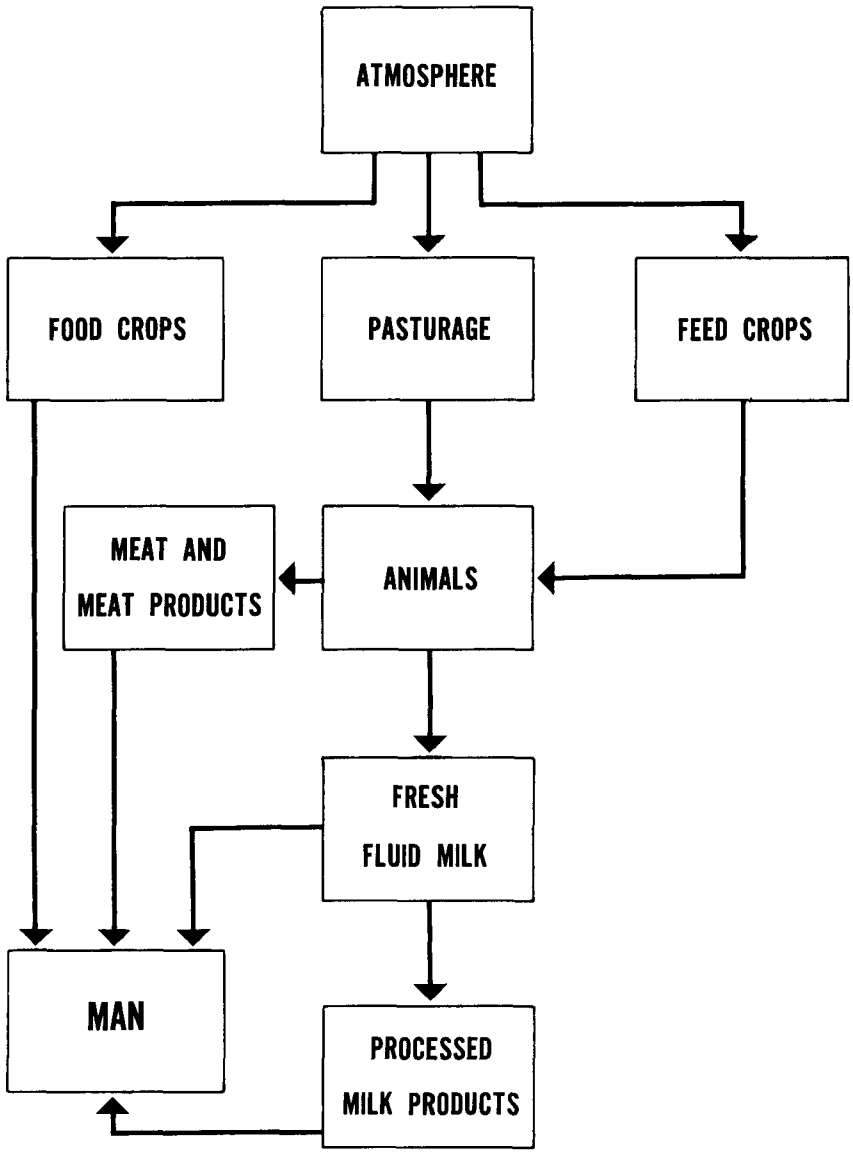

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SECTION III

PROTECTIVE ACTIONS AND THEIR APPLICATIONS

A protective action, within the scope of this report, is an action or measure taken to avoid most of the exposure to radiation that

would occur from future ingestion of foods contaminated with radioactive materials.

Since a protective action is taken to abate such an exposure risk after the radioactive material has been released, in the development of guidance for taking such action it is necessary to consider:

1. the possible risk to health associated with the projected dose to the population from fission products.
2. the amount by which the projected doses can be reduced by taking certain protective actions.
3. the total impact, including risks to health associated with these protective actions, and
4. the feasibility of taking the actions.

Protective actions are appropriate when the health benefit associated with the reduction in dose that can be achieved is considered sufficient to offset the undesirable factors associated with the action.

The value of a protective action depends on how much the projected dose per individual can be reduced by the action and the number of people affected. Protective actions will yield a greater return in relation to their disadvantages if projected doses are high rather than low. Since high levels of contamination probably will be limited to small areas, protective actions are more likely to be required in such areas rather than over large regions.

It is possible to estimate the projected dose that will result from measured concentrations of radionuclides in the environment. This estimate is usually related to a daily or total intake of radioactive materials and can be based either on the assumption that more materials will not be added to the food chain during the period of concern, or that potential additions can be quantitatively estimated. A quantitative estimate of the projected dose is necessary for determining whether or not protective action should be taken.

Impact of Protective Actions

A decision to implement a protective action involves a comparison of the risk due to radiation exposure with the undesirable features of the contemplated action.

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The impact of the protective action will involve such factors as the degree of departure from the usual practice, the length of time over which the action is applied, the relative ease with which the action can be executed, and possible health risks associated with the action.

One of the well-established actions to reduce the intake of con-

taminants on foods is based on the fact that they are on the surface of fresh fruits and vegetables. A large proportion of these contaminants, including radioactive material, can be removed by applying the usual practices of food preparation. The only departures from these usual practices are that: (1) more attention is given to insuring that the surfaces are washed, (2) the outer leaves of leafy vegetables are removed, and (3) more than normal preference is given to peeling.

The impact of these actions is small because they are already accepted practice and no innovations are involved. If it were required that all fruits be peeled before eating, the impact would be greater, and hence the risk would have had to be correspondingly greater to warrant this degree of intervention in accustomed activities.

Some actions, such as discarding a food item, involve a marked departure from usual practice. They may, nevertheless, be of low impact if limited to a small quantity of produce or to a small area, or if applied infrequently and only for short periods.

The feasibility of executing a protective action depends on the ease with which it can be applied by diversion of available resource factors such as the facilities, equipment, personnel, and alternative supplies of animal feeds or agricultural produce needed to implement the action. Diversion of a small fraction of readily available resources is usually easy, but diversion of a large proportion increases the impact and decreases the feasibility very rapidly. There will be very few factors, possibly only one, that are limiting in any complex of resources. These will not necessarily be the same at each place or time the protective action may be needed.

Types of Protective Actions

The types of actions to which guidance in this report may be related are:

1. Altering production, processing, or distribution practices affecting the movement of radioactive contamination through the food chain and into the human body. This action includes a storage of food and animal feed supplies to allow for the radioactive decay of short-lived nuclides.
2. Diverting affected products to uses other than human consumption.
3. Condemning foods.

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Other possible types of action currently are judged to be less desirable for reasons of effectiveness, safety, or practicality. The use of additives in cattle rations, soil treatment, and the chemical removal of radionuclides from milk are not included among the types of actions listed.

Protective actions to reduce the intake of radioactive materials by special alterations of the normal diet are accomplished best on an individual basis under the supervision of medical authorities.

Application of Protective Actions

In providing guidance for protective actions applicable to radioactive contamination of the environment, the Council is concerned with a balance between the risk of radiation exposure and the impact on public well-being associated with the alteration of the normal production, processing, distribution, or use of food.

It is recommended that the term "Protective Action Guide" (PAG) be used to indicate the projected dose at which the above balance is judged to occur for the general types of protective actions considered in this section. Thus, the Protective Action Guide serves as a basis for deciding when such protective actions are indicated.

In the application of the Protective Action Guides the following guidance is provided:

1. If the projected dose exceeds the PAG, protective action is indicated.

2. The amount of effort that properly may be given to protective action will increase as the projected dose increases.

3. The objective of any action is to achieve a substantial reduction of dose that would otherwise occur—not to limit it to some prespecified value.

4. Proposed protective actions must be weighed against their total impact. Each situation should be evaluated individually. As the projected doses become less, the value of protective actions becomes correspondingly less.

5. The Protective Action Guide is based on the assumption that the occurrence, in a particular area, of environmental contamination that would require protective action is an unlikely event. Circumstances that involve either repetitive occurrence or in which there appears a substantial probability of recurrence within a period of one or two years would require special consideration. In such a case the total projected dose from the several events and the total impact of the protective actions that might be taken to avoid the dose from one or more of these events must be considered. In contemplating the possibility of a future event it is necessary to consider not only the possible magnitude but also the probability that the event will occur.

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6. Federal agencies should plan protective action programs designed to reduce the projected dose to individuals in the general public by modifying the normal production, processing, distribution, or use of food products or animal feeds. The need for implementing such plans should be determined on the basis of the estimated projected dose and the appropriate PAG.

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SECTION IV

GUIDANCE APPLICABLE TO IODINE-131

The Environmental Pathway

The physical and biochemical characteristics of iodine-131 make it the radionuclide most likely to warrant rapid application of protective actions. This is especially true if radioactive contamination occurs before appreciable radioactive decay has taken place.

The important pathway for iodine-131 from the source to the body, and the one considered applicable to protective action criteria, is through pasture to the cow, milk, and into the human body.

The shortest time-span from source to individual occurs when fresh milk has not gone through processes of pasteurization and distribution. Iodine-131 may appear in milk a few hours after deposition on pasturage. From a single deposition it can reach a maximum concentration in milk as early as two to four days after deposition; it then decreases by half about every five days due to a combination of radioactive decay and weathering losses from grass.

Deposition of iodine-131 can vary greatly within a relatively small geographical area. As a result, there can be large differences between the iodine-131 concentrations in milk produced on farms only a few miles apart. Because of variations in deposition and in animal feeding habits, and inadequate data for evaluating the effects of these variations, it is not yet possible to predict reliably the maximum concentration of iodine-131 in milk from deposition data.

Development of the Protective Action Guide Against Iodine-131

Factors affecting the relationships between exposures of humans to iodine-131 and subsequent biological effects have been discussed in FRC Reports No. 1 and No. 2, in a report * prepared for

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the FRC by the National Academy of Sciences Committees on the Biological Effects of Atomic Radiation, and in the "Proceedings of the Hanford Symposium on the Biology of Radioiodine."

According to these reports, the uptake of iodine-131 in the thyroids of children and adults is approximately the same. Thus a given intake would result in a ten times larger dose to the thyroid

* Pathological Effects of Thyroid Irradiation—A report of a panel of experts from the Committees on the Biological Effects of Atomic Radiation; National Academy of Sciences; National Research Council, published by the Federal Radiation Council, July 1962.

of a one year old child (thyroid weight 2 grams) than to an adult (thyroid weight 20 grams). Children, one year of age are assumed to be the critical segment of the population.

Young children treated with X-rays in the neck region for enlarged thymus or for other benign head and neck conditions have had a significantly higher incidence of tumors, including thyroid carcinoma, than have children in control groups. Radiation doses to the thyroid found to be associated with thyroid carcinoma under these conditions range upward from about 150 rads. Experience with exposure of the thyroid to large doses of radiation from iodine-131 for therapeutic reasons is extensive but is almost entirely confined to adults. The report of the panel of experts of the NAS-NRC Committees states that, although therapeutic doses from iodine-131 to the thyroid have been in the range of a few thousand rads upward, iodine-131 has not been identified in a causative way with the development of thyroid cancer in humans, except in one doubtful case. X-ray doses to the thyroid appear to be from 5 to 15 times as effective in producing biological changes as iodine-131.

The initiation of protective action against contamination in the environment resulting from a single event (i.e., an event isolated in time from any other event that might affect the same area) involves undesirable features that may be expected to vary in importance from one circumstance to another. Of various actions that might be effective in averting the major part of the projected dose, two appear to provide the most acceptable combination of maximum effectiveness and minimum undesirable consequences. One of these is the diversion of contaminated milk to the production of dairy products that may be stored conveniently until the iodine-131 essentially has decayed, a matter of a few weeks. The other is the substitution of stored feed for pasturage until most of the iodine-131 has decayed. The choice may depend upon many factors.

Considering existing information on the biological risks associated with doses from iodine-131 and the kinds of protective action available to avert the dose from iodine-131 that has been deposited on pastures used by dairy cows, the Council has concluded that such protective action as the diversion of milk or the substitution of stored feed for pasturage to avert individual doses less than 30 rads would not usually be justifiable under the conditions considered most likely to occur. This dose is recommended as the Protective Action Guide for iodine-131.

Generally it will not be practical to estimate individual doses. In such cases decisions to take an action will be based on average

values. As noted in FRC Report No. 1, paragraph 5.4, it is assumed that the majority of the individuals do not vary from the average by a factor greater than three. As an operational technique, it is considered that the PAG will not be exceeded if the average projected doses to the thyroids of a suitable sample of the population do not exceed 10 rads. A suitable sample is considered to consist of children of approximately one year of age using milk from a reasonably homogeneous supply.

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The PAG is stated in terms of a projected dose; i.e., the dose that might otherwise be received if the protective action were not initiated. However, since the value of the contemplated action and, consequently, the justification of the action, depends on the dose averted, it is valid to use the projected dose as a basis for implementation of a proposed protective action only if it is expected that most of the projected dose will be averted.

Because of the differences that may exist in various circumstances it is necessary to evaluate each situation individually. It is not feasible to provide detailed criteria for taking into account differences that may occur. In general, the PAG represents the Council's judgment regarding the benefit-impact balance for the two protective actions considered acceptable and for the conditions considered most likely to occur. If in a particular situation there is available an effective action with low total impact, initiation of such action at a projected dose lower than the PAG may be justifiable. If only high impact protective action would be effective, initiation of such action at a projected dose higher than the PAG may be justifiable. For example, diversion of milk from fresh milk channels to processed products may be less difficult in a locality where surplus production makes allocation between the two uses a normal practice. The action would be more difficult and expensive, and the total impact would be high if the milk had to be transported large distances to a processing center, or if there were adverse effects on the quality or quantity of milk available to the consumer or adverse effects on the dietary habits of individuals in the population.

In considering the net benefit of a protective action, assuming the protective action is initiated at progressively lower values of projected dose, as the projected dose becomes less, the net benefit to public well-being from reduction of exposure becomes less.

Application of Protective Actions Against Iodine-131

The benefit of avoiding a potential dose from iodine-131 must be evaluated against the feasibility and the disadvantages of any

protective action under consideration. A selected action must be feasible for the particular situation. It must not be subject to limitations such as lack of communications or transportation which would nullify its effectiveness. If warranted under certain unusual conditions, the application of protective actions in consecutive or concurrent operation may be considered. Local conditions must also be considered. For example, the proportion of fresh milk use to processed milk use in the area, or the seasonal feeding pattern for cattle may affect the efficacy of a specific protective action.

Iodine-131 concentrations may vary widely within a given milkshed. Therefore concentrations at the point of milk production must be known if efficient protective actions are to be taken. On the other hand, concentrations at the point of consumption must be known in order to evaluate the projected doses received by the population group.

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Protetctive actions cannot attain maximum effectiveness without adequate communications. Information regarding deposition patterns and concentrations of radioiodine in milk must be obtained promptly for those groups responsible for taking protective action. The acceptance of and participation in protective actions by milk producers, processors, distributors, and consumers must be achieved. Such acceptance and participation will tend to avoid unnecessary rejection of acceptable fresh milk supplies by the public.

The specific protective actions considered in selecting the Protective Action Guide are:

1. The change of cattle from pasture to stored feed.
2. The substitution of unaffected fresh milk for affected fresh milk by alteration of processing or distributing practices.

Preference for the second action may depend upon the practicability of diverting the affected milk to the production of dairy products which may be stored for several weeks before use. This does not influence the effectiveness of the action in averting a dose from iodine-131. In a sufficiently severe situation in which a more desirable alternative did not exist, it might be appropriate to substitute unaffected milk for current use with no utilization of the affected milk.

The projected future intake at any time after the maximum concentration has been reached is approximately seven times the estimated daily intake at that time, provided that additional iodine-131 is not being deposited on the pasture. If the concentration of

iodine-131 in milk has passed its maximum value and is decreasing by half every five days, the relationship between the daily rate of intake at any time and the total projected subsequent intake is indicated in columns 1 and 2 of Table I.

Using the projected total intake, a projected dose for children approximately one year of age may be calculated by assuming that 30 percent of the ingested iodine is retained in a 2 gram thyroid, and by selecting an estimated value of 1 liter as the daily consumption of milk. The relationship between the total intake of iodine-131 and the projected dose is indicated in columns 2 and 3 of Table I.

A total intake of iodine-131 of 600 nanocuries would result in a dose of about 10 rads to a 2 gram thyroid. In a single event, about 20 to 25 percent of the total intake may result from the use of that portion of the milk produced before the maximum concentration was reached. Under these conditions, and if no protective action were taken, an estimated maximum concentration in milk of 60 to 70 nanocuries per liter would result in a total intake of about 600 nanocuries and a dose to the thyroid of 10 rads.

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TABLE 1.—INTAKE OF IODINE-131 FOR DIFFERENT RADIATION DOSES TO A 2-GRAM THYROID FOLLOWING A SINGLE DEPOSITION OF IODINE-131 ON PASTURAGE [1]

Estimated intake of iodine-131 in one day at the time of the maximum concentration or later (nanocuries)	Projected intake of iodine-131 (based on column 1) (nanocuries)	Projected thyroid dose (based on column 2) (rads)
4.2	29	.5
8.4	58	1
25	175	3
42	290	5
84	580	10
250	1750	30
1250	8750	150
2500	17500	300

[1] This table is illustrative and does not indicate specific intake values at which protective actions should be initiated or discontinued.

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The effectiveness of a protective action, if taken, will be highly dependent upon the promptness with which it is initiated. If milk from an unaffected area is to be substituted for the contaminated milk, delay of initiation of the action by as much as 10 days after the deposition occurs will reduce the total exposure that can be avoided to substantially less than half of the total exposure that

would result if no action were taken. In the case of substitution of stored feed for pasturage, the same delay would reduce even further the benefit of the action because of the time required for the iodine-131 in the cow and, consequently, the concentration in the milk to decrease to negligible levels.

The exposure avoided will also depend upon the length of time the protective action is maintained. In the case of substitution of unaffected milk for contaminated milk, the reduction in the dose that would result from subsequent intake would be about 90 percent if the action were maintained for 15 to 20 days, and about 99 percent if maintained for 30 to 40 days. In the case of substitution of stored feed for pasturage, reductions would be less.

Summary

Following release of fresh fission products iodine-131 is the radionuclide considered most likely to reach concentrations in foods which warrant protective action to reduce the projected dose. The important mode of transmission to humans is through the consumption of fresh fluid milk.

Iodine-131 can appear in milk within a few hours after its deposition on pasture. The concentration in milk may reach a maximum in two to four days, after which the concentration diminishes by half about every five days.

Removal of dairy cattle from contaminated pastures or the diversion of contaminated milk to processed dairy products are recommended as protective actions to reduce human exposure from iodine-131.

The Federal Radiation Council has developed the concept of the Protective Action Guide. The PAG is defined as the projected absorbed dose to individuals in the general population which warrants protective action following a contaminating event.

A projected dose of 30 rads to the thyroid of individuals in the general population has been recommended as the Protective Action Guide for iodine-131. As an operational technique it is assumed that this condition will be met effectively if the average projected dose to a suitable sample of the population does not exceed 10 rads.

4.1e(1) RADIATION PROTECTION GUIDANCE FOR FEDERAL AGENCIES (MEMORANDUM TO THE PRESIDENT), FEDERAL RADIATION COUNCIL

August 22, 1964, 29 Fed. Reg. 12056 (1964)

MEMORANDUM FOR THE PRESIDENT

JULY 16, 1964.

Pursuant to Executive Order 10331 and Public Law 86–373, the Federal Radiation Council is transmitting recommendations for the approval of the President for guidance of Federal agencies in their radiation protection activities. The present recommendations are directed to guidance for protective actions affecting the normal production, processing, distribution, and use of food products for human consumption. Specific guidance is provided for iodine-131. It is the intention of the Council to release the background material leading to these recommendations as Staff Report No. 5 when the recommendations herein are approved.

Background. The first two memorandums which provided guidance for Federal agencies in the conduct of their radiation protection activities were approved by the President on May 13, 1960, and September 20, 1961. These provided a general philosophy of radiation protection and general principles of control based on the annual intake of radionuclides. The recommendations contained therein provided the basis for the control and regulation of normal peacetime operations in which exposure to radiation is a factor. Numerical values were provided for the Radiation Protection Guides designed to limit the exposures of the whole body and of certain organs resulting from normal peacetime operations.

During the period of atmospheric testing of nuclear weapons in 1961 and 1962 the question arose as to the use of these Radiation Protection Guides for determining the conditions under which the production, processing, distribution, and use of food, particularly fresh fluid milk, should be altered to reduce human intake of radionuclides from fallout.

In September 1962 the Federal Radiation Council stated its position on this subject, and in 1963 the Council reiterated that existing guides were not applicable to a determination of a need for protective actions and noted that it would recommend guidance on the subject to the President.

Concept of Protective Action Guide. In previous reports the Federal Radiation Council has recommended a philosophy of radiation protection and discussed alternative approaches to the derivation of basic guidance for radiation protection. It has pointed out

that decisions concerned with radiation protection involve a balance between the possible health risks associated with radiation exposure and the reasons for accepting the exposure. The Council accepted the term "Radiation Protection Code" to express the balance between the benefits from normal peacetime operations and the health risks associated with those exposures. The radionuclide releases causing these exposures are generally controlled at the source.

Radiation protection guidance for protective actions applicable to ingestion of food contaminated with radioactive material requires a different balance. Here, the Council is concerned with a balance between the risk of radiation exposure and the impact on public well-being associated with alterations of the normal production, processing, distribution, and use of food.

For this purpose, the Council has adopted the term "Protective Action Guide" (PAG), defined as the projected absorbed dose to individuals in the general population which warrants protective action following a contaminating event. The projected dose is the dose that would be received in the future by individuals in the population group from the contaminating event if no protective action were taken. If the projected dose exceeds the PAG, protective action is indicated. According to the operational technique adopted in the Memorandum for the President, May 1960, the corresponding average projected dose to a suitable sample of the exposed population would be one-third of the PAG.

A protective action is an action or measure taken to avoid most of the exposure to radiation that would occur from future ingestion of foods contaminated with radioactive materials. Such actions are appropriate when the health benefits associated with the reduction in exposure to be achieved are sufficient to offset the undesirable features of the protective actions. The PAG represents the Council's judgment as to where this balance should be for the conditions considered most likely to occur. If, in a particular situation, there is available an effective action with low total impact, initiation of such action at a protected dose lower than the PAG may be justifiable. If only very high impact action would be effective, initiation of such action at a projected dose higher than the PAG may be justifiable.

A basic assumption in the development of the guidance in this memorandum is that a condition requiring protective action is unusual and should not be expected to occur frequently. In any event, the numerical values selected for the Protective Action Guides are not intended to authorize deliberate releases expected to result in absorbed doses of these magnitudes.

The types of actions to which application of the Protective Action Guides may be related are:

1. Altering production, processing, or distribution practices affecting the movement of radioactive contamination through the food chain and into the human body. This action includes storage of food supplies and animal feeds to allow for radioactive decay.
2. Diverting affected products to uses other than human consumption.
3. Condemning affected foods.

Measures that require an alteration of the normal diet are generally less desirable than those listed and should not be undertaken except on the advice of competent medical authorities.

Radionuclides considered. Four radionuclides are of particular importance in considering radioactive contamination of food. These are iodine-131, strontium-89, strontium-90, and cesium-137. This memorandum will deal only with iodine-131.

In contrast to the other fission nuclides, the relatively high yield of iodine-131 and the short radioactive half-life (8 days) of iodine-131 make it the radionuclide most likely to reach concentration justifying protective actions. This is especially true if the deposition occurs within a few days after the fission event. Protective action against iodine-131 must be taken promptly in order to be effective.

Physicial and biological factors related to iodine-131 have been considered in FRC Reports No. 1 and No. 2. As in FRC Report No. 2, it is assured that children one year of age, with a thyroid weight of 2 grains and 30 percent uptake of iodine-131, are the critical segment of the population.

Protective actions against iodine-131. The Council has evaluated the kinds of protective actions available for use against iodine-131, the health benefit that may result by averting a radiation dose larger than the Protective Action Guide, and the probable impact of taking the actions. Of various actions that might be effective in averting the major part of the potential exposure, two appear to provide the most acceptable combinations of maximum effectiveness and minimum undesirable consequences. One of these is the diversion of fresh milk to provide unaffected milk in the contaminated area and to use the affected milk in the production of dairy products that may be conveniently stored until the iodine-131 has effectively decayed, a matter of a few weeks. The other is the substitution of stored feed for pasturage, until most of the iodine-131 has decayed.

Recommendations. In view of the considerations summarized, the following recommendations are made.

It is recommended that:

1. The term "Protective Action Guide" (PAG) be adopted for Federal use.

The Protective Action Guide is defined as the projected absorbed dose to individuals in the general population which warrants protective action following a contaminating event. The projected dose is the dose that would be received in the future by individuals in the population group from the contaminating event if no protective action is taken.

It is recommended that:

2. The Protective Action Guide for iodine-131 be 30 rads to the thyroid.

If the projected dose exceeds the Protective Action Guide, protective action is indicated.

According to the operational technique adopted in the Memorandum for the President, May 1960, the corresponding average projected dose to the thyroids of a suitable sample of the exposed population group would be 10 rads.

3. The guidance contained herein be approved for the use of Federal agencies in the conduct of those radiation protection activities affecting the normal production, processing, distribution, and use of food and agricultural products.

ANTHONY J. CELEBREZZE,
Chairman.

The recommendations numbered "1" through '3" contained in the above memorandum are approved for the guidance of Federal agencies, and the memorandum shall be published in the FEDERAL REGISTER.

LYNDON B. JOHNSON.

4.1f REVISED FALLOUT ESTIMATES FOR 1964–65 AND VERIFICATION OF THE 1963 PREDICTIONS, REPORT NO. 6, STAFF REPORT OF THE FEDERAL RADIATION COUNCIL, MAY 1965.

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[p. 1]

SUMMARY

On the basis of information available in June 1964, new estimates of the levels of fallout expected in 1964 and 1965 from the atmospheric testing of nuclear weapons conducted through 1962 have been made by the Federal Radiation Council.

Based on the stratospheric inventory of strontium-90 in January 1964, the predicted annual depositions in 1964 and 1965 have been increased by 50 percent over those presented in FRC Report No. 4. This adjustment is well within the expected uncertainty of the original estimate and does not change the 30-year and 70-year dose estimates made on the basis of the original predictions.

The inventory of long-lived fission products such as strontium-90 and cesium-137 in the atmosphere by mid 1964 was reduced to one-half that in January 1963.

The deposition of fallout in the United States in 1963 was very close to the predicted values. The average deposition in the "wet" areas was a little less than predicted and that in the "dry" areas a little more. The time of maximum deposition occurred about a month later than it has in previous years.

Iodine-131 from the atmospheric testing of nuclear weapons had disappeared by May 1963 and strontium-89 by June 1964.

The observed levels in 1963 for strontium-89, strontium-90, and

cesium-137 in milk and dairy products, short-lived nuclides leading to external exposure, and carbon-14 in the atmosphere at ground level were all very close to the values predicted in FRC Report No. 4. The observed values of strontium-90 in the total diet and in new bone were less than predicted for 1963. This discrepancy is

[p. 2]

considered to result from the fact that some non-dairy products, particularly cereal grains, do not enter the diet in significant quantities in the same year in which they are grown.

New predictions for the strontium-90 and cesium-137 levels in milk, and strontium-90 in cereal grains and the total diet expected in 1964 and 1965 have been made to reflect the adjusted annual fallout level and the lag time for cereal grain products to enter the diet. These predictions are that the levels of long-lived radionuclides in milk in 1964 will be about the same as they were in 1963. The strontium-90 concentrations in the total diet in 1964 are expected to be higher than they were in 1963 and to drop to 1963 levels in 1965.

Based on the predictions of dietary contamination levels anticipated in 1963 and subsequent years, the Council concluded in FRC Report No. 4 that the health risks from radioactivity in food over the next several years are too small to justify protective actions to limit the intake of radionuclides by diet modifications or altering the normal distribution and use of food, particularly milk and dairy products. The present study has shown that the predictions in FRC Report No. 4 were substantially correct, and the conclusions in that report still apply.

[p. 3]

SECTION I

INTRODUCTION

1.1 In FRC Report No. 4, issued May 1963, the Federal Radiation Council evaluated the levels of fallout that might be anticipated in the United States in 1963 and subsequent years following the programs of atmospheric nuclear weapons testing conducted through 1962. The report forecast a substantial increase in the probable levels of radionuclides from fallout during 1963 with decreasing quantities in subsequent years.

1.2 On the basis of the radiation doses associated with these levels, it was concluded that the health risk from radioactivity in foods anticipated over the next several years would be too small to justify protective actions to limit the intake of these radionuclides by altering the normal production, processing, and distribution of food, particularly milk and dairy products.

1.3 The purposes of the present report are to: (1) compare the predictions made as to the levels of fallout anticipated in 1963 with the experience based on surveillance measurements, (2) make more precise estimates of the levels anticipated in 1964 and 1965, and (3) evaluate the validity of the prediction procedures when they are applied to a changing fallout situation such as now exists. The study is based on information available through June 1964. Although the probable average levels for 1964 can be projected directly from currently available surveillance information, new estimates of the anticipated average levels of radionuclides in food in 1964 and 1965 utilize the stratospheric inventory data and the cumulative levels in soil as of January 1964.

[p. 4]

SECTION II

THE INVENTORY OF LONG-LIVED RADIONUCLIDES

Verification of Predicted 1963 Fallout

2.1 As an aid in presenting the predictions contained in FRC Report No. 4, the regions in the United States were divided into "wet" and "dry" areas depending on average annual rainfall (roughly separated by the 20″ rainfall isoline). The deposition of strontium-90 in 1963 was expected to average 50 mc/mi^2 (millicuries per square mile) in the wetter regions and 20 mc/mi^2 in the drier regions. A considerable range of variability within each climatic area was expected due to rainfall and other differences (depositions in the "wet" areas were expected in the range of 30–60 mc/mi^2 and those in the "dry" areas, 10–30 mc/mi^2).

2.2 The verification of the 1963 strontium-90 fallout over the United States appears on the large map shown in Figure 1. The shading in Figure 1, taken from FRC Report No. 4, separates the "wet" (heavy shading) from the "dry" (unshaded) areas. The light shading in the midwestern United States denotes areas with slightly less than 20 inches of annual precipitation while the lighter shading over the state of Florida indicates an expected lesser fallout compared with the "wet" eastern United States because of its sub-tropical location.

2.3 The fallout in "wet" areas generally lies in the 30–60 mc/mi^2 range. No station reported a value in excess of 60 mc/mi^2. The average derived from the isolines in the "wet" areas is about 45 mc/mi^2 or within about 10 percent of the predicted average. Fallout in the drier regions of the United States was expected to be about four-tenths as large as that in the "wet" regions. Except for a few areas, deposition values were below the predicted upper

value of 30 mc/mi². The observed mean value derived from the isolines is about 25 mc/mi², which is about 25 percent greater than the prediction of fallout in the "dry" area.

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2.4 It should be noted that the prediction of fallout for the year 1963 contained the possibility that it might be in error by a factor of two. Thus, the 10 and 25 percent discrepancies fall well within the uncertainty in the prediction. The north central United States appears to have received higher fallout and the south central and southwestern United States lower fallout than expected.

2.5 The 1963 fallout data and a reexamination of the results from earlier years suggest that the designation of the "wet" and "dry" areas be modified to conform with observed fallout data. The redefined areas are shown in the inset in Figure 1.

2.6 It should also be noted that the seasonal variation in the deposition of strontium-90 during 1963 differed from that in previous years. Figure 2 presents the time history of fallout in each hemisphere. Fallout in the United States closely follows that of the northern hemisphere. From 1958 through 1962 the peak northern hemisphere fallout occurred in March, April, or May. On the average, about 70 percent of the annual fallout is deposited in the first six months of each calendar year. However, in 1963 the peak concentration extended into July and it took seven, rather than six, months for 70 percent of the annual fallout to be deposited.

Predictions of Future Fallout

2.7 The procedures used to predict the fallout anticipated in the future are the same as those described in FRC Report No. 4, and are based on measurements of the stratospheric inventory of strontium-90 as it existed in January 1964.

2.8 To reflect the stratospheric inventory as of January 1964, the predictions of the fallout expected in 1964 appearing in Table 1 have been increased by 50 percent over the prediction made for the same year in FRC Report No. 4 (1963). This increase lies well within the expected uncertainty of a factor of two or more attributed to the forecast for 1964 made in that report. The forecast for 1964 given in the present report is expected to be verified well within a factor of two.

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2.9 Table 1 also contains a prediction of 1965 fallout. This forecast has also been increased by 50 percent over that previously reported. The uncertainty in the present 1965 prediction is greater

than a factor of two. If the predictions are in error, there is more likely to be an overestimation of the 1965 fallout than an underestimation.

2.10 Table 2 lists the partition of strontium-90 in various parts of the atmosphere (to 100,000 feet) from 1963 to 1965. Figure 3 and Table 2 emphasize the presence of greatest concentrations in the northern hemisphere. It is likely that in a few years there will be a tendency for equality between hemispheres as suggested in Table 2. Thus, after the 1964 and 1965 fallout has been deposited, roughly one-half of the remaining stratospheric inventory, about one megacurie, should be in the stratosphere of the northern hemisphere. It may therefore be anticipated that in the years following 1965 the total additional strontium-90 deposition will be about 10 and 25 mc/mi^2 in the "dry" and "wet" United States respectively.

2.11 The total inventory of strontium-90 on the ground will increase until the fraction lost each year by radioactive decay equals the annual deposit. On the basis of present information it is anticipated that this condition will have been reached by 1967. The total inventory of strontium-90 on the earth's surface will then continue to decrease in subsequent years.

2.12 The increase in carbon-14 in the atmosphere at ground level predicted in FRC Report No. 4 has been verified by observations made in 1963, and original predictions in that report are considered to be substantially correct.

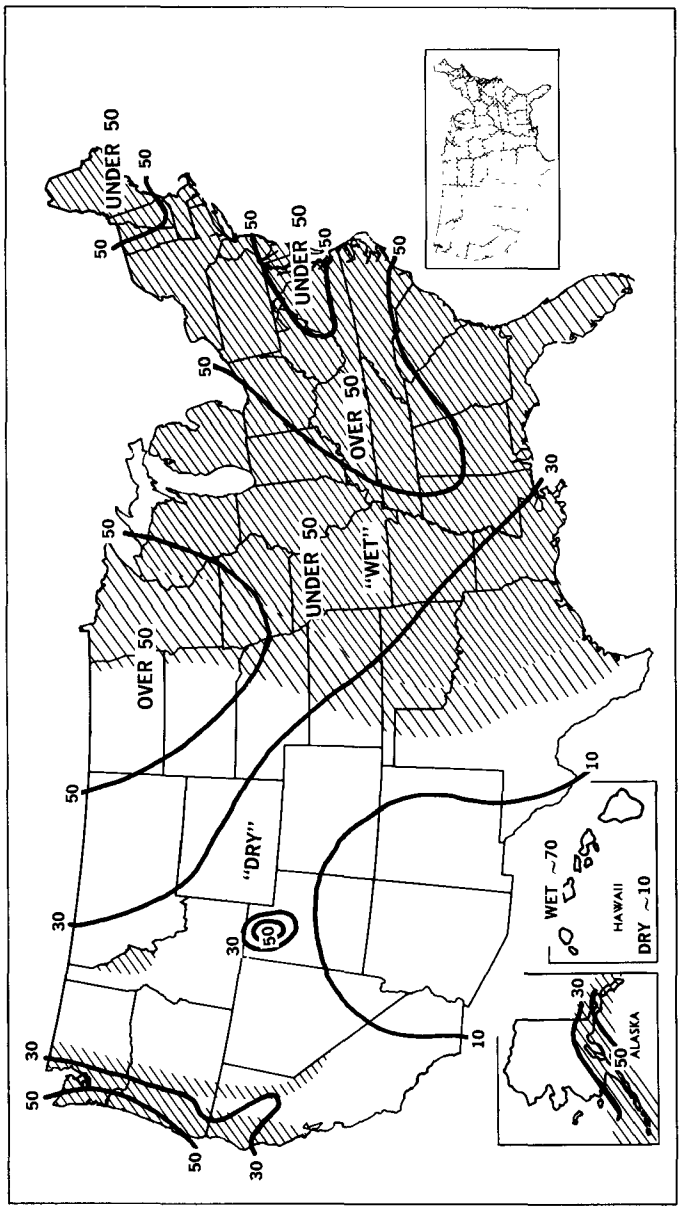

FIGURE 1.—Strontium-90 deposition over the United States during 1963, in millicuries per square mile. The heavily shaded area denotes the "wet" U.S., the unshaded area, "dry" U.S., intermediate fallout regions possess light shading. The shaded area on the small inset map depicts the modified "wet" (or heavier fallout) areas, the unshaded "dry" (or lighter fallout) areas in the conterminous U.S. used in the predictions of this report.

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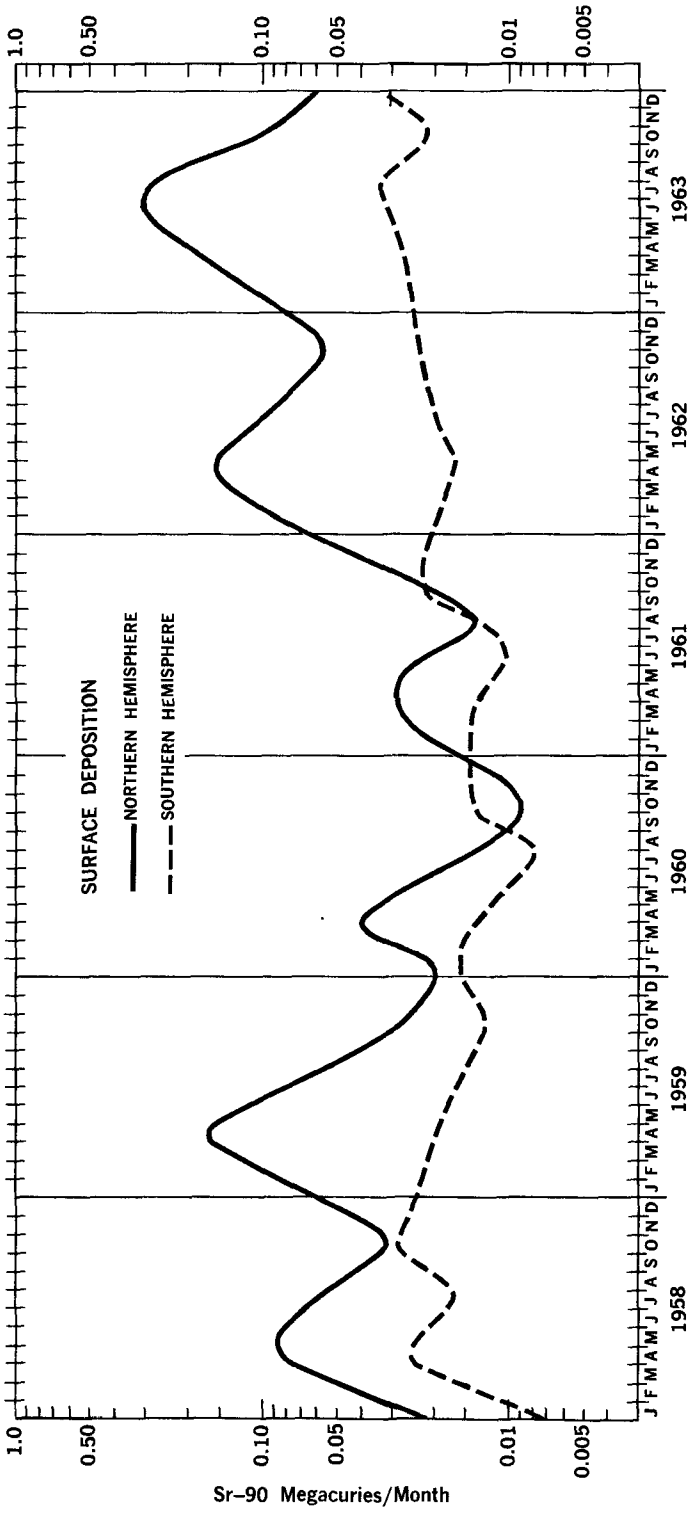

FIGURE 2.—*Time history of strontium-90 surface deposition.*

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TABLE 1.—EXPECTED ANNUAL DEPOSITION OF STRONTIUM-90 IN THE UNITED STATES.
[millicuries per square mile]

	Most probable value	Variability within area
Accumulated deposition to January 1, 1964:		
"Wet" area	150	120–190
"Dry" area	65	40–85
Expected deposition during 1964:		
"Wet" area	30	15–60
"Dry" area	12	5–20
Expected Deposition during 1965:		
"Wet" area	15	5–25
"Dry" area	6	2–10
Expected Total Deposition after January 1, 1966:		
"Wet" area	25	10–50
"Dry" area	10	5–20

Note: Designation of "wet" and "dry" areas have been modified slightly since FRC Report No. 4 (see fig. 1).

In each year, it is expected that about 70 per cent of the annual fallout will occur in the first 6 months of the year.

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TABLE 2.—GLOBAL STRONTIUM-90 IN THE ATMOSPHERE MONTH OF JANUARY (MEGACURIES)

	1963	1964	Predicted 1965
Northern hemisphere:			
Stratosphere	5.7	3.4	2.1
Troposphere	0.3	0.2	0.1
Total observed	6.0	3.6	2.2
Southern hemisphere:			
Stratosphere	0.5	0.6	0.6
Troposphere	0.1	0.1	0.1
Total observed	0.6	0.7	0.7
Total observed:			
(Both hemispheres)	6.6	4.3	2.9

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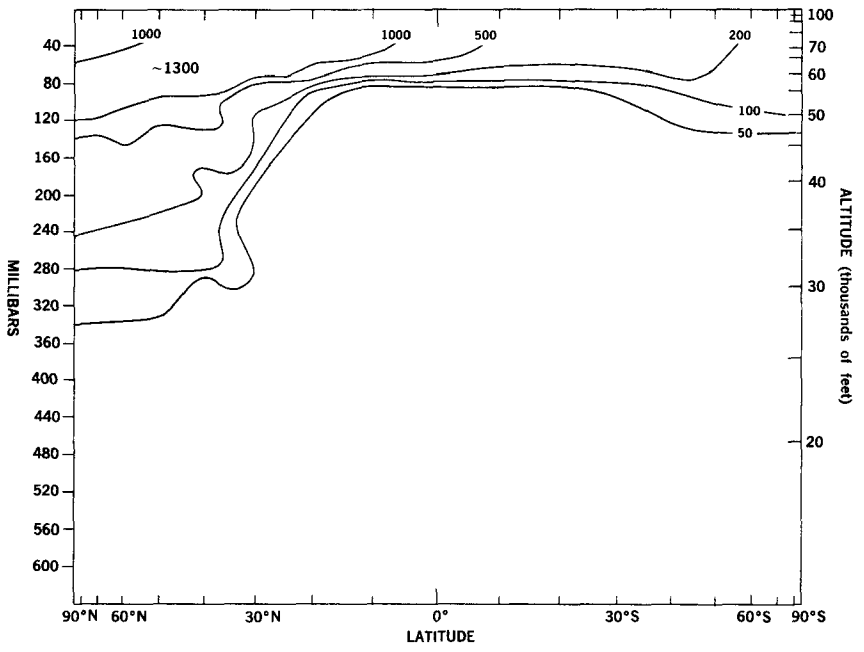

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FIGURE 3.—Mean distribution of strontium-90 in the atmosphere. Observed by Project Star Dust, the Department of Defense's stratospheric surveillance project, January 1964. (Disintegration per minute per 1,000 standard cubic feet).

SECTION III

RADIONUCLIDES IN THE DIET AND IN PEOPLE

General Considerations

3.1 This section is concerned with that part of the fallout which enters the food chain of man. Inhalation of radioactive materials and external sources from fallout are not discussed in this report. Both strontium-90 and cesium-137 have been measured in the total diet and various diet components. Quantitative relationships attempting to relate the radionuclide levels in the total diet and diet components to the quantity of fallout deposited, however, have been studied much more extensively in regard to strontium-90.

3.2 The predictions have been made by a special ad hoc group of technical representatives of all interested agencies in the Federal Government. The detailed methodology has been reported in the hearings of the Joint Committee on Atomic Energy, "Fallout, Radiation Standards, and Countermeasures," June 3, 4, and

6, 1963, and in technical reports of the Health and Safety Laboratory, U.S. Atomic Energy Commission.

3.3 These prediction procedures have been developed to describe the general situations as found in the conterminous United States. Special situations, such as the lichen-caribou-man food chain in Alaska require different procedures to adequately describe them. The factors concerned in this food chain are the subject of studies being conducted by the Atomic Energy Commission and the Public Health Service.

3.4 The general considerations related to estimates of the strontium-90 content of the total diet and diet components were outlined in FRC Report No. 4. Milk, fresh fruits, and fresh vegetables are distributed regionally or locally. Therefore, these

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items in the diet tend to reflect the local levels of fallout. Differences in the strontium-90 to calcium ratio of the total diet in different localities should be related primarily to the strontium-90 in these dietary items. Nationally distributed processed foods tend to lead to a contribution of strontium-90 that is about the same in all parts of the country. The delayed marketing and consumption of such nationally distributed foods introduces a lag between the time of fallout deposition and the appearance of strontium-90 in the total diet.

3.5 Predictions of the anticipated levels of strontium-90 in the diet and diet components may be made by one or both of two general procedures: (1) Prediction of the contamination levels expected in different dietary components as a function of the fallout rate and cumulative levels of strontium-90 in the soil, and the calculation of total diet levels on the basis of the contribution each component makes to the total diet; or (2) multiplying the strontium-90 value for milk by an empirically developed factor related to the fractional contribution of milk to the strontium-90 and calcium intake in the total diet. This factor changes when the rate of fallout deposition changes.

3.6 The predictions for strontium-90 in the total diet and milk as presented in both FRC Report No. 4 and the present report are based on estimates made for New York City as representative of the "wet" areas and for San Francisco as representative of the "dry" areas. This practice has been adopted because the numerical constants relating the fallout rate and the cumulative levels of strontium-90 in soil to the respective dietary contamination levels in these cities are the best estimates available for these factors and also because bone sampling in these areas is correlated with the diet sampling. Strontium-90 and cesium-137 levels in milk and

the total diet have been measured in many localities throughout the country under programs sponsored by the Food and Drug Administration, the U.S. Public Health Service, and the Atomic Energy Commission. Averages computed from these data for the "wet" and "dry" areas, as described in Figure 1, indicate that the averages for "wet" and "dry" regions as a whole will usually be comparable to the values predicted for New York and San Francisco respectively.

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Verification of 1963 Estimates

3.7 Based on the information available in early 1963, estimates of the anticipated levels of strontium-90, strontium-89, cesium-137, and iodine-131 in the diet and some diet components were made in FRC Report No. 4. The evaluation of iodine-131 data observed in 1963 was incorporated in FRC Report No. 4. It was also estimated that the annual average strontium-89 concentration in milk would be about the same in 1963 as it had been in 1962, and that this nuclide would be reduced to negligible levels in 1964. The observed average concentrations of iodine-131, strontium-89, strontium-90, and cesium-137 in milk from the middle of 1961 through June 1964 are shown in Figure 4. This figure illustrates the general trends. The network average is plotted instead of the separate values for the "wet" and "dry" areas. It can be seen that iodine-131 was essentially gone by May 1963 and strontium-89 by June 1964.

3.8 The estimates for the longer-lived nuclides in the diet and in people were presented in the form of the expected annual average for the "wet" and "dry" areas as described in Figure 1. These estimates were based on the most probable value of the annual fallout deposit, the expected distribution of this annual increment by month, and the cumulative deposit on the ground at the beginning of 1963.

3.9 Table 3 compares the observed levels of strontium-89, strontium-90, and cesium-137 in the 1963 diet and strontium-90 in the bone with the anticipated annual averages for the "wet" and "dry" areas. The observed values reported are based on all surveillance data available. Figure 5 shows isolines of the annual average concentrations of strontium-90 in milk based on the Pasteurized Milk Network of the U.S. Public Health Service. The computed averages are 27 and 16 picocuries strontium-90 per liter for the "wet" and "dry" areas respectively. The agreement between the predicted and observed values is quite good in all categories except for the strontium-90 to calcium ratio in the total diet and new bone. The diet values, which represent the predictions for the final

step in the chain of this radionuclide transmitted through the en-
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vironment to man, were overestimated by a factor of 1.7 for the "wet" areas and 3.5 for the "dry" areas.

3.10 The predictions in FRC Report No. 4 for strontium-90 in the diet were made before most of the 1963 fallout occurred and before some crops were grown. The predictions were not expected to differ from the observed values by more than a factor or two. The discrepancy between the predicted and observed value for the total diet is larger than expected. It is now apparent from detailed studies that non-milk products contributed less to strontium-90 content of the total diet in 1963 than would be calculated by the past prediction procedures used in relating fallout rate to the strontium-90 content of the total diet. Adjustments in the prediction procedures will be discussed in connection with the new estimates. (Par. 3.23)

3.11 Table 3 shows two values for the strontium-90 to calcium ratio in bone. The ratio in new bone being formed is one-fourth that in the average diet because the body selectively discriminates against strontium. The observed value for new bone is based on a few measurements on infants less than 1 year old. The observed value for the average of the 0-4 year age group is less because, in the older children, the concentration of strontium-90 is diluted more by the calcium already present.

3.12 The 1963 predictions of 50 and 35 picocuries strontium-90 per gram calcium as the expected values for the total diet in the "wet" and "dry" areas respectively led to predicted concentrations of 12 and 9 picocuries strontium-90 per gram calcium in new bone formed in 1963. The observed values of 7 and 2 picocuries strontium-90 per gram calcium for new bone and 5 and 3 picocuries strontium-90 per gram calcium in the 0–4 age group are in good agreement with the observed ratios in the total diets in 1963. However, they are lower than the values of 12 and 9 picocuries strontium-90 per gram calcium reported in FRC Report No. 4 as the values expected to result from fallout anticipated in 1963.
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Predictions of Future Levels

3.13 After the termination of atmospheric testing, iodine-131 essentially disappeared from the environment by May 1963 and strontium-89 by June 1964. New predictions will be made for only the long-lived nuclides strontium-90 and cesium-137.

Milk

3.14 The raiodnuclide concentrations in fresh milk follow closely the radionuclide content of the cow's fodder. In many parts of the country, the dairy cows are put on pasture in the spring, and during the months while the cows are on pasture the radionuclide concentration in milk varies with the fallout rate. As indicated in Section II, a maximum in the fallout rate is usually reached in April, May, or June. Strontium-90 and cesium-137 concentrations in milk usually increase to a maximum in these months, followed by steadily diminishing concentrations during the summer and early fall. This decrease reflects the lower fallout rate during these seasons plus the loss of surface deposits through weathering, new growth replacing the contaminated grass, and normal changes of feeding practices during the season. When the cows are shifted to stored fodder the radionuclide concentration in milk then reflects the content of the fodder. The slight perturbation in the pattern of fallout deposited by month in 1963 as compared to previous years did not have much effect on the annual average concentrations in milk possibly because dairy cattle were on pasture in many parts of the country during the whole period of interest.

3.15 Table 4 summarizes the data on the average strontium-90 content of milk from 1959 through 1963 and presents new predictions for 1964 and 1965. These predictions reflect the new values for the annual increment of fallout in 1964 and 1965, as shown in Table 1, and the cumulative level of strontium-90 in the soil at the beginning of 1964. Figure 4 shows the trends in average concentrations of strontium-90 and cesium-137 in milk through June 1964. A breakdown of the data into separate estimates for the "wet" and "dry" areas suggests that the prediction for the average concentration of strontium-90 in milk of the "wet"

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areas in 1964 will probably be very close to the observed value and that the prediction for the "dry" areas may be less than the observed value. This possible discrepancy is not expected to exceed a factor of two.

3.16 The formulas used to relate cesium-137 concentrations in milk to the fallout rate and the cumulative deposit of cesium-137 on the ground are more uncertain than those for strontium-90. On the basis of present information it is expected that the average concentration of cesium-137 in milk in 1964 will be about the same as it was in 1963 and will decrease in 1965. The ratio of cesium-137 to strontium-90 is not expected to remain constant with time

because of the different mechanisms involved in the movement of these nuclides through the food chain to milk. In general, the cesium-137 concentrations are expected to decrease faster than the strontium-90 concentrations.

Wheat and Flour

3.17 The strontium-90 content of wheat and flour in the United States from 1959 through 1961 was shown in Table 8 of FRC Report No. 4. The analyses of the 1962 crop were not available at the time that report was written, so the expected value in 1962 was estimated on the basis of what was known about the fallout rate in 1962. The expected values of strontium-90 per kilogram of wheat were given as 130 picocuries in 1962, 250 picocuries in 1963, and 100 picocuries in 1964.

3.18 Table 5 summarizes the average concentrations of strontium-90 observed in wheat and flour from 1959 through 1963 and makes new predictions for 1964 and 1965. The observed value of strontium-90 in 1962 wheat was 40 per cent less than the estimated value used in preparing the estimates of FRC Report No. 4. There is good agreement between the predicted and observed values for the 1963 crop.

3.19 The contamination of cereal grains by fallout appears to be far more sensitive to the fallout rate between the time the grain has headed out and harvest than to either the cumulative total in the soil or to the total annual increment of fallout. This time-span

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is about 6 to 8 weeks for the most important crops, and makes the relative levels of contamination from year to year very sensitive to perturbations in the fallout rate by month. Under these conditions it is not surprising to find large variations in the same crops grown in different areas, or different crops grown in the same areas. The difference between the predicted and observed values for 1962 may be attributable at least in part to this cause.

3.20 The new estimates for 1964 and 1965 are based on the adjusted figures for the annual increment of fallout for those years as shown in Table 1 and the cumulative level of strontium-90 in the soil at the beginning of 1964. The formula used in making the present predictions assumes that the level of contamination in wheat is primarily determined by the fallout rate in the month of June of each year.

Total Diet

3.21 The levels of cesium-137 in the total diet in 1964 are expected to differ from those observed in 1963 by about the same per-

centage as strontium-90 in the total diets for the same years. The factors entering the prediction of the strontium-90 content of the total diet have been discussed in paragraphs 3.1–3.6. Tabulated predictions have been given for the strontium-90 levels in milk and wheat. Wheat may be considered representative of the cereal grains. In the past, these two components have accounted for 60 to 70 percent of the total strontium-90 intake and about 75 percent of the total calcium intake in the United States diet. The ratio of strontium-90 to calcium in the total diet should be close to the ratio estimated from these two components. The strontium-90 intake through fruits and vegetables is subject to a considerable regional variation. This source accounts for most of the remaining 30 percent of strontium-90 and an additional 13 percent of calcium.

3.22 Observations of the strontium-99 to calcium ratio in the total diet compared to that in milk have generally fluctuated between 1 and 2 for the past several years. The most logical explanation for this variability appears to be that the lower values

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of the total diet to milk ratio occur during the periods of increased fallout deposition when the strontium-90 in milk, fresh fruits, and fresh vegetables is increasing; other non-milk components reflect the strontium-90 to calcium ratio of products grown before the fallout deposition started increasing. Following a period of relatively high fallout desposition and when the deposition rate is decreasing, the strontium-90 to calcium ratio in milk decreases. However, relatively high ratios of strontium-90 to calcium may be found in the total diet because the non-milk components will reflect the strontium-90 to calcium ratio of products grown during the time of the higher fallout deposition rate. It has been assumed that the strontium-90 to calcium ratio of the total diet will be 1.5 times the predicted value for milk for purposes of long-term prediction. However, this ratio (1.5) cannot be considered reliable for developing short-term predictions especially when the annual rate of fallout deposition changes such as it has done since 1962.

3.23 The predictions in FRC Report No. 4 utilized both the diet to milk ratio method and the procedure of directly predicting the anticipated strontium-90 levels in different dietary components. For the direct estimates it was assumed that the time lag between the production of all dietary components and the entry of the produce into the market is less than one year. In the present report, it is assumed that milk products and fruits and vegetables are consumed in the same year in which the products are produced. However, for the cereal grains it is assumed that 25 percent comes from the crop grown during the year of interest while 75 percent

comes from the crop grown during the previous year. New predictions for the strontium-90 to calcium ratio of the total diet are shown in Table 6. These predictions reflect the adjusted estimates of the fallout deposition rates for 1964 and 1965 as shown in Table 1.

3.24 When the adjusted assumptions are applied to the 1963 figures, the "predicted" values would be 40 and 20 picocuries strontium-90 per gram calcium for the total diets of the "wet" and "dry" areas respectively. Although these values are closer to the observed values of 30 and 10 picocuries strontium-90 per gram

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calcium than the original predictions of 50 and 35 picocuries strontium-90 per gram calcium, the adjusted assumptions would still overestimate the strontium-90 contamination of the total diet as it existed in 1963. However, the new predictions of 40 and 20 picocuries strontium-90 per gram calcium for the total diet in the "wet" and "dry" areas respectively in 1964 may be closer to the observed annual averages since 1964 is the second successive year of relatively high fallout deposition.

Bone

3.25 The ratios of strontium-90 per gram calcium in bone observed in the past and predicted for the future are shown in Table 7. The numerical values for 1964 and 1965 are one-fourth the predicted ratio of strontium-90 to calcium in the total diet shown in Table 6. The difference between the strontium-90 concentrations in new bone being formed and the average level in the 0–4 year age group (illustrated in Table 3) is expected to decrease with time.

Dose Estimates

3.26 The estimates made in FRC Report No. 4 for the expected 30-year and 70-year doses are not altered by the revised estimates of radioactive nuclides in the diet. The doses estimated for external exposure from short-lived nuclides and for strontium-89 correspond to the observed values for these nuclides in 1963. The shift of one year in the time of the maximum value of strontium-90 expected in the diet has very little effect on the estimated 70-year dose from strontium-90.

3.27 During the past three years a whole body counter has been used to measure the cesium-137 body burdens of the inhabitants of several villages in artic Alaska chosen to evaluate environmental factors and dietary patterns unique to that region. Estimates of doses to individuals in 1964 based on these measurements range up to about 400 millirems. Depending upon the further fallout ex-

pected and the long-term retention in the food chain, this might correspond to 30-year doses ranging up to several rems.

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3.28 On the basis of present information, the estimates made in FRC Report No. 4, regarding the maximum concentrations of radionuclides to be expected from fallout, the projected doses from these nuclides, and the evaluation of the possible risks were essentially correct. However, the time of the maximum contamination of the total diet is now expected to occur in 1964 instead of 1963. It is concluded that the predictions made in FRC Report No. 4 were substantially correct and the conclusions in that report still apply.

[p. 22]

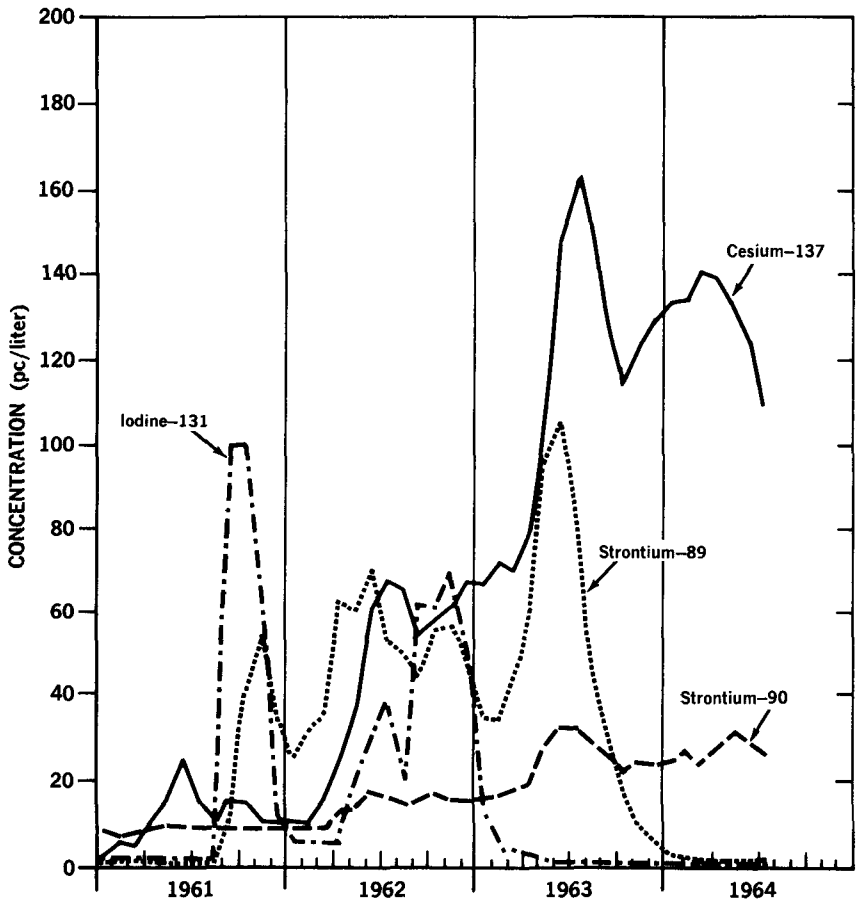

FIGURE 4.—Average concentration of radionuclides in milk samples from Public Health Service pasteurized milk network (pc/liter).

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TABLE 3.—COMPARISON OF PREDICTED AND OBSERVED LEVELS OF RADIONUCLIDES DEPOSITED AND IN THE U.S. DIET IN 1963*

	"Wet"		"Dry"	
	Predicted	Observed	Predicted	Observed
Deposition (mc Sr^{90}/mi^2):				
Range	30–60	—	10–30	—
Most probable value	50	45	20	25
Milk:				
Sr^{90} (pc/liter)	30	25	10	15
Sr^{89} (pc/liter)	55	50	40	40
Cs^{137} (pc/liter)	140	125	—	85
Wheat (pc Sr^{90}/kg wheat)	250	220	—	—
Flour (pc Sr^{90}/gm Ca)	40	40	—	—
Total Diet (pc Sr^{90}/gm Ca)	50	30	35	10
New Bone (pc Sr^{90}/gm Ca)	12	7	9	2
Age 0–4 Bone (pc Sr^{90}/gm Ca)	[2]5	5	[2]3	2

[1] Except for bone, both predicted and observed values have been rounded to the nearest 5 units for purposes of comparison since this is considered to be more in keeping with the reliability of the estimates.

[2] Calculated from the observed strontium-90 calcium ratio in the diet.

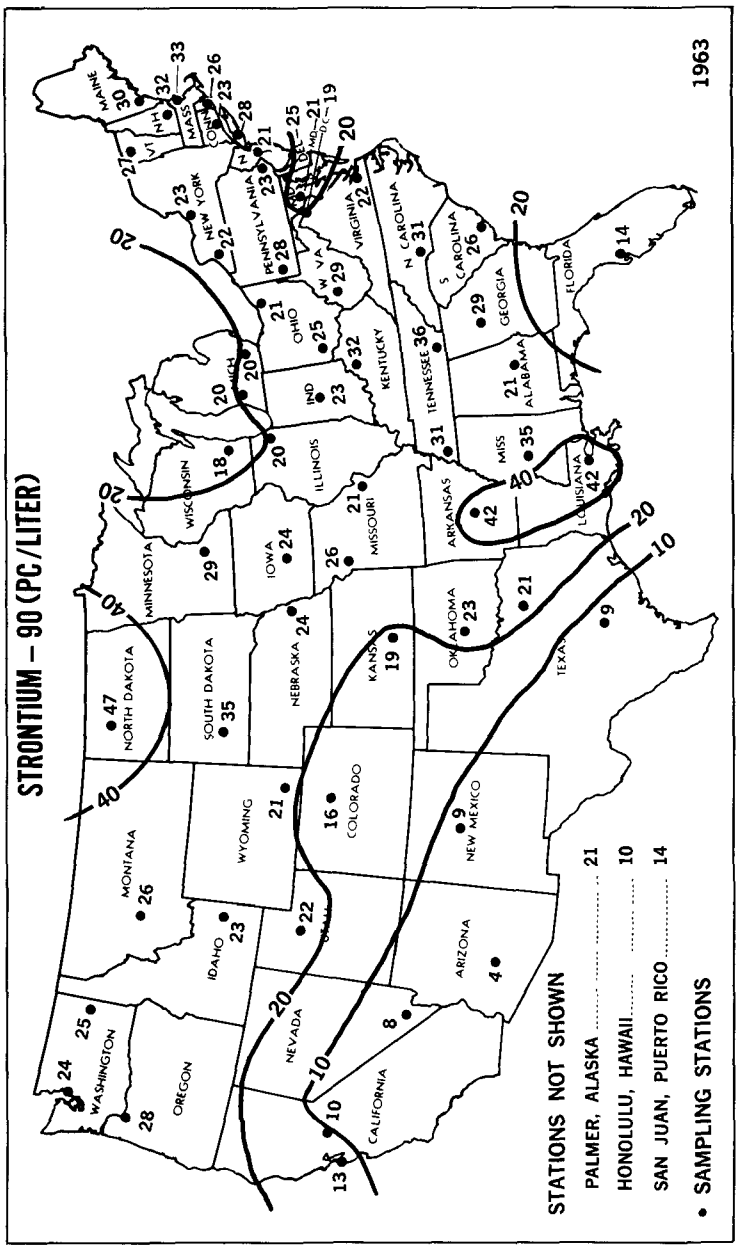

FIGURE 5.—Strontium-90 concentrations in pasteurized milk.

TABLE 4.—AVERAGE STRONTIUM-90 CONTENT OF MILK IN THE U.S.*

[Picocuries strontinum-90 per liter of milk]

	New York	"Wet" Areas	San Francisco	"Dry" Areas
	Observed			
1959	10	15	—	10
1960	10	10	5	5
1961	10	10	5	5
1962	15	15	5	10
1963	30	25	10	15
	Predicted			
1964	30	—	10	—
1965	25	—	5	—

[1] Predicted and observed values have been rounded to the nearest 5 units for purposes of comparison since this is considered more in keeping with the reliability of the estimates.

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TABLE 5.—STRONTIUM-90 CONTENT OF WHEAT AND FLOUR IN THE U.S.*

[Picocuries per kilogram]

Year of harvest	Average from 9–15 States weighted for production Observed	
	Wheat	Flour
1959	50	10
1960	25	5
1961	25	10
1962	85	15
1963	220	40
	Predicted	
1964	140	20
1965	80	10

[1] Predicted and observed values have been rounded to the nearest 5 units for purposes of comparison since this is considered more in keeping with the reliability of the estimates.

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TABLE 6.—AVERAGE STRONTIUM-90 CONTENT OF U.S. TOTAL DIET*

[Picocuries strontium-90 per gram calcium]

	N.Y.C. ("Wet" Area)	S.F. ("Dry" Area)
	Observed	
1959	15	10
1960	10	5
1961	5	5
1962	10	5
1963	30	10
	Predicted	
1964	40	20
1965	30	15

[1] Predicted and observed values have been rounded to the nearest 5 units for purposes of comparison since this is considered more in keeping with the reliability of the estimates.

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TABLE 7.—AVERAGE STRONTIUM-90 CONTENT OF HUMAN BONE IN THE U.S.

[Picocuries strontium-90 per gram calcium]

	"Wet" Areas	"Dry" Areas
	Bone[1] observed (0–4 years old)	
1958	2.0	2.0
1959	2.7	2.2
1960	2.4	1.8
1961	2.6	0.9
1962	3.1	1.1
1963	5.0	1.9
	Predicted (new bone 0–4 years old)	
1964	10	5
1965	8	4

[1] See paragraph 3.25.

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4.1g BACKGROUND MATERIAL FOR THE DEVELOPMENT OF RADIATION PROTECTION STANDARDS, PROTECTIVE ACTION GUIDES FOR STRONTIUM-89, STRONTIUM-90 AND CESIUM-137, REPORT NO. 7, STAFF REPORT OF THE FEDERAL RADIATION COUNCIL, MAY 1965

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SUMMARY

This report provides information and guidance for actions appropriate to situations involving contamination of the environment by the radionuclides strontium-89, strontium-90, and cesium-137. Two conditions of environmental contamination have been examined: an acute localized contaminating event in which prompt action may be necessary to avoid the exposure that would

otherwise result; and a widespread, generally increasing, low-level of contamination (from stratospheric fallout) that causes a continuous intake of radioactive materials by large numbers of people for a period of years. Special consideration has been given to the situation in the arctic region where, because of unusual ecological conditions and food chains, some population groups are exposed to levels higher than those in other parts of the United States.

In developing this report, the Staff of the Federal Radiation Council has had the assistance of an advisory committee from the National Academy of Sciences—National Research Council in regard to the biological effects from irradiation by strontium-89, strontium-90, and cesium-137; the assistance of an ad hoc panel of scientists to provide data on biological, chemical, and physical factors involving radioactive contamination of the environment; and a second panel to provide information on the dosimetry models related to these radionuclides.

The Acute Contaminating Event

The problem of evaluating when protective actions may be indicated following an acute contaminating event has been separated into three categories. Category I is limited to the transmission of radionuclides through pasture-cow-milk-man pathway. If pasture is contaminated the concentration of radionuclides in milk would build up rapidly, reach a maximum in about a week and then diminish by about half every two weeks as the result of weathering losses, new plant growth, and similar mechanisms. Protective actions initiated at approximately two weeks following the contaminating event will avert 50 percent of the projected intake; actions initiated at approximately 1 week following the event will avert 75 percent; and actions initiated within two days will avert 90 percent.

Category II is concerned with the transmission of radionuclides to man through dietary pathways other than that specified as Category I during the first year following an acute contaminating

event. This involves the use of feed crops for animals, including dairy cattle, and plant products used directly for human consumption. Immediate action to reduce the potential intake will not usually be required because of the normal delay in the use of such crops. However, an early decision will be required as to the need for examination of harvested crops to determine the degree of contamination before they enter normal marketing channels. Protective actions in Category II are not normally expected to be indicated unless action was first needed in Category I.

Category III is primarily concerned with the long-term transmisson of strontium-90 through soil into plants in the years following a contaminating event. Residual contamination of cesium-137 may be a consideration for 1 to 2 years.

The benefits of a protective action taken in one category are largely independent of whether action is taken in another. The types of actions considered in the development of guidance in the report include:

1. Altering production, processing or distribution practices affecting the movement of radioactive contamination through the food chain and into the human body. This action may include storage of food supplies and animal feeds to allow for radioactive decay.
2. Diverting affected products to uses other than human consumption.
3. Condemning affected products.

The term "Protective Action Guide" has been defined as the projected absorbed dose to individuals in the general population that warrants protective action following a contaminating event; and a "protective action" as an action that will avert most of the exposure that would otherwise occur.

It is generally impossible to predict total doses solely from the degree of contamination of a particular crop. Therefore, the definition of protective action is extended in this report so that if the total projected dose from the use of all crops in Category II exceeds the Protective Action Guide, in order to make a substantial reduction in the total dose, action should be initiated against those crops that would make major contributions to that dose.

It is the purpose of the recommendations to discourage deliberate introduction of contaminated food into supplies of uncontaminated

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food as an acceptable solution to environmental contamination. Rather, it is recommended that if the contamination of a particular crop or dietary component is so high that it would not be acceptable for local use, the crop or dietary component not be considered acceptable for use in other areas to which it may be transported.

The recommended Protective Action Guides are:

For Category I—A mean dose of 10 rads in the first year to the bone marrow or whole body of individuals in the general population; and provided further that the total dose resulting from Category I not exceed 15 rads. For purposes of applying the guide, the total dose from strontium-89 and cesium-137 is assumed to be the same as the dose in the first year, whereas the total dose from strontium-90 is assumed to be 5 times the dose in the first year.

For Category II—A mean dose of 5 rads in the first year to the

bone marrow or whole body of individuals in the general population. As an operational technique it is assumed that the guide will be met effectively if the average dose to a suitable sample of the population is one-third the PAG or approximately 3 rads for Category I and 2 rads for Category II.

For Category III—A Protective Action Guide is not recommended. Rather, if it appears that annual doses to the bone marrow of individuals may exceed 0.5 rad or 0.2 rad to a suitable sample of the populaiton, such situations shall be appropriately evaluated.

Worldwide Contamination From Stratospheric Fallout

Studies of stratospheric fallout in the United States from past testing were reported in FRC Report Nos. 4 and 6. On the basis of this information, the Council concluded that the health risk from radioactivity in food over the next several years would be too small to justify protective actions to limit the intake of radionuclides either by diet modifications or by altering the normal distribution and use of foods, particularly milk and dairy products.

In Alaska, although the amount of fallout deposited per unit area is about one-fifth as much as that deposited in the 30°–40° latitude band, a combination of ecological conditions and specific dietary habits of some Eskimos and Indians causes higher cesium body burdens than are found in the conterminous United States. Average body burdens of cesium-137 in these inhabitants were

[p. 3]

about three times as high in 1964 as they were in 1962. The estimated whole body doses to these individuals in 1964 ranged from about one-fourth to one-half of the numerical value of the Radiation Protection Guide (RPG) for individuals in the general population.

The practicality and value of protective actions against widespread environmental contamination from stratospheric fallout is limited because:

1. The condition to be alleviated is chronic exposure from long-term continuous intake (10 years or more).
2. A reduction in potential intake under these conditions requires basic changes in long-term agricultural practices, food processing practices, dietary habits, or all three.
3. The actions would have to be applied on a broad enough scale to reduce the average quantity of radionuclides in the total diet from foods produced throughout large areas or the entire country.

A Protective Action Guide is not recommended for this situation. Rather, annual doses from fallout equal to or greater than the

numerical values of the RPG's can be used as an indication of when there is a need for a careful evaluation of fallout exposures.

In view of these considerations it is recommended that surveillance of the radionuclide content of food products contaminated with worldwide fallout be continued at levels appropriate to the situation. It is also recommended that surveillance and research programs examining the special ecological situations in the arctic region continue until future trends can be predicted with greater confidence.

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SECTION I

INTRODUCTION

1.1 This background staff report provides information and guidance for actions appropriate to situations involving contamination of the environment by the radionuclides strontium-89, strontium-90, and cesium-137. In certain circumstances, such as the unforeseen or uncontrollable dispersal of large quantities of radioactive materials in the environment, the resulting exposure can be reduced only by protective actions taken against the radionuclides in the environment. In these circumstances, changes in the normal production, processing, distribution, and use of foods may be required.

1.2 FRC Report Nos. 1 and 2 provide radiation protection guidance for the control and regulation of the normal peacetime uses of nuclear technology in which control is exercised primarily on the design and use of the radiation source. The Radiation Protection Guides (RPG's) in those reports were developed as guidelines for the protection of radiation workers and the general public against exposures which might result from routine uses of ionizing radiation. In formulating those guides there was a judgment, or balance, between the possible risks associated with a particular radiation exposure and the reasons for allowing the exposure.

1.3 An important factor in providing guides for any purpose is the change in risk assigned to higher or lower doses and the corresponding effort to reduce them. Other factors influencing informed opinion of where and why a particular balance should be made include views regarding prevailing practices and the relative importance of health risks in relation to economic, political, or

other considerations of national welfare. With respect to environmental levels of radioactivity, the RPG's reflect the residual risk considered acceptable after engineering and procedural controls have been applied at the source (i.e., place of origin) of the radioactivity to limit releases to the environment. The numerical values for these guides were placed as close to the annual dose from natural background radiation as technical, economic, and operational considerations allowed.

1.4 Although radiation doses numerically equal to the RPG's may impose a risk so small that they can be accepted each year for a lifetime if there is significant benefit from the programs causing the exposure, they do not and cannot establish a line that is safe

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on one side and unsafe on the other. Rather, some risk of injury may exist at any level of dose and the risk continuously increases with dose. Caution should be exercised in decisions to take protective actions in situations where projected doses are near the numerical values of the RPG's, since the biological risks are so low that the actions could have a net adverse rather than beneficial effect on the public well-being.

1.5 In contrast to the guidance given in FRC Report Nos. 1 and 2, FRC Report No. 5 provided general guidance for the protection of the population against exposure resulting from the accidental release, or from the unforeseen appearance, of radioactive materials in the environment. Specific guidance, including a numerical value for the Protective Action Guide (PAG), was provided for iodine-131. The PAG represents a consensus as to when, under the conditions considered most likely to occur, intervention is indicated to avoid radiation exposure that would otherwise result from transient environmental contamination. This consensus involves health, economic, sociologic and political factors for which the relative values are different than for the RPG. For the PAG these factors may include agricultural policies, the known feasibility of protective actions, related health impacts and similar considerations involved in the national interest.

Scope

1.6 This report provides background material used in the development of guidance for Federal agencies in planning activities to protect the population from strontium-89, strontium-90, and cesium-137 for certain situations in which these radionuclides may appear in the environment. A basic assumption in the development of the guidance is that a condition requiring protective

action is unusual and should not be expected to occur frequently. Two conditions of environmental contamination have been examined: An acute localized contaminating event in which prompt action may be necessary to avoid the exposure that would otherwise result; and a widespread, generally increasing, low-level of contamination (from stratospheric fallout) that would cause a continuous intake of radioactive nuclides by large numbers of people for a period of years.

1.7 Exposure of the general population to radioactive materials in the environment may result from external irradiation, inhalation, and ingestion of such materials. For most environmental situations, ingestion will produce the greatest absorbed dose. Ingestion of radioactive materials may be limited by protective

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actions affecting the normal production, processing, distribution, and use of food. As in FRC Report No. 5, only ingestion is considered in the present report. Only the transmission pathway from pasture through fluid milk to man was considered important for iodine-131. In this report it is necessary to consider the additional routes through animal feed crops, human food crops, and root uptake due primarily to the longer radioactive half lives of the nuclides under consideration. The report also considers the situation in the arctic region where, because of unusual ecological conditions and food chains, some population groups are exposed to levels higher than those in other parts of the United States.

1.8 The numerical values of absorbed doses specified as guides for an acute contaminating event are not intended to authorize deliberate releases expected to result in absorbed doses of these magnitudes, nor do they have any relevance to civil defense applications.

Preparation of Staff Report

1.9 The staff reviewed the applicable literature on the biological aspects of exposure to the radionuclides of interest in this report. The literature included reports from such groups as the National Council on Radiation Protection and Measurements, International Commission on Radiological Protection, United Nations Scientific Committee on the Effects of Atomic Radiation (UNSCEAR), International Atomic Energy Agency, and the Committee on Protection Against Ionizing Radiations of the United Kingdom's Medical Research Council. In addition, a review has been made of the practices and procedures in the agricultural and food processing fields that might be useful in reducing potential radionuclide intake.

1.10 Upon invitation from the Federal Radiation Council, the National Academy of Sciences—National Research Council (NAS-NRC) selected a committee of experts to prepare a summary of the biological effects to be expected in man from irradiation by strontium-89, strontium-90, and cesium-137. The committee's findings have been helpful to the Council in developing guidance presented in this report.

1.11 The staff also convened two ad hoc panels of scientists actively engaged in research projects involving strontium and cesium; one panel to provide data on the biological, chemical and physical factors involving radioactive contamination of pasture, milk, and other foods; and the second panel to provide information

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on the dosimetric relations for these radionuclides. Applicable information provided by these panels has been incorporated into this report.

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SECTION II

GENERAL CONSIDERATIONS

Origin and Distribution of Radioactive Materials in the Environment

2.1 The origin and distribution of radioactive materials injected into the atmosphere and their transport mechanisms through the environment to man have been studied intensively both nationally and internationally for the past decade in connection with the atmospheric testing of nuclear weapons. The past and anticipated concentrations of radioactive materials in the environment from weapons testing through 1962 have been studied and evaluated by the Council in its Report Nos. 3, 4, and 6.

2.2 When radioactive materials are released to the atmosphere at ground level, as would generally be the case from an industrial accident, dispersion in the troposphere is limited in extent. In this case, a single incident may cause deposition of high concentrations of radioactive materials within limited areas. Similar localized high-level deposition might also occur with tropospheric fallout deposited under unusual meteorological conditions.

2.3 Material injected into the stratosphere by nuclear weapons tests eventually descends to the troposphere from which it is deposited on the earth's surface. During storage in the stratosphere,

short-lived radionuclides decay essentially to zero. Long-lived radionuclides that find their way to the troposphere deposit relatively uniformly on a regional basis, although the quantities vary with latitude and with rainfall. A somewhat similar distribution pattern of short-lived radioactive material such as iodine-131 has been observed in the United States for the tropospheric distribution of debris from tests conducted outside the United States.

2.4 Thus, from past experience one can distinguish two limiting situations of environmental deposition. The first situation (see Section III) can be characterized as a high level of contamination that is limited in time and geographical area. This situation is generally identified with an accidental release of material from an industrial source or as the result of a localized high-level contamination resulting from deposition of tropospheric fallout during unusual meteorological conditions. The second situation (see

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Section IV) can be characterized as a geographically widespread, low level contamination, resulting from relatively uniform deposition of radioactive materials originally injected into the troposphere or stratosphere. This situation is generally identified with nuclear explosions in the atmosphere. There may be conditions which fall between these two situations. However, for these intermediate cases, it is difficult to predict the relative magnitude of such factors as areas involved, crops affected, and the population at risk.

Radioactive Nuclides of Interest

2.5 Although nuclear fission produces many nuclides, most of which are radioactive, their chemical and physical properties are such that few of them are of biological concern as potential radioactive contaminants of food. Some of these radionuclides have such short radioactive half lives that their radioactive decay to stable nuclides is essentially complete before the food is consumed. Those of principal interest are isotopes of elements readily utilized by vegetation or animals and of sufficiently long radioactive half lives that much of their radioactivity will not have disappeared before the food is consumed.

2.6 The relative importance of different radionuclides may depend on additional factors such as: the time that elapses between fission and the release of fission products to the environment; chemical or physical separation or fractionation; conditions of release; and season of the year. For example, in unseparated fission products only a few days of age, the properties of iodine make it the most important radionuclide; in fission products aged a few weeks the longer-lived strontium-89, strontium-90, and cesium-137

are the nuclides of importance. Studies of possible types of release have lead to the conclusion that events requiring protective actions are most likely to involve iodine-131.

The Transmission Pathways

2.7 The transmission pathways of radioactive material from the atmosphere through the food chain to man are shown in Figure 1. The radioactive material is scavenged from the atmosphere by meteorological processes, particularly rain. The most serious contamination problems would arise from direct deposition of the radionuclides on animal feed crops or on food crops directly consumed by man. Following the initial deposition on vegetation the radioactive materials tend to be removed by various processes, such as being washed off by rain or being blown off by the wind. The extent to which such removal occurs depends on a number of

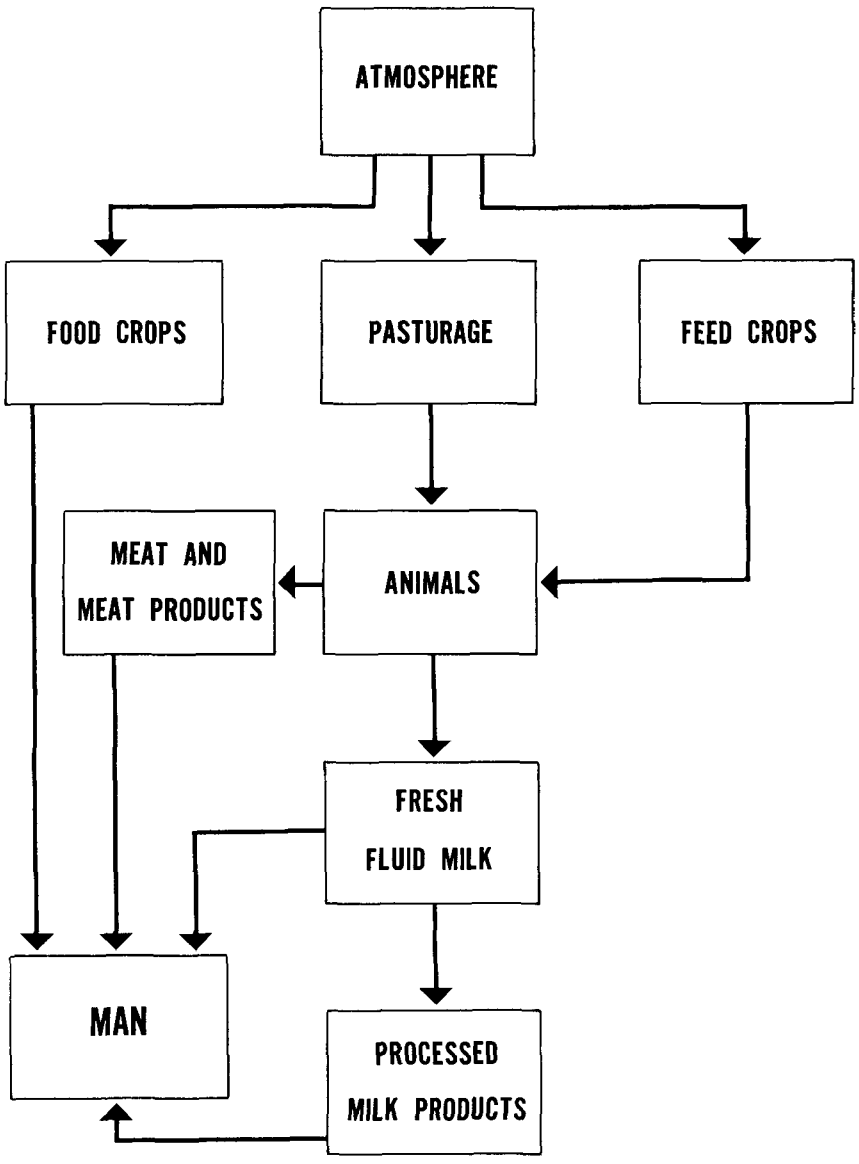

FIGURE 1.—Important steps in the transmission of radioactive material through the food chain to man.

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considerations, including particle size and chemical properties of the material deposited and environmental or biological factors.

2.8 The time of deposition relative to the various stages in the plant growth cycle is a major factor affecting the projected intake by man resulting from a given deposition. Much less radioactive

material will enter the food chain if the deposition occurs during a period when there is less vegetation or when animals are not on pasture than if the deposition immediately precedes the harvest of a crop. With increasing time between deposition and harvest the transmission of radioactive materials through the food chain would diminish as a result of dilution by new plant growth, removal by weathering and decay, and in some instances by fixation in the soil.

2.9 As seen in Figure 1, man's ingestion of radioactive material may result from contaminated food crops, from contaminated meat or meat products, and from contaminated milk or milk products. The relative importance of the various pathways of intake depends on the radioactive half lives of the radionuclides, the rate and routes by which they pass through the transmission chain, and the dietary habits of the population.

2.10 The immediate and usually the most significant transmission of all these radionuclides will occur through the pasture-cow-milk-man pathway. Because of the various types of plant losses the immediate phase will ordinarily not be of importance after the first 100 days following deposition.

2.11 A later transmission of radionuclides through milk may occur from use of stored feed if this feed was contaminated in the field at the time of the deposition. The relative importance of this pathway may vary greatly due to differences in time between deposition and harvest, the portion of the feed supply contaminated, and the use of the feed supply.

2.12 Foods other than milk may be contaminated to some extent as a result of deposition of radionuclides on food crops or on pasture and feed crops used for meat animals. The variables involved are similar to those of the transmission to milk through stored feed. Cesium-137 would usually be the only significant contaminant present in meat.

2.13 After the first year there may be a residual problem result-

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ing from deposition on soil and subsequent root uptake. This problem would generally concern only strontium-90. Strontium-89 would be essentially removed by radioactive decay and cesium-137 in the soil is generally unavailable to plants.

2.14 Once the radioactive material is ingested by man, the uptake depends upon the chemical properties of the elements and the physiology of the organ involved. Thus, iodine-131 tends to concentrate in the thyroid and strontium-89 and -90 in the bone, while cesium-137 is more-or-less uniformly distributed throughout the body.

Concentrations of Radionuclides in Milk and Projected Intake by Man Following a Contaminating Event

2.15 The ad hoc panel that provided data on the factors involving radioactive contamination of pasture, milk and other foods following a postulated acute deposition, used the following assumptions: (1) physical and chemical properties of the radionuclides were the same as found in worldwide fallout, (2) deposition time was short, (3) deposition was on pasture for dairy cows, and (4) the background and previous cumulative soil contamination levels were negligible. Animal tracer and surveillance network data were used to derive the relationships between concentrations of strontium-89, strontium-90, and cesium-137 in milk and the projected intakes by man.

2.16 Three factors are involved in estimating concentrations of radionuclides in milk after a contaminating event: (1) the secretion rate of the radionuclides into milk following ingestion of a constant daily intake of contaminated vegetation by the cow, (2) reduction of the pasture contamination by weathering and dilution by plant growth, and (3) radioactive decay. When all of these factors are considered, the concentrations of strontium-89, strontium-90, and cesium-137 in milk, as a function of the cow's intake, are described by the equation:

$$A = (ce^{k1t}) \quad (1-e^{-k2t}) \quad (e^{-k3t}) \quad (e^{-k4t}) \qquad (1)$$

A is the radionuclide concentration in milk; c, $^{k}1$, $^{k}2$, $^{k}3$, and $^{k}4$ are constants for a given radionuclide, and t is the time in days after deposition. The first two terms of the equation describe the radionuclide concentration in milk resulting from a constant intake by the cow. The third term describes the rate of loss from vegetation, and the fourth term describes the radioactive decay. This

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equation is illustrated in Figure 2 as the radionuclide concentration in milk at any time, expressed as a fraction of the maximum concentration (A_m).

2.17 In order to derive the constants (Table 1) for the equation it was necessary to relate the radionuclide concentration in milk to the cow's radionuclide intake during the first day after contamination of the pasture, but knowledge of the cow's intake is not needed to apply the equation. The secretion rate of radionuclides into milk following deposition was estimated from animal experiments in which there was a constant daily intake of the radionuclides by each cow. The rate of loss from vegetation was estimated from surveillance data and from experimental field work. There is a

range of measured values for the effective half-time of the radionuclides on grass, most of which are close to 14 days. This value has been selected for use in this report. The effect of radioactive decay in the case of strontium-90 and cesium-137 can be neglected because of the short grazing season compared to the long half lives of these radionuclides.

TABLE 1.—CONSTANTS FOR EQUATION (1)

	Strontium–89	Strontium–90	Cesium–137
c $\frac{(nCi/l)}{(nCi/day)}$	0.001	0.001	0.013
k_1 ($days^{-1}$)	0 008	0.008	0.01
k_2 ($days^{-1}$)	0.26	0.26	0.41
k_3 ($days^{-1}$)	0.05	0.05	0.05
k_4 ($days^{-1}$)	0.014	NA	NA

NA=Not applicable.

nCi=nanocurie=1×10^{-9} curie.

2.18 The values for T_m, A_m normalized to 1 nanocurie per liter of milk, and the projected intake by man in nanocuries assuming a daily consumption of 1 liter of milk, are listed in Table 2.

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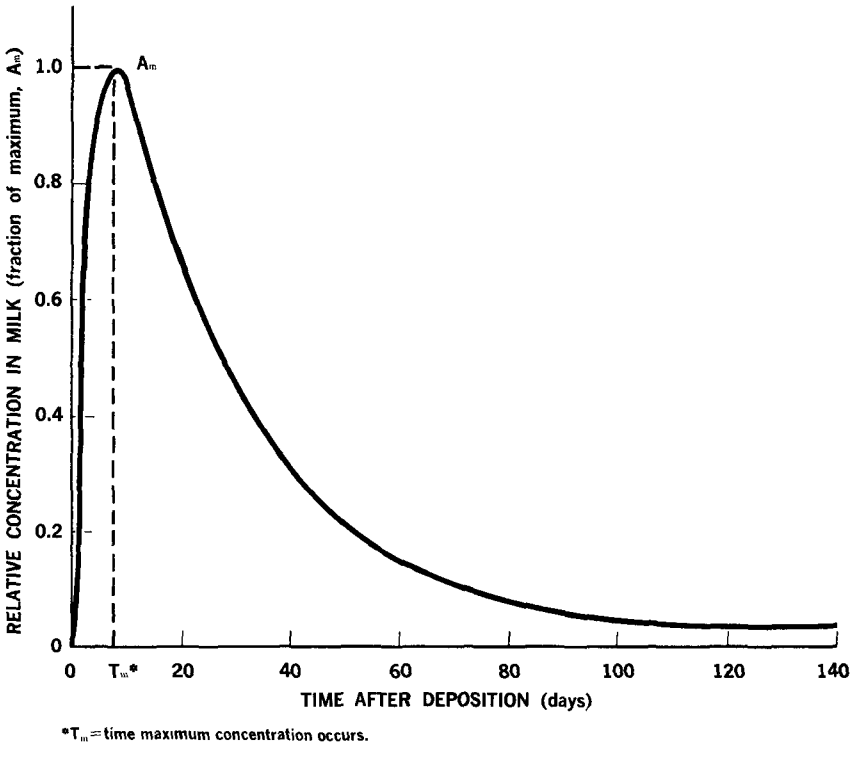

FIGURE 2.—The relative concentration of radionuclides in milk following a single deposition on pasture.

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2.19 The reduction of radionuclide concentration in milk after changing cows from pasture to an uncontaminated feed source has been estimated from the exponential decline of radionuclide concentration in milk following a single intake of a tracer by cows. After the shift to uncontaminated feed, and assuming a constant daily consumption of milk by man, it has been calculated that the remaining intake will equal 2.9, 3.4, and 5.1 times the daily intake of strontium-89, strontium-90, and cesium-137, respectively, at the time of the shift. These relations make it possible to estimate when the shift has to be made in order to avoid various percentages of the total projected intake by man. The results are summarized in Table 3.

TABLE 2.—T_m, A_m AND PROJECTED INTAKE BY MAN AFTER AN ACUTE CONTAMINATING EVENT INVOLVING PASTURE

	Strontium–89	Strontium–90	Cesium–137
T_m (days)	7	7	6
A_m (nCi/liter)	1	1	1
Projected Intake (nCi)	27	33	32

TABLE 3.—INTAKE AVOIDED VERSUS TIME OF INITIATING PROTECTIVE ACTION

Projected Intake Avoided (%)	Strontium–89 (days)*	Strontium–90 (days)*	Cesium–137 (days)*
50	13	17	14
75	6	7	5
90	2	2	2

*Days after the initial contamination of pasture at which cows would have to be shifted to uncontaminated feed.

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Biological Risk Considerations

2.20 The possible biological effects that might follow irradiation of human tissue under differing conditions have been previously reviewed by the FRC in Report Nos. 1 and 2, and more recently by the UNSCEAR (1962 and 1964). In 1964 the Federal Radiation Council asked the National Academy of Sciences—National Research Council to prepare a report on the effects to be expected in man from irradiation by internally deposited strontium-89, strontium-90, and cesium-137 for doses of 25 rads or less from a single contaminating event.

2.21 The Academy in turn established a committee of experts to evaluate the possible effects of these radionuclides in man. The committee considered the particular metabolic properties of these radionuclides, the known effects of irradiation from these and other internally deposited radionuclides, and from external sources. The committee gave particular consideration to the effects that might result from the short-term uptake of any one of these radionuclides by a small fraction of the population.

2.22 The possible risk to segments of a population with a typical distribution of adults, including pregnant women, as well as of children and infants has been examined. The population at risk from local contamination of the environment will be small. In a population with a typical distribution of ages about 50 percent are age 30 or younger, about 10 percent will be of age 4 or younger, and about 2 percent are pregnant women.

2.23 In regard to hereditary effects, it is assumed that any increase in radiation exposure to the genetic cells causes some in-

crease in the mutation rate. The hereditary load induced in a population is proportional to the average dose to the entire population. However, the dose to the individual must also be considered. The NAS-NRC Committee on Genetic Effects of Atomic Radiation expressed the opinion in 1956 that the chance of genetic damage of such a nature as to be expressed in an individual's immediate family would be acceptably small if the dose to the individual was less than 50 rads in 30 years. This opinion was reaffirmed in 1964, and it was concluded that genetic considerations are not limiting under circumstances for which protective action may be needed provided that the exposed population is small and the dose to an individual is small compared to 50 rads (NAS Report to FRC, 1964, par. 4.10).

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2.24 Available estimates of the risk of somatic injury following irradiation have been obtained largely from high dose rates (a few rads or greater per minute), high radiation doses (exceeding 100 rads), or both. These estimates can be considered valid only for the conditions of irradiation for which they were obtained, since there is evidence indicating that the effect of an irradiation depends on both the total dose and the dose rate.

2.25 It has not been established whether internal emitters selectively deposited in bone (bone-seekers) are leukemogenic in man. In addition the specific sites of leukemogenesis, particularly as a function of age, are essentially unknown. However, for the purposes of this report, bone marrow is considered to be the most significant tissue from the standpoint of susceptibility to harmful effects of irradiation.

2.26 Evidence based largely on the survivors of Hiroshima and Nagasaki indicates that, if a population of a million people were to receive a radiation dose of 100 to 500 rads, the average increase in the incidence of leukemia over a period of about 15 years would be from one to two cases per year per rad. (NAS Report to FRC, 1964, par. 5.15; UNSCEAR, 1964, Appendix B, par. 30). An approximately equal number of other neoplasms attributed to the irradiation was found in the same population (UNSCEAR, 1964, Appendix B, par. 179) giving a total increase of 2 to 4 cases per year per million persons per rad averaged over the same number of years.

2.27 An association between antenatal exposure and an increased incidence of cancer in childhood has also been reported. This has been related to single exposures (essentially whole body) to the fetus that may have been as low as 2 to 5 R (NAS Report to FRC, 1964, par. 5.10). The increased incidence of leukemia and

total neoplasms calculated on the assumption of linearity was 4 to 10 and 8 to 20 cases per year, respectively, per million fetuses exposed per rad up to the age of 10 years (NAS Report to FRC, 1964, par. 5.11). The risk following antenatal exposure at high dose rate was accordingly estimated to be about 2 to 5 times the risk per rad following postnatal irradiation.

2.27 These estimates of radiation risk cannot be corrected to account for the effects of differences in dose rate and dose distribution. For comparable total doses the dose rate from strontium and cesium under the conditions of present interest is about 10^{-5} to 10^{-6} of the dose rates associated with the estimates of radi-

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ation risk in antenatal exposure. Since the strontium nuclides irradiate only that portion of the tissue adjacent to the sites of deposition in the skeleton, the dose distributions are very different from those for which there are risk estimates.

2.29 However, there is evidence from radiobiological experiments indicating that somatic cells, even in the embryo, and genetic cells generally sustain less injury from a given dose if irradiated at low dose rates than if irradiated at high dose rates. For example, genetic studies on mice led to the estimate that when both parents are irradiated at low dose rates, the effectiveness of irradiation in producing mutations may be as little as one-sixth that of the same dose given at high dose rates (FRC Report No. 3, p. 7). Similar observations on the influence of dose rate have been made for radiation-induced leukemogenesis in animals (NAS Report to FRC, 1964, par. 5.17). Hence, the magnitude of the dose rate effect may be considered to be in the same range as the reported difference in radiation sensitivity between antenatal and postnatal populations exposed at high dose rates. From these considerations it is estimated that the upper limit of risk per rad related to antenatal exposure under the conditions of interest (low dose rate) will be no greater than the risk heretofore related to postnatal exposure to the same dose at high dose rates.

Dosimetry Considerations

2.30 The small organ size of infants results in a relatively larger dose per unit intake of radioactive material than for older age groups. Also, from the preceding discussion, the fetus is more susceptible to injury than infants or adults per unit dose. For these reasons special consideration has been given to antenatal and infant exposure.

Strontium

2.31 The metabolism of strontium is linked to the metabolism

of calcium in a complex way. The body preferentially absorbs calcium and preferentially excretes strontium. However, strontium and calcium are incorporated into new bone in the same ratio as they exist in blood. It is not known whether the biological risk from radioactive strontium depends upon the dose to bone marrow adjacent to the sites where strontium is incorporated in the skeleton, or upon the mean dose to all the bone marrow in the skeleton. Under the linear hypothesis the mean dose to all bone marrow is

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the dose of interest for the evaluation of biological risk, and is the one used in this report.

2.32 The radiation dose to mineral bone that would result from the ingestion of radioactive strontium from the diet depends on the fraction of ingested strontium reaching bone and the length of time it remains there. Inadequate knowledge of the way strontium may be initially distributed in the skeleton makes a calculation of radiation dose, particularly to bone marrow, very difficult. If uniformly distributed throughout the mineral bone of the adult, 1 nanocurie of strontium-89 per gram of calcium would result in a dose of 0.3 rad to mineral bone (derived from UNSCEAR, 1962, Annex F, par. 52, p. 356). One nanocurie of strontium-90 per gram calcium uniformly distributed in adult bone would result in a dose of 2.7 rads in a year (UNSCEAR, 1962, Annex F, par. 29, p. 353). The dose to mineral bone of the fetus and infant may be about one-half the adult values because the young skeleton has less mineral per gram of bone, and because the young skeleton absorbs less of the available beta energy (*Some Aspects of Internal Irradiation,* Pergamon Press, Oxford 1962, p. 447).

2.33 The estimation of the dose to bone marrow resulting from the incorporation of radioactive strontium in the surrounding mineral bone is a complex problem. The energies of the beta particles from the radioactive decay of strontium are distributed over a broad spectrum, and for each energy a specific range of the particle in bone, soft tissue, or in a combination of the two must be considered. The dose to bone marrow from strontium-89 and strontium-90 uniformly distributed in the adult skeleton has been estimated to be about one-fifth the calculated dose to mineral bone for strontium-89 and about one-fourth the dose to mineral bone from strontium-90 (UNSCEAR, 1962). The Federal Radiation Council used a value of one-third for both nuclides in FRC Report No. 2.

2.34 Although the lower density of mineralization in the infant and fetal skeleton results in a lower dose to mineral bone than the dose from the same concentration of strontium in the adult skel-

eton, the resulting dose to bone marrow of the infant or fetus will be relatively higher for the same reason. Therefore, one-third of the dose that would be calculated for mineral bone per unit of strontium in the adult skeleton is also a reasonable estimate of the dose from the same concentration to bone marrow of the fetus and infant. The calculations in this report accordingly assume that for estimating radiation dose to the bone marrow of a fetus or

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infant from radioactive strontium in the skeleton (1) the radioactive strontium is uniformly distributed in the mineral bone, (2) a concentration of 1 nanocurie strontium-89 per gram calcium in the skeleton will give a total dose of 0.1 rad to bone marrow, and (3) a concentration of 1 nanocurie strontium-90 per gram calcium in the skeleton will give a dose of 0.9 rad in one year to bone marrow. With present information, these dose conversion factors give the best available estimates of the biologically important dose, i.e., the average dose to bone marrow following short-term intake of radioactive strontium.

2.35 The relationship of strontium and calcium in children's bones compared to the strontium to calcium ratio in the diet is based on results obtained from measurements made on strontium-90 from fallout. The proportion of radioactive strontium incorporated into the skeleton from the diet mainly involves two factors: first, discrimination by the body against strontium in favor of calcium; and second, the amount of calcium with its associated strontium which is incorporated into the skeleton each day by the formation of new bone.

2.36 The first factor, discrimination between strontium and calcium in the passage of these elements from the diet to a given tissue in the body, is usually expressed as the Observed Ratio (OR). The OR relates the ratio of strontium to calcium that exists at equilibrium in a given component of the body to the ratio of strontium to calcium in the diet. If the body component is the bone, then:

$$\text{OR bone/diet} = \frac{\text{Sr/Ca in bone}}{\text{Sr/Ca in diet}} \qquad (2)$$

The OR, fetal bone to mother's diet is estimated to be about 0.1. The OR, bone to diet changes from about 1 at birth, to about 0.5 at 6 months to 1 year, and to about 0.25 shortly thereafter (NAS Report to FRC, 1964, par. 3.14). An OR of 0.35 has been selected as the most representative value for the age group of interest (i.e., 6 months to 2 years).

2.37 The second factor is related to the sum of the calcium involved in skeletal growth (net accretion) plus the quantity of calcium in the existing skeleton that is replaced (turnover). Mitchell, et al. (J. Biol. Chem. 158, 625, 1945) have estimated the net annual calcium accretion from birth to 20 years, after which skeletal growth ceases. The quantity of calcium in the skeleton at birth and at ages 1 and 2 has been estimated to be 28, 100, and 150 grams, respectively. The estimated net accretion of calcium

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is 28 grams in the fetal period, 72 grams during the first year of life, and 50 grams in the second year of life. The bone mineral turnover rate during the first two years of life is estimated to be about 50 percent per year (NAS Report to FRC, 1964, par. 3.12). The turnover rate decreases to an adult value of about 1 percent per year in the shafts of long bones and 10 percent in cancellous bone.

2.38 The radiation dose delivered to the skeleton during the first year following a contaminating event varies with the length of time the diet is contaminated. Estimates have been made for a contaminating event that would result in a total intake of one microcurie of strontium-89 or strontium-90 in 100 days, the period of interest for the transmission of these radionuclides through the pasture-cow-milk-man pathway. Assuming that the typical calcium intake is about 1 gram per day, the radioactive strontium intake would then be associated with 100 grams of calcium. Thus, an intake of one microcurie of radioactive strontium in 100 days would result in an average dietary level of 10 nanocuries of radioactive strontium per gram of calcium.

2.39 For estimating dose following the ingestion of radioactive strontium, the ad hoc dosimetry group recommended a model embodying: formation of a specified amount of new bone per day; further resorption and remodeling of a specified amount of existing bone per day; and use of the OR to relate the strontium to calcium ratio in the diet to that in bone. A dynamic model which simulates incremental changes in skeletal strontium on a day to day basis was developed utilizing computer techniques. Evaluation of the results from the computer model indicated that a less refined approach using strontium diet levels averaged for the period of intake and other simplifying assumptions regarding net calcium accretion and bone turnover would provide comparable estimates of dose.

2.40 An estimate of the dose to bone marrow from radioactive strontium in the diet can be reduced to two considerations:

1. An estimate of the average strontium to calcium ratio in the skeleton from average dietary levels for a short-term intake.

2. The use of a dose conversion factor to convert the skeletal concentrations of strontium into dose to the bone marrow. The average strontium to calcium

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ratio (R_a) in the skeleton may be estimated from:

$$R_a = R_d \times OR \times F \quad (3)$$

where:

R_d = strontium to calcium ratio in the diet averaged over the period of intake.
OR = Observed Ratio.
F = Fraction of skeletal calcium incorporated by accretion and turnover during the period of intake.

An estimate of dose (D) can be calculated by:

$$D = R_a \times \text{Dose Conversion Factor} \quad (4)$$

Application of the appropriate dose conversion factors from par. 2.34 will give the total dose from strontium-89 or the dose in one year from strontium-90, which would result from the calculated average skeletal strontium to calcium ratios.

2.41 For the antenatal period the maximum strontium burden of the developing skeleton would result when the 100 day intake coincides with the third trimester, i.e., when essentially all of the mineralization of the fetal skeleton occurs. Thus F would be 1.0. Using an R_d of 10 nanocuries of radioactive strontium (denoted as Sr* in the equations) per gram of calcium in the mother's diet and an OR of 0.1 for mother's diet to fetal bone, the average strontium to calcium ratio in the fetal skeleton would be:

$$R_a = 10 \times 0.1 \times 1.0 = 1.0 \frac{\text{nCi Sr*}}{\text{g Ca}}$$

2.42 For the infant one to two years old, the fraction F must be estimated from the annual net accretion and turnover. The net accretion during the second year of life is estimated to be about 50 grams of calcium. The turnover is estimated to be an additional 50 grams of calcium during this year. The fraction of calcium in the skeleton that is incorporated during the 100 day intake is:

$$F = \frac{50 + 50}{150} \times \frac{100}{365} = 0.18$$

Using an R_d of 10 nanocuries of strontium per gram of calcium in

the diet and an OR of 0.35, the average strontium to calcium ratio

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in the infant skeleton would be:

$$R_a = 10 \times 0.35 \times 0.18 = \frac{0.65 \text{ nCi Sr*}}{\text{g Ca}}$$

Strontium-89

2.43 The total dose resulting from the 100 day intake of strontium-89 can be calculated using the dose conversion factor previously given. A concentration of 1 nanocurie strontium-89 per gram of calcium in the skeleton would give a total dose of 0.1 rad to bone marrow. For the two cases presented the doses would be:

Fetus: $D = 1.0 \times 0.1 = 0.1$ rad
Infant: $D = 0.65 \times 0.1 = 0.065$ rad

Thus the resulting total dose to the bone marrow of the infant is estimated to be about two-thirds of the total dose to the bone marrow of the fetus for the same intake by the infant and the pregnant mother. This difference is less than the uncertainties inherent in the estimate, and is not considered significant.

Strontium-90

2.44 Using the relationship that one nanocurie of strontium-90 per gram of calcium in the skeleton will give a dose of 0.9 rad in one year to the bone marrow, the doses from strontium-90 for the two cases presented would be:

Fetus: $D = 1.0 \times 0.9 = 0.9$ rad in one year
Infant: $D = 0.65 \times 0.9 = 0.6$ rad in one year

2.45 Since one trimester is about one-fourth of a year, the dose to the fetus before birth would be about one-fourth the dose in one year estimated from the strontium-90 to calcium ratio in the fetal skeleton, or approximately 0.2 rad. The strontium-90 burden at birth would be one nanocurie of strontium-90 per gram of calcium times 28 grams of calcium or 28 nanocuries. With a bone turnover rate of 50 percent per year there would be $28 \times 0.5 = 14$ nanocuries strontium-90 per 100 grams calcium in the skeleton at age 1, and 7 nanocuries strontium-90 per 150 grams of calcium at age 2. These concentrations of strontium-90 give dose rates of 0.1 and 0.04 rad per year, respectively. Computer analysis led to the estimate that the total (70 year) dose from a short-term intake of

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strontium-90 would be about 5 times the dose in the year when the infant is age 1. Assuming that the dose in a year can be reason-

ably approximated by the average of the dose rates at the beginning and end of the year, the projected total dose to bone marrow of an individual whose mother had an intake of 1 microcurie of strontium-90 during the last 3 months of pregnancy would be:

$$D = 0.2 + \left[\frac{0.9 + 0.1}{2}\right] + 5\left[\frac{0.1 + 0.04}{2}\right] = 1.1 \text{ rads, total dose}$$

The total bone marrow dose for the infant would be:

$$D = 0.6 \times 5 = 3 \text{ rads, total dose}$$

It is concluded that for an identical intake over 100 days by the infant and by the pregnant woman the total dose to the infant would be approximately three times the total dose to the individual exposed as a fetus.

2.46 In view of the considerations discussed in the previous paragraphs, the estimates of projected doses to individuals in the general population are based on a dose of 0.1 rad to bone marrow following the ingestion of 1 microcurie of strontium-89 associated with 100 grams of calcium, and a dose of 0.6 rad in the first year with a total dose of 3 rads to bone marrow following the ingestion of 1 microcurie of strontium-90 associated with 100 grams of calcium.

Cesium-137

2.47 Cesium-137 is an alkali metal which is chemically and metabolically similar to potassium. Its distribution after ingestion is relatively uniform throughout the body resulting in irradiation of the whole body, including bone marrow. It is eliminated from the body at a rate which may be expressed in terms of the biological half life. This is the time required for the body to eliminate one-half of an initial body burden of cesium.

2.48 The dose resulting from a given intake of cesium-137 is directly proportional to the biological half life and inversely proportional to the lean body mass. A review of the literature indicates that the biological half life ranges from about 60 to 180 days in adults. The value for normal adults in the general population is estimated to be about 100 days (NAS Report to FRC, 1964, par. 2.12). The data for persons younger than 25 years suggest that the biological half life before maturity may be a function of age. Biological half lives of about 20 days or less have

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been reported for infants. For this report a value of 30 days is used as the biological half life of cesium-137 in infants.

2.49 The radiation dose per microcurie of cesium-137 ingested

may be approximately related to the body size and the biological half life by the formula:

$$D = \frac{I}{W} \times 0.03 \times 1.44\, T_B \qquad (5)$$

where:

D = the total dose in rads
I = the total intake in microcuries of cesium-137
W = the body weight in kilograms
0.03 = kilogram rads per microcurie day (based on the absorption of 0.59 MeV per disintegration).
T_B = the biological half life in days

2.50 An infant weighing 10 kg (about 22 pounds) and ingesting 1 microcurie of cesium-137 would receive a dose of 0.13 rad. An adult weighing 70 kg and ingesting 1 microcurie of cesium-137 would receive a dose of 0.06 rad. The dose rate to the fetus is considered to be the same as the dose rate to the mother. Therefore, for equal intakes of cesium-137 the dose to the infant would be about twice the maximum dose to the fetus. Most of the dose from a short-term intake of cesium-137 would be received in one year. A value of 0.13 rad following the ingestion of 1 microcurie of cesium-137 is used to estimate projected doses to the general population.

Protective Actions and Guides

2.51 As stated in FRC Report No. 5, a protective action is an action or measure taken to avoid most of the exposure to radiation that would occur from future ingestion of foods contaminated with radioactive materials. In the present report the concept of protective action must be extended in its application because the longer half lives of strontium-90 and cesium-137 may lead to a more persistant contamination of a number of food and animal feed crops. Therefore, in order to achieve a substantial reduction

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in the total dose, it is necessary to consider protective actions against those animal feed crops or food crops that would make major contributions to that dose.

2.52 Some basic considerations in the development of protective actions and guides are:

1. The occurrence of an acute contaminating event which will require protective action is considered to be so infrequent that it is unlikely that the same individual will be exposed to more than one event.

2. Exposure to the public from radionuclides in the environment is directly

related to the concentration of the radionuclides in food supplies and the length of time (weeks, months, or years) over which unusual exposures would be expected to occur. The need for protective actions is generally independent of the source of contamination.

3. The substitution of food or feeds of lower radionuclide content for contaminated products is both effective and practicable.

4. The potential intake of radionuclides by individuals in the general public from radionuclides in the environment can be reduced whenever modifications in the normal production, processing, distribution, or dietary practices are considered to be less objectionable than the radiation risk that would otherwise have to be accepted.

5. Protective actions, by their very nature, are short-term modifications in such practices.

6. If the contamination of a particular crop or dietary component is so high that it would not be acceptable for local use, the crop or dietary component is not considered acceptable for use in other areas to which it may be transported.

2.53 Also, in the development of guidance for taking protective action it is necessary to consider:

1. The possible risk to health associated with the projected dose to the population from radioactive materials.

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2. The amount by which the projected dose can be reduced by taking certain actions.

3. The total impact, including risks to health, associated with these actions.

4. The feasibility of taking the actions.

2.54 Decisions to implement protective actions involve a comparison of the risk due to radiation exposure with the undesirable features of the contemplated actions. The critical decisions to be made are whether to permit unrestricted use of feed crops or food products, to place restrictions on the normal use of feed crops or food products, or to destroy feed crops or food products. The value of a protective action depends on how much the projected dose per individual can be reduced by the action and the number of people affected. Protective actions affecting a particular population group will yield a greater return in relation to their disadvantages if projected doses are high rather than low. Since high levels of contamination probably will be limited to small areas, protective actions are more likely to be required in such areas rather than over large regions.

2.55 The Council has adopted the term "Protective Action Guide" (PAG), defined as the projected absorbed dose to individuals in the general population that warrants protective action following a contaminating event. The projected dose is the dose that would be received by individuals in the population group from the contaminating event if no protective action were taken. If the projected dose exceeds the PAG, protective action is indicated.

2.56 Protective actions are appropriate when the health benefits associated with the reduction in exposure to be achieved are sufficient to offset the undesirable features of the protective actions. The PAG's represent the judgment as to where this balance should be for the conditions considered most likely to occur. If, in a particular situation, there is available an effective action with low total impact, initiation of such action at a projected dose lower than the PAG may be justifiable. If only high impact action would be effective, initiation of such action may be justifiable only at a projected dose higher than the PAG. The types of actions considered in the development of guidance in this report include:

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1. Altering production, processing, or distribution practices affecting the movement of radioactive contamination through the food chain and into the human body. This action may include storage of food supplies and animal feeds to allow for radioactive decay.
2. Diverting affected products to uses other than human consumption.
3. Condemning affected products.

2.57 An alteration of the normal diet of an individual is generally less desirable than the measures listed and should not be undertaken except on the personal advice of a physician.

2.58 In the situations where there are slowly increasing levels of widespread contamination over a period of months or years throughout the nation's food producing areas, protective actions presently contemplated for acute, local contamination situations would not be effective. The consideration of long duration protective actions to reduce the average intake of radioactive materials for large populations involves many complex interacting factors of available, or potentially available, resources. In addition, a decision to require changes in agricultural and food processing practices or dietary habits could be implemented only through policy decisions involving land utilization, work force distribution, and the allocation of technical talent to the long-term control effort.

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SECTION III

THE ACUTE LOCALIZED CONTAMINATING EVENT

3.1 Situations justifying protective actions could occur from such events as an industrial accident, possibly involving a nuclear reactor or a nuclear fuel processing plant, and release of radio-

active materials from nuclear explosions. The considerations involved in determining appropriate criteria for protective action following an acute contaminating event have led to the development of three categories of dietary pathways. Categories I and II relate to intake in the first year following acute deposition, while Category III considers intake after the first year.

3.2 Category I is concerned with the immediate transmission of the radionuclides through the pasture-cow-milk-man pathway. The three nuclides of interest may be transmitted through this pathway simultaneously when they are deposited simultaneously on pasture. Experimental data indicate that nearly all the radioactive materials appearing in milk through this pathway will have occurred within 100 days, and protective actions may have to be applied for this length of time. Protective action must be initiated within about a week to be effective in averting most of the potential exposure. This category of transmission may be the only one of importance for strontium-89 because of its relatively short radioactive half life (50.5 days).

3.3 Category II is concerned with the transmission of radionuclides to man through dietary pathways other than that specified as Category I during the first year following an acute contaminating event. This involves the use of feed crops for animals, including dairy cattle, and plant products used directly for human consumption. The radioactive materials initially deposited on such crops in the field do not gain access to the human food chain until after the crops are harvested. Immediate action to reduce the potential intake will not usually be required because of the normal delay in the use of such crops. However, an early decision will be required as to the need for examination of the radionuclide content of harvested crops before they enter normal marketing channels. Strontium-90 and cesium-137 may be transmitted through the cow's feed to milk; cesium-137, in particular, may be transmitted through feed to meat; both may be transmitted to man through the direct consumption of plant products.

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3.4 Category III is primarily concerned with the long-term transmission of strontium-90 through soil into plants in the years following a contaminating event. Residual contamination of cesium-137 on pasture when there is a heavy root mat may be a consideration for one to two years following a sufficiently severe contaminating event. Because of the long lead time available to assess the possible radionuclide intakes, immediate action is not necessary. Any action that may be taken must be based on the

long-term reduction of the radionuclide concentrations in products grown in the area.

3.5 In considering the desirability of initiating protective actions following a contaminating event, it is necessary to consider the three categories separately. The benefits of a protective action taken in one category are largely independent of whether action is taken in another. Individuals may be exposed to radioactivity from all three categories; however, the guides for individual categories recommended in this report are sufficiently conservative (i.e., low) that it is unnecessary to provide an additional limitation on combined doses. Actions that are likely to be taken in Categories I and II would be effective against any of the three nuclides. Since all nuclides contribute to bone marrow dose, the sum of the projected doses to the bone marrow should be compared to the numerical value of the respective guide in the appropriate category when the need for protective action is considered.

Guidance Applicable to Category I

3.6 Conditions in Category I develop rapidly from the onset of radionuclide deposition, and protective actions must be initiated within about a week to avert most of the intake. The protective actions considered effective are:

1. The change of cattle from pasture to stored feed.
2. The substitution of unaffected fresh milk for affected fresh milk by alteration of processing or distributing practices, with subsequent diversion (depending on the radionuclides) or disposal of contaminated milk.

Since these actions are effective for all radionuclides of concern, actions taken for one contaminant will simultaneously reduce the intake of others. Protective actions to avert exposure may be appropriate for a shorter or longer time than 100 days, depending on

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the circumstances.

3.7 The concept of the Protective Action Guide, as presented in Report No. 5, was developed for use as guidance in situations involving the rapid transmission of radionuclides from pasture to milk to man with the inherent limitations on the types of effective actions for which the necessary resources would be generally available. Such a situation has many of the characteristics of an emergency requiring an immediate decision as to the need for protective actions. The possible need for early actions to avoid most of the projected intake that may result from an acute localized contaminating event involving strontium-89, strontium-90, and cesium-137 is also present in Category I.

3.8 In the application of the PAG's the following guidance is provided:

1. If the projected dose exceeds the PAG, protective action is indicated.
2. The amount of effort that properly may be given to protective action will increase as the projected dose increases.
3. The objective of any action is to achieve a substantial reduction of the dose that would otherwise occur—not to limit it to some prespecified value.
4. The value of the proposed protective actions must be weighed against their total impact. Each situation should be evaluated individually. As the projected doses become less the value of protective actions becomes correspondingly less.

3.9 The guidance applicable to strontium-89, strontium-90, and cesium-137 is given in terms of the projected dose to the whole body or bone marrow. Because of the risk associated with irradiation of bone marrow or the whole body as compared to irradiation of the thyroid, and the comparability of the protective actions available to avert the exposure, it is considered appropriate that the PAG's applicable to these radionuclides be lower than the PAG recommended for iodine-131. In view of these considerations it is recommended that:

1. The PAG for the transmission of strontium–89, strontium–90, and cesium–137 through milk under the conditions of Category I be a mean dose

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of 10 rads in the first year to the bone marrow or whole body of individuals in the general population; and provided further, that the total dose resulting from Category I not exceed 15 rads. For purposes of applying this guide the total dose from strontium–89 and cesium–137 is assumed to be the same as the dose in the first year, whereas the total dose from strontium–90 is assumed to be five times the dose from strontium–90 in the first year. As an operational technique it is assumed that the guide will be met effectively if the average projected dose to a suitable sample of the population (children approximately 1 year of age) does not exceed one-third of the numerical value prescribed for the individual.

3.10 For the radionuclides of interest, the total intake by man in Category I following a contaminating event is estimated from the assumptions that: (1) Equation (1) describes the radionuclide concentrations in milk as a function of time; (2) the average calcium content of milk is 1 gram per liter; (3) the daily intake of milk is 1 liter; and (4) the total intake will occur within 100 days. Tables 4, 5 and 6 are based on these assumptions and the relationships between total intake and projected dose, given in paragraphs 2.46 and 2.50.

TABLE 4—RELATION BETWEEN STRONTIUM-89 INTAKE THROUGH MILK AND THE AVERAGE DOSE TO BONE MARROW[1]

Maximum concentration in milk (nCi ^{89}Sr/l)	Total intake (μCi ^{89}Sr)	Average dose to bone marrow (rads)
63	1.7	0.17
370	10	1.0
740	20	2.0
1110	30	3.0
1870	50	5.0
3700	100	10
18700	500	50

[1] Based on a dose of 0.1 rad to bone marrow following an intake of 1 microcurie associated with 100 grams of calcium.
μCi=microcurie=1×10^{-6} curie.

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TABLE 5—RELATION BETWEEN STRONTIUM-90 INTAKE THROUGH MILK AND THE AVERAGE DOSE TO BONE MARROW[1]

Maximum concentration in milk[2] (nCi ^{90}Sr/l)	Total intake (μCi ^{90}Sr)	Average dose to bone marrow in first year (rads)	Total dose to bone marrow (rads)
8	0.28	0.17	0.85
51	1.67	1.0	5.0
100	3.34	2.0	10.0
155	5.0	3.0	15.0
250	8.3	5.0	25.0
510	16.7	10	50

[1] Based on a dose of 0.6 rad in the first year and a total (70-year) dose of 3 rads to bone marrow following an intake of one microcurie associated with 100 grams of calcium.
[2] Numbers below 100 have been rounded to the nearest unit; numbers above 100 to the nearest 5 units.
μCi=microcurie=1×10^{-6} curie.

TABLE 6—RELATION BETWEEN CESIUM-137 INTAKE THROUGH MILK AND THE DOSE TO WHOLE BODY[1]

Maximum concentration in milk (nCi ^{137}Cs/l)	Total intake (μCi ^{137}Cs)	Dose to whole body (rads)
41	1.3	0.17
240	7.7	1.0
480	15.4	2.0
720	23	3.0
1190	38	5.0
2400	77	10

[1] Based on a dose of 0.13 rad following an intake of one microcurie.
μCi=microcurie=1×10^{-6} curie.

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Guidance Applicable to Category II

3.11 Conditions in Category II that may warrant action develop more slowly, in comparison to those of Category I, and generally

permit more time for application of protective actions after the deposition of radioactive material has occurred. The time of deposition of radioactivity relative to the various stages in the plant growth cycle will be a major factor affecting the concentration of radionuclides in food and feed. Although the variations can be large, depending on the time of year and the particular produce grown in the contaminated area, the concentrations of radionuclides reaching man through Category II pathways will be less, in most cases, than those in Category I. The need for initiating a program to assess the degree of contamination and the use of crops in Category II can generally be deduced from the situation found in Category I. Protective actions usually will not be required in Category II if they were not required in Category I.

3.12 The significance of radioactive contamination should be evaluated in terms of potential daily and total intakes by persons who are assumed to derive major portions of their diets from the use of locally grown crops. A wide range of situations may exist within Category II. It is generally impossible to predict total radiation doses solely from the degree of contamination of a particular crop. The complexity of such situations and the fact that for most crops immediate action, beyond assuring that the questionable crops are not marketed before appropriate assessment can be made, make it impractical to provide numerical guides applicable to individual products. However, if it appears that the total projected dose to a suitable sample of a population group from the use of all crops in Category II is larger than the PAG recommended for this category, protective actions should be initiated against those crops that would make major contributions to that dose. In order to meet the objective of Item 6, paragraph 2.52, this suitable sample would be from a group considered to live in a contaminated area and also be considered to make maximum utilization of locally produced food products.

3.13 Depending on the circumstances, the protective actions considered appropriate for Category II are:

1. Modification of animal feed utilization practices or of food processing and marketing practices.
2. Diversion of one or more crops so that the radionuclides of interest are

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removed from access to the human food chain.

3. Destruction of one or more food crops or animal feed crops.

The effectiveness of the actions in eliminating potential intake from the use of the crops increases in the order listed. The kinds of protective action applicable to the use of animal feed crops and food crops directly contaminated by deposition and their relative

feasibility can be expected to vary quite widely from one situation to another. Destruction of food crops should seldom be required. The selection of individual foodstuffs for disposal or for diversion to non-human use will depend on many factors, including: (1) the fractional contribution of radioactive material that each dietary item makes to the total diet, assuming a normal diet; (2) the reduction in projected dose that could result from the elimination of each dietary item; and (3) the possible access to the food chain through diversion to alternate non-human uses.

3.14 In view of these considerations it is recommended that:

2. The Protective Action Guide for the transmission of strontium–89, strontium–90, and cesium–137 through food crops or animal feed crops under the conditions in Category II be a dose of 5 rads in the first year to the bone marrow or whole body of individuals in the general population. As an operational technique it is assumed that the guide will be met effectively if the average projected dose to a suitable sample of the local population is no larger than 2 rads in the first year to the whole body or bone marrow.

3.15 The intent of the recommendation is to discourage deliberate introduction of contaminated foods into supplies of uncontaminated foods as an acceptable means of solving a problem involving radioactive contamination of the environment. It is recognized that all crops that might be affected by a contaminating event will not be harvested at the same time. In addition, some crops might not normally be used until more than a year after the event. The PAG for this category is intended to apply to the evaluation of the projected dose from the use of crops that were contaminated at the time of the event and are harvested within a year.

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3.16 The transmission of strontium-89, particularly to children approximately 1 year of age, through dietary products other than milk should generally be insignificant in comparison to its transmission through milk. Under certain conditions it is conceivable that significant quantities of strontium-89 could be transmitted to milk if contaminated crops are used to feed dairy cattle before the strontium-89 has been lost by radioactive decay. Once the crop has been harvested, strontium-89 is lost only by the process of radioactive decay during storage, and the relationship between the concentration of strontium-89 in milk and the total intake differs from that in Category I. The maximum projected intake in this case is 74 (1.44 $\times$ radioactive half-life) times the measured concentration per liter of milk assuming a consumption of 1 liter of milk per day.

3.17 The strontium-90 and cesium-137 content of animal feed

depends on the concentration at the time the crop is harvested. There is no significant loss of these radionuclides by radioactive decay in time periods of 1 to 2 years. If the feed is used for dairy cows the strontium-90 and cesium-137 concentration in milk would reach a steady state value related to the cow's daily intake. The concentration in milk would remain at that value as long as the feed is used. Therefore, the relation between the concentration of strontium-90 and cesium-137 in milk and the total quantity secreted into the milk would vary, depending on how long the particular feed crop is used. However, this quantity can be estimated in advance if the concentrations in the feed are known and the use of the feed has been determined.

3.18 In addition to the transmission of strontium-90 and cesium-137 to milk through the use of contaminated crops for feeding dairy cattle, the possible contribution resulting from the use of other crops such as fruits, vegetables, or cereal grains growing in the same area must also be considered. In these cases, it is expected that the largest part of the contamination will be associated with one or two particular crops and the action should be directed at eliminating this part of the potential exposure.

3.19 The relationship between the total intake of strontium-89 and strontium-90 and the projected doses as shown in columns 2 and 3 of Tables 4 and 5 is valid if the particular intake is to be evaluated over a period of 1 to 3 months. The relationship between the total intake of cesium-137 and dose shown in columns 2 and 3 of Table 6 may be used in estimating the projected dose from cesium-137

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Guidance Applicable to Category III

3.20 In this category there can be extremely wide variations in the situations that might exist in relation to (1) areas involved, (2) crops affected, (3) possible rate of the decrease in strontium-90 gaining access to plants, and (4) possible actions. In addition, one is now concerned with problems of long-term chronic exposure. Actions that may be effective in Category III involve major long-term changes in farming practices such as selection of crops, chemical or mechanical treatment of soil, land utilization, or all three of these. Following a sufficiently severe event, long-term restrictions may be placed on the use of farmland for food or feed production. The range of considerations that may enter into a decision to take action in this category together with the length of time available for detailed evaluations make it less meaningful to provide a numerical PAG than to provide guidance for evaluation

of long-term situations. The nature of the situation is such that detailed evaluation would not be required except in situations in which levels of environmental contamination are greater than those that might occur under guidance provided for normal peacetime operations.

3.21 In view of these considerations it is recommended that:

3. The desirability of protective action against exposure to environmental radioactivity from situations in Category III be determined on a case-by-case basis. If it appears that annual doses to the bone marrow after the first year may exceed 0.5 rad to individuals or 0.2 rad to a suitable sample of the population, such situations shall be appropriately evaluated.

3.22 Strontium-89 will have essentially disappeared through radioactive decay within 12 to 18 months after the initial deposition. This radionuclide, therefore, is not a consideration in the utilization of land in the years following a high deposition.

3.23 Long-term exposure from strontium-90 entering the food chain through root mats on pastures or through the soil into plants may be an important factor in land utilization for several years following a sufficiently high deposition of strontium-90 in the environment. Land used for pastures, animal feed crops, or other

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crops such as fruits and vegetables may be affected in varying degrees.

3.24 Cesium-137, particularly on pastures with a heavy root mat, may be an important factor in land utilization for 1 to 2 years after an acute contaminating event. Direct transmission to plants from cesium-137 in the soil is generally not expected to be limiting since cesium-137 is tenaciously bound by soil particles.

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SECTION IV

WORLDWIDE CONTAMINATION FROM STRATOSPHERIC FALLOUT

4.1 Stratospheric fallout from past atmospheric testing of nuclear weapons has led to a worldwide deposition of fission products in the environment. It has led to a generally fluctuating but gradually increasing level of long lived radionuclides in food products. These levels reached their peak in 1964. All food supplies may be

affected simultaneously to a greater or lesser degree but the average radionuclide levels in the food produced in a large area, such as a state, are more significant than local fluctuations within the area. The general situation has been studied by the FRC from the standpoint of worldwide fallout from past atmospheric testing (FRC Report Nos. 3, 4, and 6).

4.2 It appears that the intra-regional variations of food contamination are relatively small. In 1963 the highest annual average strontium-90 content of milk from stations among "wet" areas was less than three times the annual average of all stations in these areas. The highest monthly average for this station was about twice its annual average and its highest weekly sample was about three times its annual average. In the United States the annual average of the station with the highest average was about 20 times that of the station with the lowest average. Regional variations in cesium-137 and strontium-89 concentrations were comparable. (FRC Report No. 6)

4.3 The relationship between the amount of fallout deposited per unit area and the resultant dietary intake by man is not constant, but is influenced by a variety of factors. These include those factors influencing the subsequent movement of radionuclides through the environment to the diet and the dietary habits of specific population groups or individuals.

4.4 The studies of fallout in the United States from past testing (FRC Report Nos. 4 and 6) have indicated that:

1. From tests conducted in 1962, strontium–89 gave an estimated average dose of 0.04 rad to bone and 0.01 rad to bone marrow. These doses were divided about equally between 1962 and 1963, giving an annual dose in each year equal to about 3 to 4 percent of the numerical values of the RPG's for bone and bone marrow. In 1964 the estimated dose from strontium–89 was negligible.

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2. The average annual strontium–90 content of the total diet in the "wet" areas of the United States from all past testing reached a peak value of approximately 40 picocuries of strontium–90 per gram calcium in 1964. During the period this concentration is maintained, it would lead to annual doses of about 0.03 rad in new bone and about 0.01 rad in bone marrow. These values are about 6 percent of the numerical values of the RPG's for bone and bone marrow.

3. Internal exposure from cesium–137 to be taken in through the diet in the conterminous United States during the next 30 years has been estimated to be about 0.01 rad. This is about 0.2 percent of the RPG for the gonads (5 rems in 30 years averaged over the population).

4.5 The RPG's were developed for controlling normal peacetime operations assuming a condition of continuous intake and chronic exposure affecting large numbers of people for time-spans

of generations. The numerical values of the RPG's do not and cannot establish a line which is safe on one side and unsafe on the other. Nevertheless, annual radiation doses from fallout equal to or greater than the numerical values of the RPG's can be used as an indication of when there is a need to initiate a careful evaluation of fallout exposures. Caution should be exercised in instituting protective actions in situations where exposures are near the numerical values of the RPG's, since the biological risks are so low that the actions could have a net adverse rather than beneficial effect on the public well-being.

4.6 The practicality and value of protective actions against widespread environmental contamination from stratospheric fallout is limited because:

1. The condition to be alleviated is chronic exposure from long-term continuous intake (10 years or more).

2. A reduction in potential intake under these conditions requires basic changes in long-term agricultural practices, food processing practices, dietary habit, or all three.

3. The actions would have to be applied on a broad enough scale to reduce the average quantity of radionuclides in the total diet from foods produced throughout large areas or the entire country.

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Cesium-137 and Strontium-90 in Arctic Alaska

4.7 Although the amount of fallout deposited per unit area in the Arctic is about one-fifth that deposited in 30°–40° latitude band, a combination of ecological conditions and specific dietary habits of the Eskimos and Indians result in higher strontium and cesium body burdens than are found in the conterminous United States. The lichen-caribou (reindeer)-man pathway is the most important food chain contributing to these body burdens.

4.8 Lichens accumulate nutrients and certain other materials which are deposited directly on them from the air. Their growth is slow and they tenaciously retain the fallout materials to which they are exposed. The concentrations of cesium-137 and strontium-90 in lichens are among the highest in plant life measured anywhere in the world. These radionuclides also tend to accumulate in other persistent vegetation, such as sphagnum moss and the crowns of sedge.

4.9 Lichens are important in the diet of caribou and reindeer, particularly during the winter. Other plants such as sedges are also consumed by these animals. This diet leads to relatively high concentrations of cesium-137 and strontium-90 in the meat of these animals. High levels in the food chain can be expected to persist for several years in the arctic region. The individuals and small

population groups with the highest body burdens of cesium-137 are those whose dietary preference is caribou meat. Average body burdens of cesium-137 in these inhabitants were about three times as high in 1964 as they were in 1962. People with more diversified diets have lower body burdens. In 1964 the annual dose to the Eskimos having the highest body burdens was slightly more than one-half the RPG of 3,000 nanocuries for whole body exposure of individuals in large population groups. Average doses for adults of the same village are less than one-third the RPG. Although the Federal Radiation Council did not set a specific RPG for cesium-137, in either Report No. 1 or No. 2, it did state in the Memorandum for the President (*Federal Register*, September 26, 1961): "The characteristics of cesium-137 lead to direct comparisons with whole body exposure for which recommendations by the Council have already been made." This implies that the RPG would be 0.5 rem * in a year to the whole body of individuals in the general population when the doses can be measured directly, or an average of 0.17 rem to a suitable sample of the population group, when direct measurement is not practicable. Therefore, an annual average

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body burden in adults of 3,000 nanocuries and 1,000 nanocuries would be estimated to result in these respective doses. The body burdens of cesium-137 in the groups of interest are being measured directly. If a comparison with the guidance provided by the FRC is to be made, the applicable RPG is 0.5 rad per year and the corresponding annual average body burden is 3,000 nanocuries of cesium-137 in adults. Strontium-90 burdens in bone appear to be about four times as high as those found in the conterminous United States.

Conclusions

4.10 Reduction in transmission of radionuclides to man under worldwide fallout conditions could only be achieved by long-term changes in (1) agricultural practices, (2) food processing practices, or (3) basic dietary habits. Consideration of such basic economic and social changes is not warranted when annual doses from environmental contamination are comparable to the numerical value of the annual dose recommended for the RPG. It has not been possible to visualize circumstances in which the balancing of the risk of radiation against the undesirable consequences of the protective measures on social, economic, and

*For the purposes of this report the units "rem" and "rad" are considered numerically equal.

political institutions can be reduced in advance to numerical guides for mandatory action under these circumstances.

4.11 On the basis of this information on stratospheric fallout the Council concluded that the health risk from radioactivity in food over the next several years would be too small to justify protective actions to limit the intake of radionuclides either by diet modifications or by altering the normal distribution and use of food, particularly milk and dairy products.

4.12 In view of these considerations it is recommended that:

5. Surveillance of the radionuclide content in food products contaminated with worldwide fallout be continued at levels appropriate to the situation.

6. Surveillance and research programs examining the special ecological situations in the arctic region continue until future trends can be predicted with greater confidence.

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7. Nationwide programs to reduce potential exposure of the population from gradually increasing levels of environmental contamination, such as that associated with worldwide fallout, are not necessary now nor for future levels of fallout from past testing.

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4.1g(1) RADIATION PROTECTION GUIDANCE FOR FEDERAL AGENCIES (MEMORANDUM TO THE PRESIDENT), FEDERAL RADIATION COUNCIL

May 22, 1965, 30 Fed. Reg. 6953 (1965)

FEDERAL RADIATION COUNCIL

RADIATION PROTECTION GUIDANCE FOR FEDERAL AGENCIES

MEMORANDUM FOR THE PRESIDENT

MAY 17, 1965.

Pursuant to Executive Order 10831 and Public Law 86–373, the Federal Radiation Council is transmitting recommendations for the approval of the President for guidance of Federal agencies in their radiation protection activities. The present recommendations are directed to guidance for protective actions affecting the normal production, processing, distribution, and use of food products for human consumption when such products are contaminated with strontium–89, strontium–90, or cesium–137. It is the intention of the Council to release the background material leading to these recommendations as Staff Report No. 7 when the recommendations are approved.

Background. The first two memorandums that provided guidance for Federal agencies in the conduct of their radiation protection activities were approved by the President on May 13, 1960, and September 20, 1961. These provided a general philosophy of radiation protection and the general principles of control based on the annual intake of radionuclides. The recommendations also provided the basis for the control and regulation of normal peacetime operations in which exposure to radiation is a factor. The Radiation Protection Guides (RPG's) were designed to limit the exposures of the whole body and of certain organs of radiation workers and the general population resulting from the use of ionizing radiation in normal peacetime operations.

During the atmospheric testing of nuclear weapons in 1961 and 1962 the question arose as to the use of those RPG's for determining the conditions under which the production, processing, distribution, and use of food, particularly fresh fluid milk, should be altered to reduce human intake of radionuclides from fallout. In September 1962 the Federal Radiation Council stated its position on this subject, and in 1963 the Council reiterated that those existing guides were not applicable to a determination of a need for protective actions and noted that it would recommend guidance on the subject to the President.

Specific guidance for protective actions applicable to contamination of food by iodine–131 was approved by the President in July 1964.

Data on worldwide fallout from past testing of nuclear weapons in the atmosphere have been reviewed by the Federal Radiation Council and the findings reported in FRC Report Nos. 3, 4, and 6.

Fundamental differences between Radiation Protection Guides and Protective Action Guides. FRC Report Nos. 1 and 2 provide radiation protection guidance for the control and regulation of the normal peacetime uses of nuclear technology in which control is exercised primarily on the design and use of the radiation source. The RPG's in those reports were developed as guidelines for the protection of radiation workers and the general public against exposures that might result from routine uses of ionizing radiation.

In formulating these guides there was a judgment, or balance, between the possible risks associated with a particular radiation exposure and the reasons for allowing the exposure.

An important factor in providing guides for any purpose is the change in risk assigned to higher or lower doses and the corresponding effort to reduce them. Other factors influencing informed opinion of where and why a particular balance should be made in-

clude views regarding prevailing practices and the relative importance of health risks in relation to economic, political, or other considerations of national welfare.

Although radiation doses numerically equal to the RPG's may impose a risk so small that they can be accepted each year for a lifetime if there is significant benefit from the programs causing the exposure, they do not and cannot establish a line that is safe on one side and unsafe on the other. Rather, some risk of injury may exist at any level of dose and the risk continuously increases with dose. Caution should be exercised in decisions to take protective actions in situations where projected doses are near the numerical values of the RPG's since the biological risks are so low that the actions could have a net adverse rather than beneficial effect on the public well-being.

In contrast to the guidance for control at the point of release, FRC Report No. 5 provided general guidance for the protection of the population against exposure resulting from the accidental release, or to the unforeseen appearance, of radioactive materials in the environment. Specific guidance, including a numerical value for the Protective Action Guide (PAG) was provided for iodine–131. The PAG represents a consensus as to when, under the conditions considered most likely to occur, intervention is indicated to avoid radiation exposure that would otherwise result from a transient environmental contamination condition. This judgment involves health, economic, sociologic, and political factors for which the relative values are different than for the RPG. These factors for the PAG may include agricultural policies, the known feasibility of protective actions, related health impacts, and similar considerations involved in the national interest.

Radionuclides considered. Four radionuclides are particularly important in considering radioactive contamination of food. These are iodine–131, strontium–89, strontium–90, and cesium–137. Iodine–131 was considered in FRC Report No. 5, and this memorandum will deal only with strontium–89, strontium–90 and cesium–137.

Physical and biological factors related to the metabolism of strontium and cesium have recently been reviewed for the Federal Radiation Council by a committee selected by the National Academy of Sciences. Consideration has been given to the irradiation of the embryo or fetus by these nuclides, as well as irradiation of infants, children, and adults. Irradiation of bone marrow is considered to be the most significant from the standpoint of producing harmful effects. Strontium–89 and strontium–90 deposit selectively in the skeleton causing irradiation of bone marrow adjacent

to the sites of deposition in the skeleton. Cesium–137 is distributed through soft tissues and irradiates the whole body, including bone and bone marrow.

Protective Actions Guides. As stated in Report No. 5, a protective action is an action or measure taken to avoid most of the exposure to radiation that would occur from future ingestion of the foods contaminated with radioactive materials.

Decisions to implement protective actions involve a comparison of the risk due to radiation exposure with the undesirable features of the contemplated actions. The critical decisions to be made are whether to permit unrestricted use of feed crops or food products, to place restrictions on the normal use of feed crops or food products, or to destroy feed crops or food products.

The Council has adopted the term Protective Action Guide, defined as the projected absorbed dose to individuals in the general population that warrants protective action following a contaminating event. The projected dose is the dose that would be received by individuals in the population group from the contaminating event if no protective action were taken. If the projected dose exceeds the PAG, protective action is indicated. Making use of the operational technique adopted in the Memorandum for the President, May 1960, protective action would be indicated at an average projected dose to a suitable sample of the exposed population equal to one-third of the PAG.

Protective actions are appropriate when the health benefits associated with the reduction in exposure to be achieved are sufficient to offset the undesirable features of the protective actions. The PAG represents the Council's judgment as to where this balance should be for the conditions considered most likely to occur. If, in a particular situation, there is available an effective action with low total impact, initiation of such action at a projected dose lower than the PAG may be justifiable. If only high impact action would be effective, initiation of such action may be justifiable only at a projected dose higher than the PAG. The types of actions considered in the development of guidance in the memorandum include:

1. Altering production, processing, or distribution practices affecting the movement of radioactive contamination through the food chain and into the human body. This action may include storage of food supplies and animal feeds to allow for radioactive decay.
2. Diverting affected products to uses other than human consumption.
3. Condemning affected products.

An alteration of the normal diet of an individual is generally less desirable than the measures listed and should not be undertaken except on the personal advice of a physician.

Two limiting conditions of environmental contamination have been examined; an acute localized contaminating event in which prompt action may be necessary to avoid the exposure that would otherwise result; and a widespread, generally increasing, low-level contamination (from stratospheric fallout) that would cause a continuous intake of radionuclides by large numbers of people for several years.

The acute localized contaminating event. Situations justifying protective actions could occur from such events as an industrial accident, possibly involving a nuclear reactor or a nuclear fuel processing plant, and release of radioactive materials from nuclear explosions. The considerations involved in determining appropriate criteria for protective action have led to the development of three categories of dietary pathways which may require decisions following an acute contaminating event. Categories I and II related to intake in the first year following acute deposition, while Category III considers subsequent intake after the first year.

Category I is concerned with the immediate transmission of the radionuclides through the pasture-cow-milkman pathway. The three nuclides of interest may be transmitted through this pathway simultaneously if they are deposited simultaneously on pasture. Experimental data indicate that nearly all the radioactivity appearing in milk through this pathway will have occurred within 100 days, and protective actions may have to be applied for this length of time. Protective action must be initiated within about a week to be effective in averting most of the potential exposure. This category of transmission may be the only one of importance for strontium–89 because of its relatively short radioactive half life (50.5 days).

Category II is concerned with the transmission of radionuclides to man through dietary pathways other than that specified as Category I during the first year following an acute contaminating event. This involves the use of feed crops for animals, including dairy cattle, and plant products used directly for human consumption. The radioactivity initially deposited on such crops in the field does not gain access to the human food chain until after the crops are harvested. Immediate action to reduce the potential intake will not usually be required because of the normal delay in the use of such crops. However, an early decision will be required as to the need for examination of the radionuclide content of harvested crops before they enter normal marketing channels. Strontium–90 and cesium–137 may be transmitted through the cow's feed to milk; cesium–137, in particular, may be transmitted through feed to meat; both may be transmitted to man through the

direct consumption of plant products.

Category III is primarily concerned with the long-term transmission of strontium–90 through soil into plants in the years following a contaminating event. Residual contamination of cesium–137 on pasture when there is a heavy root mat may be a consideration for 1 to 2 years following a sufficiently severe contaminating event. Because of the long leadtime available to assess the possible radionuclide intakes, immediate action is not necessary. Any action that may be taken must be based on the long-term reduction of the radionuclide concentrations in products grown in the area.

In considering the desirability of initiating protective actions following a contaminating event, it is necessary to consider the three categories separately. The benefits of a protective action taken in one category are largely independent of whether or not action is taken in another. Individuals may be exposed to radioactivity from all three categories; however, the guides for individual categories recommended in this memorandum are sufficiently conservative that it is unnecessary to provide an additional limitation on combined doses. Since actions that are likely to be taken in Categories I and II would be effective against any of the three nuclides in either category, the sum of the projected doses to the bone marrow should be compared to the numerical value of the respective guide in the appropriate category when the need for protective action is considered.

Considerations in the development of Protective Actions. The basic considerations in the development of guidance for the acute event are:

1. The occurrence of an acute contaminating event which will require protective action is considered to be so infrequent that it is unlikely that the same individual will be exposed to more than one event.

2. Exposure to the public from radionuclides in the environment is directly related to concentration of the radionuclides in food supplies and the length of time (weeks, months, or years) over which unusual exposures would be expected to occur. The need for protective actions is generally independent of the source of contamination.

3. The substitution of food or feeds of lower radionuclide content for contaminated products is both effective and practicable.

4. The potential intake of radionuclides by individuals in the general public from radionuclides in the environment can be reduced whenever modifications in the normal production, processing, distribution, or dietary practices are considered to be less objectionable than the radiation risk that would otherwise have to be accepted.

5. Protective actions, by their very nature, are short-term modifications in such practices.

6. If the contamination of a particular crop or dietary component is so high

that it would not be acceptable for local use, the crop or dietary component is not considered acceptable for use in other areas to which it may be transported.

SPECIFIC GUIDANCE

Category I. The concept of the PAG, as presented in Report No. 5, was developed for use as guidance in situations involving the rapid transmission of radionuclides from pasture to milk to man with inherent limitations on the types of effective actions for which the necessary resources would be generally available. Such a situation has many of the characteristics of an emergency requiring an immediate decision as to the need for protective actions. The possible need for early actions to avoid most of the projected intake that may result from an acute localized contaminating event involving strontium–89, strontium–90, and cesium–137 is also present in Category I.

Recommendation. In view of these considerations it is recommended that:

1. The Protective Action Guide for the transmission of strontium-89, strontium-90, and cesium-137 through milk under the conditions of Category I be a mean dose of 10 rads in the first year to the bone marrow or whole body of individuals in the general population; and provided further that the total dose resulting from Category I not exceed 15 rads. For purposes of applying this guide, the total dose from strontium-89 and cesium-137 is assumed to be the same as the dose in the first year, whereas the total dose from strontium-90 is assumed to be five times the dose from strontium-90 in the first year. As an operational technique it is assumed that the guide will be met effectively if the average projected dose to a suitable sample of the population (children approximately 1 year of age) does not exceed one-third of the numerical values prescribed for the individual.

Category II. The time of deposition of radioactive materials relative to the various stages in the plant growth cycle will be a major factor affecting the concentration of radionuclides in food and feed. Although the variations in these concentrations can be large, depending on the time of year and the particular produce grown in the contaminated area, the concentrations of radionuclides reaching man through Category II pathways will be less, in most cases, than those in Category I. The need for initiating a program to assess the radionuclide content and the use of crops in Category II can be deduced from the situation found in Category I. Protective actions usually will not be required in Category II if they were not required in Category I.

When a need for quantitative examination of crops has been established the significance of radioactive contamination should be evaluated in terms of potential daily intake by persons deriving major portions of their diets from local foods. Within Category II

a wide range of situations may exist. It is generally impossible to predict total radiation doses solely from the degree of contamination of a particular crop. The composition of population groups consuming food crops in Category II usually will differ from the composition of groups affected by Category I. The complexity of such situations and the fact that for most crops, immediate action beyond assuring that questionable crops are not marketed before appropriate assessment can be made, make it impractical to provide numerical guides applicable to individual products. However, if it appears that the total projected dose to a suitable sample of a population group from all crops in Category II would be larger than the PAG recommended for this category, protective actions should be initiated against those crops that would make major contributions to that dose. In order to meet the objective of item No. 6 of the basic considerations in the development of this guidance, the suitable sample would be from a group considered to live in a contaminated area and also be considered to make maximum utilization of locally produced food products.

Recommendation. In view of these considerations it is recommended that:

2. The Protective Action Guide for the transmission of strontium-89, strontium-90, and cesium-137 through food crops or animal feed crops under the conditions in Category II be a mean dose of five rads in the first year to the bone marrow or whole body of individuals in the general population. As an operational technique it is assumed that the guide will be met effectively if the average projected dose to a suitable sample of the local population is no larger than two rads in the first year to the whole body or bone marrow.

Category III. In this category there can be extremely wide variations in the situations that might exist in relation to (1) areas involved, (2) crops affected, (3) possible rate of change in strontium-90 gaining access to plants, and (4) possible actions. In addition, one is now concerned with problems of long-term chronic exposure. Actions that may be effective in Category III involve major long-term changes in farming practices such as selection of crops, chemical or mechanical treatment of soil, land utilization, or all three of these. Following a sufficiently severe event, long-term restrictions may be placed on the use of farmland for food or feed production. The range of considerations that may enter into a decision to take action in this category together with the length of time available for detailed evaluations make it less meaningful to provide a numerical PAG than to provide guidance for evaluation of long-term situations. The nature of the situation is such that detailed evaluation would not be required except in situations in which levels of environmental contamination are greater than

those that might occur under guidance provided for normal peacetime operations.

Recommendations. In view of these considerations it is recommended that:

3. The desirability of protective action against exposure to environmental radioactivity from situations in Category III be determined on a case-by-case basis. If it appears that annual doses to the bone marrow after the first year may exceed 0.5 rad to individuals or 0.2 rad to a suitable sample of the population such situations shall be appropriately evaluated.

It is recommended that:

4. The guidance contained in the preceding recommendations be approved for use of Federal agencies in the conduct of those radiation protection activities affecting the normal production, processing, distribution, and use of food and agricultural products following acute radioactive contamination of the environment.

The numerical values of absorbed doses specified as guides for an acute contaminating event are not intended to authorize deliberate releases expected to result in absorbed doses of these magnitudes, nor do they have any relevance to civil defense applications.

Worldwide contamination from stratospheric fallout. Stratospheric fallout from past atmospheric testing of nuclear weapons has led to a worldwide deposition of fission products in the environment. The studies of fallout in the United States from past testing (FRC Report Nos. 4 and 6) have indicated that:

1. In the conterminous United States strontium-89 gave estimated average total doses of 0.04 rad to bone and 0.01 rad to bone marrow. These doses were divided about equally between 1962 and 1963. In 1964 the estimated dose from strontium-89 was negligible.

2. The average annual strontium-90 content of the total diet in the "wet" areas of the United States reached a value of approximately 40 picocuries of strontium-90 per gram calcium in 1964. This could lead to an average annual dose in new bone and in bone marrow of about 0.03 and 0.01 rad, respectively. In Alaska strontium-90 burdens in bone of a few individuals appear to be about four times as high as those found in the conterminous United States.

3. Internal exposure from cesium-137 to be taken in through the diet in the conterminous United States during the next 30 years has been estimated to be about 0.01 rad. In Alaska, although the amount of fallout deposited per unit area is about one-fifth as much as that deposited in the 30°–40° latitude band, a combination of ecological conditions and specific dietary habits of some Eskimos and Indians causes higher cesium body burdens than are found in the conterminous United States. Average body burdens of cesium-137 in these inhabitants were about three times as high in 1964 as they were in 1962. The estimated annual whole body doses to these individuals ranged from about one-quarter to one-half of the numerical value of the RPG for individuals in the general population.

On the basis of this information on stratospheric fallout the Council concluded that the health risk from radioactivity in food over the next several

years would be too small to justify protective actions to limit the intake of radionuclides either by diet modifications or by altering the normal distribution and use of food, particularly milk and dairy products.

Recommendations. In view of these considerations it is recommended that:

5. Surveillance of the radionuclide content in food products contaminated with worldwide fallout be continued at levels appropriate to the situation.

It is recommended that:

6. Surveillance and research programs examining the special ecological situations in the arctic region continue until future trends can be predicted with greater confidence.

It is recommended that:

7. Nationwide programs to reduce potential exposure of the population from gradually increasing levels of environmental contamination, such as that associated with worldwide fallout, are not necessary now nor for future levels of fallout from past testing.

ANTHONY J. CELEBREZZE,
Chairman.

The recommendations numbered "1" through "7" contained in the above memorandum are approved for the guidance of Federal agencies, and the memorandum shall be published in the FEDERAL REGISTER.

Dated: May 20, 1965.

LYNDON B. JOHNSON.

4.1h GUIDANCE FOR THE CONTROL OF RADIATION HAZARDS IN URANIUM MINING, REPORT NO. 8, STAFF REPORT OF THE FEDERAL RADIATION COUNCIL, SEPTEMBER 1967.

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SECTION I

INTRODUCTION

1.1 This report supersedes the preliminary FRC staff Report No. 8 which was released on May 7, 1967, for discussion in the Joint Committee on Atomic Energy hearings on radiation exposure of uranium miners. It contains background material used in the development of guidance for Federal agencies in regulatory programs and in programs of cooperation with States concerning radiation protection in the mining of uranium ore, and seeks to provide guidance for long-term radiation protection in uranium mining. Periodic review will be necessary to incorporate new information and new surveillance or control techniques as they are developed. The report also includes recommendations for additional research and recordkeeping needed to provide a firmer basis for the evaluation of radiation risks in this industry.

1.2 The use of uranium, as a source of nuclear energy for the electric power industry, is developing during a period when Government procurement for military purposes is declining. These two needs are complementary with respect to ore production, and operate to maintain the uranium mining industry as an activity of substantial importance to the national economy. The uranium mining industry is located in 10 Western States, 5 of which produce over 90 percent of the total domestic uranium ore. The value of recoverable uranium in ore produced in four of these States as a whole is about half the combined values of copper, lead, and zinc ores produced from the same States.

1.3 The natural radioactive decay of uranium leads to the formation of various radioactive nuclides in ore bodies; one of which, radon, is gaseous. Radon gas formed by the radioactive decay of radium 226 escapes from exposed rock surfaces into the air of uranium mines, where it continues to decay, generating a series of other radioactive products commonly termed radon daughters. Radon gas is also present in aboveground air in concentrations that may vary with location, time of day, and weather conditions. Some of the radon daughters contained in the air breathed by miners are known to be deposited, retained, and to irradiate tissues in the miner's respiratory system. Studies by the U.S. Public Health Service in cooperation with the Atomic Energy Commission and State agencies disclose that underground uranium miners are subject to lung cancer to a degree substantially greater than the general population, or of that in miners in other kinds of underground mines. The excess incidence apparently is related to the uranium

miner's occupational environment, and is believed to be induced by the radioactive decay of radon daughters in the respiratory system.

1.4 Emphasis is focused on the radiation hazards associated with underground uranium mining, since control is more difficult than that which can be achieved in open pit mining or in subsequent milling operations. Open pit mining, being an aboveground operation, presents no special problems in radiation protection. Primary attention is given in this report to the evaluation of radia- [p. 1]
tion hazards resulting from the inhalation of radon and radon daughters in the confines of underground mines and methods by which these hazards can be controlled. In making this review, it is recognized that the benefit derived by the application of progressively more stringent control requirements must be evaluated in light of the resulting reduction in radiation risk and the total impact of the more stringent controls.

1.5 In addition to the recognized authority of the States to establish health and safety standards for mining operations conducted within their respective jurisdictions, responsibilities have been designated to certain Federal agencies. They include the Department of the Interior in the administration of the Federal Metal and Nonmetallic Mine Safety Act; the Department of Labor in the administration of the Walsh-Healey Act; the Department of Health, Education, and Welfare in providing technical advice in the matter of health standards and control of health hazards; and the Atomic Energy Commission in the regulation of source material (*i.e.*, uranium and thorium), after removal from the place of deposit in nature. States, Federal agencies, and the mining industry all have a direct interest in the development of uniform standards applicable to the practical problems of uranium mining, including a standard for radiation protection.

1.6 In the preparation of this staff report technical experts from various Federal and State agencies, industry, and individual nongovernment scientists assisted in developing information concerning mining practices, economic aspects of uranium mining, epidemiological evidence for associating adverse health effects with radon daughter concentrations in mine atmospheres, and considerations involving basic radiobiological mechanisms and the absorbed dose to tissue resulting from breathing mine atmospheres. Coordination of information between the staff of the Federal Radiation Council, the National Council on Radiation Protection and Measurements, the USA Standards Institute (formerly called the American Standards Association), and the Atomic Industrial Forum was achieved by including individuals associated

with these organizations in the FRC task groups. In addition, the staff has had the benefit of consulting with representatives of organized labor, members of the International Commission on Radiological Protection, and with individuals in other countries where uranium is mined.

1.7 The Federal Radiation Council Working Group, which consists of senior technical personnel from the agencies comprising the Council, has supplied advice and information from their respective agencies for inclusion in the report. Personnel from the U.S. Bureau of Mines, Department of Interior, also have actively participated in the preparation of this report.

SCOPE OF URANIUM MINING INDUSTRY

Production

1.8 The domestic uranium mines in 1966 produced approximately 50 percent as much uranium ore as was produced in 1961, the year when the industry was at its peak. This curtailed rate is due to a stretch-out of Government procurement contracts designed to balance procurement with requirements and to tide the industry over an interim period between diminishing Government needs and the developing needs for the electric power industry. Procurement under the remaining Government contracts during

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the period July 1967 through 1970 is estimated at 28,300 tons of U_3O_8. Procurement for electric power plants in this period will be of the order of 18,000 tons of U_3O_8.

1.9 The U.S. Atomic Energy Commission estimates that "by 1980 the United States will have between 120– and 170–million kilowatts of electricity generated by nuclear power, with a mid-range of this projection—about 150–million kilowatts—the best single estimate." (*1*) This estimate takes into account the growing demand for electric power, engineering and economic factors, and the current rapid acceptance of nuclear power. An increase of this magnitude in nuclear power plant facilities will probably require on the order of 250,000 tons of U_3O_8 over the 15–year period from 1966 through 1980 inclusive, (*2*) taking into account the pertinent factors of probable reactor types, sizes, and characteristics, as well as enrichment factors and fuel economy. About 100-million tons of mined ore would be needed to provide this quantity of uranium, assuming no major change in the U_3O_8 content of ore processed (currently about 0.23 percent U_3O_8). Although this is in excess of presently known low cost domestic ore reserves (economic at a price of $10 per pound of U_3O_8), it is con-

sidered reasonable to expect that additional ore will be discovered to keep pace with demand. The 1966 mining rate was 4.2–million tons. To meet the estimated total 15–year requirement, this rate is expected to rise to 16– to 18–million tons annually by 1980. The accuracy of these future estimates, however, is subject to the possible effect of foreign trade in uranium.

1.10 A substantial fraction of the known uranium deposits can be mined by the open pit method. Currently, about one-third of the domestic ore production is derived from open pit mines, some of which have been converted from shallow underground operations. Current technological developments tend to increase the advantages of the open pit method and therefore to extend the depth of economically recoverable deposits. On the other hand, deposits discovered in the future are expected to be at progressively increasing depths, so that the proportion of ore mined from open pits during the next 15 years may be expected to decline somewhat. Thus, underground ore production may, by 1980, rise to somewhat over 12–million tons per year, or several times the current underground mining rate.

1.11 Some perspective on the relative significance of uranium mining to the States involved is provided by comparison with copper, lead, and zinc mining. The latest comparative statistics available appear in the 1965 issue of the U.S. Bureau of Mines Minerals Yearbook. The total amount of copper, lead, and zinc ore produced from mines located in the principal uranium-producing States (New Mexico, Wyoming, Colorado, and Utah) was about 43–million tons, with a recoverable metal value of about $295 million. In the same year these States produced 4 million tons of uranium ore containing about $150 million worth of uranium.

EMPLOYMENT IN U.S. URANIUM MINES

1.12 The first recorded production of uranium-vanadium carnotite-type ore in the United States was in 1898 from the Uravan mining district, Montrose County, Colo.(*3*) Limited production continued until about 1935 when demand for vanadium for use in alloy steels increased the market for carnotite ores. Despite this production uptrend, there was no sustained large-scale employment until after the Atomic Energy Act of 1946. The first price schedule of the Atomic Energy Commission that became effective April 9, 1948, launched a new major mining industry. Thereafter

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employment in uranium mines increased rapidly until 1961, when it declined as a consequence of curtailed Government purchases.

Open pit mining of uranium did not become significant until 1955. The number of uranium mines providing ore during the years 1954 through 1966 and the corresponding employment figures are shown in tables 1 and 2, respectively.

TABLE 1.—ESTIMATES OF THE NUMBER OF MINES PRODUCING URANIUM ORE DURING THE CALENDAR YEAR AS REPORTED BY THE INDUSTRY TO THE U.S. BUREAU OF MINES (1954–64) AND AEC (1965–66)

Year	Underground mines	Open pit mines	Year	Underground mines	Open pit mines
1954	450	50	1961	497	122
1955	600	75	1962	545	139
1956	700	100	1963	573	162
1957	850	125	1964	471	106
1958	850	200	1965	562	74
1959	801	165	1966	533	88
1960	703	166			

TABLE 2.—NUMBER OF MEN EMPLOYED IN URANIUM MINES

Year	Underground Mines •	Open pit mines	Year	Underground Mines •	Open pit mines
1954	916	53	1961	4,182	1,047
1955	1,376	293	1962	4,174	1,074
1956	1,770	584	1963	3,510	886
1957	2,430	574	1964	3,249	726
1958	2,796	1,175	1965	2,900	700
1959	3,996	1,259	1966	2,545	359
1960	4,908	1,499			

• Excludes aboveground employees who may occasionally go underground.

1.13 Some further perspective is provided by considering the number of underground miners related to the size of mine. The categories selected for this purpose are: (1) mines employing 15 or fewer men (2) those employing from 16 to 50 and (3) those with more than 50. The data assembled in table 1–52 of U.S. Bureau of Mines report, "Health and Safety Study of Metal and Nonmetal Mines"(4) for 1963; are as follows:

Number of men per mine	Percent of mines	Percent of men
15 or less	60	16
16 to 50	27	32
More than 50	13	52

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1.14 During 1966 a total of 621 mines produced ore, but the number in operation at any one time probably did not average

more than 400. Underground mines account for the variability; the number of producing open pit mines was fairly constant at about 80. The number of underground miners involved was probably less variable than the number of operating mines because men customarily move from one mine to another when mine operations are intermittent. Many uranium miners have worked previously in nonuranium mines; conversely, uranium miners often quit uranium mines to work in nonuranium mines. The turnover rate in the work force is therefore difficult to evaluate. However, in a group of 1,888 uranium miners identified in a 1954 survey made by the U.S. Public Health Service, only 26 percent were found still working in uranium mines 6 years later. It is also estimated that less than 1 percent work longer than 15 years in uranium mines.

HEALTH AND SAFETY HAZARDS OTHER THAN RADIATION IN URANIUM MINING

INJURY EXPERIENCE

1.15 The hazards of traumatic injury associated with mining are commonly recognized. Although there are wide variations in the frequency and severity of accidents within the industry, miners as a group are exposed to serious risks. Experience in the metal mining industry shows that injury rates have been reduced to less than half over the last 30 years but, nevertheless, current injury rates remain about four times the average of all manufacturing industries. (*4*)

1.16 Uranium mining became prominent at a time after the injury rate in metal mines had been substantially reduced, but the rapid growth of uranium mining, and the fact that much of it was concentrated in areas remote from other metal mines, necessitated the employment of some inexperienced miners. The injury rate in uranium mines during the late 1950's was as high as that experienced in other metal mines 15 to 20 years earlier. Since 1960, however, experience in uranium mines has improved significantly.

PHYSICAL HAZARDS

1.17 U.S. Bureau of Mines records show that most disabling work injuries occurring in underground uranium mines arise from machinery, haulage, handling of materials, falls of persons, and falls of ground. Fatal injuries have resulted primarily from explosives, haulage, and falls of ground. This has also been the experience in other underground metal mines. The fatal ac-

cident rate in underground uranium mines during 1965 averaged about 1.93 per million man hours. (*5*)

ENVIRONMENTAL HEALTH HAZARDS IN UNDERGROUND MINES

1.18 The quality of the atmosphere in underground mines is of primary importance to the health and safety of underground workers. The mine atmosphere is subject to contamination by harmful dusts and gases. Such contamination might result from drilling (dust), blasting (gases and dust), materials handling (dust), use of diesel engines (exhaust gases), emission of strata gases, welding and cutting, and from mine fires. In uranium mines and some other types of mines the radiation environment must also be considered (see sec. II). In general, appropriate measures used to control the hazards owing to common dust and gases will serve also to reduce concentrations of radioactive materials in the mine air.

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1.19 Most uranium ore is mined from sandstone that contains free silica, the causative agent of silicosis. (*6*) Surveys in uranium mines having highly siliceous ores indicate that effective dust control measures are necessary to restrict the concentration of airborne dust to less than recommended limits. Wet drilling and wetting of blasted material before and during loading and transportation are normally supplemented by ventilation to the extent required for effective control of dusts and gases. Toxic gases may constitute a hazard to the health of mine workers if ventilation is not adequate, or if men return to work areas before the gases have been removed or sufficiently diluted by ventilation. Ventilating fans can provide positive means for controlling the volume and flow of air underground. With a properly arranged duct system fresh air can be delivered directly to work areas or, alternatively, contaminated air can be withdrawn from such areas and delivered above ground.

1.20 The use of diesel engines in underground mines necessitates ventilation to dilute and remove toxic exhaust gases and to replace oxygen consumed by combustion in engines. (*7*) Required volumes of ventilating air for individual units are stipulated on approval plates of diesel-powered equipment approved by the U.S. Bureau of Mines for use in underground mines.

1.21 Guides for limiting concentrations of gases, mineral dusts, and airborne contaminants—other than radioactive substances that are likely to be encountered in underground atmospheres—are published annually by the American Conference of Governmental

Industrial Hygienists. These threshold limits are widely used by engineers, inspectors, and regulatory agencies as guides for controlling underground atmospheric environments. These values represent conditions under which it is believed that nearly all workers may be repeatedly exposed without adverse effect. The concept of threshold limits is not used in radiation protection.

1.22 Control of temperature is an important factor in the operation of ventilation systems in underground uranium mines, particularly in cold climates. Incoming fresh air is often heated to prevent freezing of pipes and to prevent icing problems in shafts and haulageways.

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SECTION II

THE RADIATION ENVIRONMENT ASSOCIATED WITH URANIUM MINING

2.1 The atmosphere in underground uranium mines will normally contain a number of contaminants capable of producing various deleterious effects in the respiratory system. These entities include:

1. Airborne dust particles: Silica, alkaline earth and other metal carbonates, silicates, vanadates and aluminates with smaller amounts of iron, molybdenum, and uranium minerals—including the radioactive uranium decay products, notably radium 226. Thorium and its radioactive decay products might also be present in minor amounts. Atoms of the radon decay products rapidly become attached to these particles (see par. 2.5).
2. The radioactive gas radon (and thoron if thorium is present).
3. Free ions: Single atoms of the radioactive elements resulting from the decay of radon, *e.g.*, polonium 218 (RaA), the first decay product of radon 222. Other free ions may be formed by the radioactive decay of a free polonium 218 atom, or may be ejected by recoil of a decay product from the surface of a larger particle and other mine surfaces.
4. Nuclei: Aggregations of a few molecules (*e.g.*, water molecules) around a polonium 218 atom or other decay product, or solid particles so small that diffusion is the dominant transport mechanism.

2.2 The naturally occurring radionuclide uranium 238 is the parent of the radioactive decay chain in which radon 222 is found. Table 3 presents the principal components of the uranium series. The parallel branches in the chain from polonium 218 to astatine 218 and from bismuth 214 to thallium 210 have been omitted; only the energies of the alpha particles of interest are shown. Natural thorium sometimes occurs as a constituent of uranium ore, but in domestic ores it is generally less than 1 percent by weight of the uranium content.

2.3 External gamma radiation intensities in domestic uranium mines seldom exceed 2.5 mR per hour, (*1*) and the average intensities are only a fraction of this. It is accordingly unlikely that uranium miners will be exposed to external whole-body radiation doses as large as the Radiation Protection Guide (RPG) recommended by the FRC for occupational radiation exposure (5 rems per year). However, in mining occasional high grade ore pockets (5 percent or greater U_3O_8) external radiation levels may necessitate limitation of personnel exposure. Beta radiation intensities near broken ores may be higher than gamma intensities by a factor of 10,(*2*) but are of relatively minor importance as an external radiation hazard under mining conditions.

TABLE 3.—THE URANIUM SERIES

Isotope	Symbol	Historical name	Half-life	Radiation	Alpha energy (MeV)
Uranium 238	^{238}U	Uranium I	4.5×10^9 yrs	α	
Thorium 234	^{234}Th	Uranium X_1	24.1 days	β, γ	
Protactinium 234	^{234}Pa	Uranium X_2	1.18 mins	β, γ	
Uranium 234	^{234}U	Uranium II	2.50×10^5 yrs	α, γ	
Thorium 230	^{230}Th	Ionium	7.6×10^4 yrs	α	
Radium 226	^{226}Ra	Radium	1620 yrs	α, γ	
Radon 222	^{222}Rn	Radon	3.82 days	α	5.49
Polonium 218	^{218}Po	Radium A	3.05 mins	α	6.00
Lead 214	^{214}Pb	Radium B	26.8 mins	β, γ	
Bismuth 214	^{214}Bi	Radium C	19.7 mins	β, γ	
Polonium 214	^{214}Po	Radium C_1	164×10^{-6} sec	α	7.69
Lead 210	^{210}Pb	Radium D	22.0 yrs	β, γ	
Bismuth 210	^{210}Bi	Radium E	5.0 days	β	
Polonium 210	^{210}Po	Radium F	138.4 days	α	5.30
Lead 206	^{206}Pb	Radium G	Stable		

Radon and Radon Daughters

2.4 Radon 222 results from the radioactive decay of radium 226. Being an inert gas it diffuses readily through the interstices of rock to the rock face and from there into the air of the mine spaces. It has been observed that the rate of radon diffusion into the mine air varies inversely with changes in the barometric pressure. As noted in table 3, the half-lives of the first four successive daughters of radon are short. Under static conditions (quiet air) radioactive equilibrium will develop in about three hours. However, an equilibrium state is seldom found in an actively worked uranium mine area where fresh air is being continually brought into the mine. The amount of fresh air that is brought into a mine affects the concentration of the radon daughter products more than it affects the concentration of radon. The radon daughter concentration in the air is reduced by dilution and by adherence to dust particles and by preferential deposition on mine walls, whereas additional radon is diffusing into the air from the rock surfaces and from mine water.

2.5 Laboratory experiments have demonstrated that the unattached daughter products of radon 222 exhibit a high rate of diffusion in air;(*3*) that they quickly become attached to moisture or dust particles suspended in the air (the mean lifetime existence as free unattached ions is of the order of 10 to 50 seconds),(*3*) and that the human respiratory system retains a substantial portion of radon daughters attached to moisture or dust particles and virtually all of the unattached portion.(*4*)

2.6 The principal dose to lungs of uranium miners is generally attributed to the alpha particles emitted by the decay of the radon daughter products. In most United States uranium mines the concentration of radon daughters is obtained by using a specific field method of measurement, and the result is compared to the "Working Level" (WL), which is defined as any combination of radon daughters in 1 liter of air that will result in the ultimate emission of 1.3×10^5 MeV of potential alpha energy.(*5*) The numerical value of the WL is derived from the alpha energy released by the total decay of the short-lived radon daughter products at radioactive equilibrium with 100 picocuries (pCi) radon 222 per liter of air. The 100 pCi of polonium 218 give 1.3×10^4 MeV from the total decay of the polonium 218 and the same number of terminal polonium 214 atoms. The 100 pCi of lead 214 give 6.6×10^4 MeV from the decay of the resultant polonium 214. The 100 pCi of bismuth 214 give 4.8×10^4 McV from the resultant polonium 214. The resultant total is 1.27×10^5 MeV which is rounded to 1.3×10^5 MeV.

2.7 A significant advantage in the concept of the WL it its practical application to field measurements of the radon daughter concentrations in mine air. The method of measuring the concentration of decay products in terms of total alpha particle emission is widely used for control and regulatory purposes. Exposure of an individual to radon daughters in air can be estimated from the length of time the individual breathes an atmosphere containing a stated burden of radon daughters. The Public Health Service publications usually express exposures as "Working Level Months" (WLM), although other time periods are sometimes used. Inhalation of air with a concentration of 1 WL of radon daughters for 170 working hours results in an exposure of 1 WLM.

2.8 Historically, radon daughter measurements have been made in the United States uranium mines since about 1950, and the records are preserved in large part by the U.S. Public Health Service Occupational Health Field Station in Salt Lake City, Utah. Since about 1960 similar records also have been kept by State regulatory agencies. The records maintained by the USPHS Occupational Health Field Station comprise such items as mine identity and location, identification of personnel working underground at the time of the survey, location of sampled mine areas, and concentrations of radon daughters in mine air expressed in terms of the WL. From time to time this agency has made summaries of these records available for public purposes. The summaries generally display WL data averaged on a calendar year basis prior to 1962. For subsequent years the reported averages use data for the third

calendar quarter. The data are further detailed according to the State in which the mine is located; the States of main concern being New Mexico, Wyoming, Colorado, Utah, and Arizona. Uranium mines located in these States produced more than 90 percent of the total domestic uranium ore in 1966.

2.9 Table 4 presents a summary derived from records of radon daughter measurements in underground uranium mines prior to 1960. The table shows the number of mines measured and the percentage of mines with radon daughter concentrations falling in various ranges of WL values. These percentages are estimated to be about the same as the percentage of the work force whose annual average exposures fall within the WL ranges shown in the table, and are considered to reflect the status of the whole industry during that period of time.

[p. 11]

TABLE 4.—ESTIMATED DISTRIBUTION OF MINES BY WORKING LEVEL RANGES FROM 1956 THROUGH 1959

Year	Number mines measured	<1.0 WL %	1.0–2.9 WL %	3.0–10.0 WL %	>10.0 WL %	Total %
1956	108	19	25	33	23	100
1957	158	20	26	28	26	100
1958	53	28	21	36	15	100
1959	237	18	26	28	28	100

2.10 This breakdown suggests that about one-fourth of the work force was probably exposed to atmospheres leading to annual exposures larger than 10 WL, and about one-fifth was exposed at average levels lower than 1 WL. It is also noteworthy that the number of mines surveyed between 1956 and 1959 was but a small fraction of the total uranium mines. This low coverage was due to the common event that many small mines were not in operation at the time of the survey. Many such mines were located in remote areas and operated only a few weeks or months in each year because of such factors as available ore, operating funds, labor supply, weather, and so forth.

2.11 In December 1960 a Governor's conference on health hazards in uranium mines (*6*) was held in Denver, Colo. This was an outgrowth of interagency studies on the occupational health problems of uranium miners carried out by the Public Health Service, the Atomic Energy Commission, the U.S. Bureau of Mines, and the Department of Labor. The objectives of the conference were to present to the Governors of States engaged in uranium mining, data on the prevailing radon daughter levels,

such as those indicated in table 4; to present information on experience in controlling radiation hazards; and to assist in developing cooperative programs to reduce radiation hazards in uranium mines. As a result of this conference, many of the States placed more emphasis on their mine inspection programs.

2.12 As a measure of the prevailing levels of radon daughters in the mines, table 5 indicates the results of samples taken in the third calendar quarter of 1965 and 1966. These data indicate considerable success in reducing concentrations of radon daughters. The mine operating companies are cooperating with State regulatory agencies to improve control of radon daughter concentrations in working areas of the mines. The possibility of further reduction in the mines reporting average WL values between 1 and 10 involves considerations discussed in section IV.

2.13 The significance of these recorded data is limited by several considerations: (1) individual WL measurements usually represent a 10-minute sample at a selected location; (2) the number of samples taken per survey is restricted by the number of survey personnel that can be accommodated in an operating mine and by the man hours available to collect and analyze the individual samples; and (3) the frequency of surveys in individual mines varied widely; a single survey per year was common practice in some states, while in others surveys were even less frequent.

2.14 The U.S. Bureau of Mines carried out a study in 1962 on a modification of the usual practice in selecting locations to be sampled in a mine. The report on this project(7) indicates that an estimate of the time-weighted assessment of miner occupancy

TABLE 5.—SUMMARY OF RADON DAUGHTER CONCENTRATIONS BY WORKING LEVEL RANGES DURING THE THIRD QUARTER OF 1965 AND 1966

1965						
State	Number mines	<1.0	Percent of mines in each WL range			
			1.0–2.9	3.0–4.9	5.0–10.0	>10.0
Arizona	16	50	19	12	19	
Colorado	124	39	42	12	6	1
New Mexico	26	15	38	42	5	
Utah	47	49	43	4	4	
Wyoming	16	44	56	—	—	
Total	229	39	41	13	6	1

1966						
State	Number mines	<1.0	Percent of mines in each WL range			
			1.0–2.9	3.0–4.9	5.0–10.0	>10.0
Arizona	14	57	29	14		
Colorado	148	45	42	7	5	1
New Mexico	23	17	47	30	6	
Utah	33	55	39	—	6	
Wyoming	13	38	54	8	—	
Total	231	44	42	9	4	1

in spot-sampled areas permits an approximate evaluation of the exposure of individuals for the day of sampling. The report indicates that as few as four area samples may be sufficient to evaluate the exposure of an individual with a probable accuracy of ± 25 percent. The examples cited in the Bureau report illustrate the method: (1) a miner working in various areas having concentrations ranging from 3.7 to 8.0 WL had an estimated weighted exposure of 6.1 WL, (2) another miner working in concentrations ranging from 0.3 to 6.4 WL had a weighted exposure of 1.0 WL, and (3) a third one working in concentrations of 0.2 to 1.4 WL had a weighted exposure of 0.5 WL. The results of this study suggest that the arithmetic average of concentrations found in the mine air does not give a reliable estimate of exposure. Similarly, the maximum concentration found in any representative mine sampling bears no direct relation to the exposure of individual miners.

2.15 Time-weighted assessment for evaluating exposures in uranium mines has not been generally adopted for regulatory purposes. Rather, pertinent State regulations and the recommendations of the USA Standards Institute stipulate a maximum concentration that, when exceeded, is used as a basis for closing the mine area concerned. Two of the five States (Colorado and New Mexico), for which data are reported in tables 4 and 5, main-

tain records both of concentrations found at each inspection and of the estimated time-weighted average exposure of individual workers who work in different areas in the mines.

2.16 Radon and its daughter products have also been measured in other than uranium mines. One study(*8*) showed that the air in certain nonuranium mines contained radon daughters in concentrations of about 0.1 to 0.2 WL. Jacoe(*9*) reported radon daughter concentrations in 24 nonuranium metal mines in Colorado ranging up to 2.0 WL, and a similar range in five clay mines. Rabson, *et al.*,(*10*) reported on radon daughter concentrations in the gold mines of South Africa. In five of these mines, which also contain uranium, radon daughter concentrations averaged between 0.1 and 0.9 WL with maximum concentrations up to 4 WL. The existence of relatively high concentrations of radon in water and air in Canadian fluorspar mines has been reported.(*11*) The authors found individual samples in unused spaces higher than 10 WL, and estimated that average mine air concentrations ranged from 2.5 to 10 WL.

[p. 14]

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SECTION III

BIOLOGICAL EFFECTS ASSOCIATED WITH EXPOSURE TO RADON AND RADON DAUGHTERS WITH SPECIAL REFERENCE TO LUNG CANCER

3.1 When the mining of uranium-bearing ores began in the United States in 1898(*1*) it was known that radioactivity was associated with the ore, but the potential health hazards from this agent were not suspected until about 1921 when Uhlig(*2*) suggested that the high numbers of lung cancers found among Schnedberg miners might be due to ionizing radiation. From a knowledge of radiobiology and of exposure conditions in uranium mine environments, one might expect the manifestation of radiation injury in the respiratory tract to be of three basic types: tumors, atrophy of functional tissue, and increased susceptibility to other disease agents. Possible effects from external radiation and effects related to the deposition of dust particles containing radionuclides on the skin and in the eyes cannot be excluded. However, these radiation doses are so minor in comparison to the doses to the respiratory tract that they are not treated in this report.

Animal Experiments

3.2 Animal experiments have demonstrated that doses of ionizing radiation delivered to the lungs may reduce pulmonary dust clearance,(*3*) produce emphysema,(*4*) cause loss of pulmonary function,(*5 6*) and cause pulmonary neoplasia, fibrosis, or changes in bronchial epithelium.(*7–25*) These experiments have explored many parameters: (1) species—rats, mice, rabbits, dogs; (2) radiation type—α, β, γ, x-rays; (3) internal and external radiation; (4) relationships between response and dose rate or total

dose; and (5) tumor types. Such experiments are useful to the extent that they lead to sufficient insight into the mechanisms of radiation-induced carcinogenesis to aid in the interpretation of human experience. However, most of the pulmonary radiation dose received by uranium miners is from alpha particles. Since these particles have a very short range in tissue and are densely ionizing (high linear energy transfer), the different spatial distribution of energy absorption in tissue limits the utility of dose-effect relationships derived from animal experiments using beta, gamma, or x-rays.

3.3 In general, it has not been possible to produce pulmonary carcinomas in animals in a systematic way from controlled exposure to radon or radon daughters, although several attempts have been made.(*26–28*) Some animal experiments using radon alone, in combination with varying amounts of its decay products, or in combination with ore dusts, produced metaplasia of the bronchial epithelium and a few pulmonary tumors.(*13 29–32*) The small number of tumors and inadequate controls in some of the experiments precludes drawing definite conclusions from them. The administration of plutonium 239 (also an alpha emitter), in relatively large doses, has induced pulmonary malignancy in addition to severe lung damage in dogs.(*12 33 34*)

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Mortality and Disease Patterns among Uranium Miners and Others

3.4 It has been known for many years that underground uranium miners are subject to elevated mortality rates from accidents and from lung disease. Accidental death rates among uranium miners decreased over a period of years to a low of 1 per million man hours in 1964, comparable to those of other underground miners.(*35*) However data presented in paragraph 1.17 indicate an accidental death rate of 1.93 per million man hours in 1965. Elevated lung cancer rates have been reported among fluorspar miners,(*36*) iron miners,(*37 38*) United States base metal miners,(*39*) and the gold miners of Gwanda.(*40*) Other authors report that no increase in lung cancer incidence was observed among South African gold miners,(*41 42*) nor among British coal miners.(*43*) The pneumoconioses (including silicosis with accompanying emphysema and cor pulmonale) found among most groups of miners may have predisposed them to pulmonary infections such as pneumonia and tuberculosis. The incidence of disability from silicosis and related chest diseases appears to have been markedly reduced by the use of modern industrial hygiene techniques, the most important of which is ventilation.(*44*)

3.5 Several methods have been used to express epidemiological findings in published papers. The two given below will be the principal ones used in this report:

1. "Incidence" is the number of cases of a disease appearing in a stated population per unit of time. Vital statistics are normally reported in terms of annual incidence. Since lung cancer has a high case fatality rate, the incidence of mortality is practically the same as the incidence of the disease.

2. "Mortality ratio" relates the number of observed deaths to the number that would be expected in the same population if the mortality rates derived from the vital statistics records in large populations were applicable. Calculation of the "expected" value must take into account such variables as age, sex, race, and years at risk. Of all the malignant diseases, lung cancer is the most common cause of death among males in the United States. The incidence of lung cancer in the general population increases rapidly after age 40 and reaches a peak around age 60. (*45*)

U.S. Uranium Miners

3.6 In 1950 the USPHS, in cooperation with other Federal and State agencies, initiated a program to evaluate the health problems inherent in the uranium mining industry. Miners were enrolled in the study if they volunteered for at least one physical examination and provided social and occupational data in sufficient detail to allow followup of their health status. Small numbers of men were examined in 1950, 1951, and 1953. During 1954, and later, attempts were made to examine as many men as could be located and would cooperate. It has been estimated that in 1957 and 1960, 90 percent of the men working in the industry in the areas visited were examined. (*46*)

3.7 Estimates were made of each man's exposure to radon daughters, expressed in WLM (see para. 2.7), on the basis of his occupational history and measurements of radon daughter levels in mine air. Where such measurements were not available, the probable value was estimated from measurements made in mines of similar location, depth, ore type and grade, and ventilation arrangements. The occupational history, including identification of

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particular mines and when the individual worked in each, depends on individual recall rather than payroll records.

3.8 For various reasons the PHS study group does not represent the entire mining population or a random sample thereof. This complicates the evaluation of the number of lung cancers that would be expected in the group from causes unrelated to exposure to radon daughters in the mine atmosphere, since a bias resulting from the voluntary method of selection is possible. This possibility was examined by the PHS in a previous analysis, and it was

concluded that this factor, although present, did not affect the general conclusions of that analysis. (*46*)

3.9 The total study group consists of approximately 5,000 underground miners, uranium mill workers, and other types of aboveground workers in the industry (both white and nonwhite) who have had at least one physical examination under the program. After examining the composition of the group enrolled in the PHS study from different viewpoints, the analysis made for the Federal Radiation Council focused on a subgroup of 1,981 white miners who started underground uranium mining before July 1, 1955.

3.10 The number of lung cancers observed in the subgroup selected for analysis was compared with the number that might be expected based on examination of vital statistics records of the male population of the States in which the miners worked (see par. 3.5). For purposes of the analysis, person-years were divided into categories according to increasing exposure to radon daughters expressed as cumulative WLM (see table 6).

3.11 As an example of the procedure, consider a subject who was born in July 1900, and started underground uranium mining in July 1950 in a mine where the atmosphere was estimated to contain 10 WL of radon daughters in 1950 and each year thereafter. He mined full time until December 1957 and has not mined since. In July 1954 this miner was first examined by a PHS team and thereby entered the study group. For August and each succeeding month in 1954 he was assigned one person-month at risk in the age group 50–54, WLM category C (360–839 WLM) and the category for less than 5 years after he started underground uranium mining. This individual was in comparable categories during the first 6 months of 1955. However, in July 1955 he was removed from the age group 50–54 and changed to age group 55–59 years. Also, this individual was removed from the category of less than 5 years since he started mining to the category of 5–9 years since he started mining. The 12 months at risk in 1956 and the first 6 months of 1957 did not alter the category designations for this particular individual. In July 1957 the calculated WLM value reached 840 and thereafter the person-months were assigned to category D (840–1,799 WLM) where he remained until the cutoff date for the analysis (June 1965). If the individual had died during this period, the month of death would have been used to determine the last person-month at risk.

3.12 After this accounting procedure had been completed for each member of the study group, the person-months were converted into person-years at risk, classified by calendar year, age group, WLM category, and time after the individual started under-

ground uranium mining. The expected number of lung cancer deaths was then calculated for the person-years in each of these categories. For example, in 1958 there were 16.59 person-years in age group 45–49 and WLM category D (840–1,799) with 5–9 [p. 19] years after the individuals started underground uranium mining. The annual lung cancer rate for white males in this age group in Colorado, Utah, New Mexico, and Arizona combined was 2.827 per 10,000 in that year. The term "lung cancer" is used in this report to designate cancer of the lung or of other tissues of the respiratory tract. The expected number of lung cancer deaths in this particular group is therefore $16.59 \times \frac{2.827}{10,000}$ or 0.0047. Expected numbers obtained in this way for all age groups and calendar years in each exposure category were then added to obtain the expectations shown in the analysis (see table 6).

3.13 A basic requirement for a comparison of the number of lung cancers observed in the uranium miner group with the rates in the general population is that the same criteria be used for including a lung cancer death in the study group that were used in deriving the basis for calculating the expected deaths, *i.e.*, lung cancer was listed on the death certificate as the underlying cause of death. The analysis, shown in table 6, is the same as that appearing in table 8 of the preliminary draft issued May 1967, with three additional columns—(1) the number of person-years at risk, (2) the expected annual lung cancer mortality per 10,000 miners, and (3) the calculated annual mortality per 10,000 miners. The 95 percent confidence limits for the observed mortality rates are also shown. This information, expressed in terms of expected and observed rates per 10,000 miners, is also shown graphically in figure 1.

3.14 The analysis indicates the presence of a clear association between exposure to radon daughters in mine air expressed as cumulative WLM and the number of lung cancer deaths in the study group. The 24 deaths observed versus 1.82 expected in exposure categories D, E, and F, may be compared to 10 deaths observed versus 3.31 expected in exposure categories A, B, and C. As can be seen from figure 1, all of the lung cancer rates for categories D, E, and F are significantly above the expected rate. Even though the observed incidence for categories A, B, and C is above that expected, only category B is significantly high and the lack of a progressively increasing incidence fails to support a causal role for radon daughter exposures at these levels. However, the absence of a steadily increasing incidence could easily be

the result of chance alone, so that the data do not suggest or exclude the existence of a threshold. Since the quantitative relationship shown in table 6, and figure 1 may be, in part, a consequence of the way exposure categories were selected, alternative breakdowns of 1,000 WLM categories in the upper range and of 250 WLM under 1,000 WLM were considered. These alternative cumulative WLM exposure category designations for the 1,981 miners in table 6 were estimated from a random stratified sample of 299 white underground uranium miners without lung cancer and from the 49 cases of lung cancer. Examination of the ratios of cases to estimated number of miners by exposure categories at the end of 1963 suggests that the first clearly demonstrable excess of lung cancer with progressively increasing risks at each higher WLM level may be in a category somewhat above 1,000 WLM. This is hardly surprising in view of the sampling variation which might commonly occur with the small number of cases in most categories. In any event the data are not sufficient to indicate an association between exposure to radon daughters and the subsequent development of lung cancer when the cumulative exposures are less than about 1,000 WLM.

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TABLE 6.—LUNG CANCER MORTALITY BETWEEN JULY 1955 AND JUNE 1965 INCLUSIVE—WHITE MINERS WHO BEGAN UNDERGROUND URANIUM MINING BEFORE JULY 1955

Exposure category	Estimated cumulative WLM	No. of miners[1]	No. of person-years at risk	Years between beginning of underground uranium mining and death from lung cancer								Calculated annual mortality per 10,000 miners			
				<5		5–9		≥10		Total		Expected	Observed (95% confidence limits)		
				Exp. no.	Obs. no.	Exp. no.	Obs. no.	Exp. no.	Obs. no.	Exp. no.	Obs. no.[2]				
A	<120	383	3,788	0.20	1	0.48	0	0.37	1	1.05	2	2.8	0.6—	5.3—	19.1
B	120–359	421	3,914	.11	0	.43	0	.50	5	1.04	5	2.7	4.1—	12.8—	29.8
C	360–839	496	4,036	.07	0	.36	0	.79	3	1.22	3	3.0	1.5—	7.4—	21.7
D	840–1,799	400	3,148	.02	0	.22	2	.77	6	1.01	8	3.2	11.0—	25.4—	50.1
E	1,800–3,719	218	1,623	.00	0	.08	0	.58	9	.66	9	4.1	25.4—	55.5—	105.2
F	≥3,720	63	455	.00	0	.02	3	.13	4	.15	7	3.3	61.8—	153.8—	316.9
Total		1,981	16,964	.40	1	1.59	5	3.14	28	5.13	34	[3]3.0	13.9—	20.0—	[3]28.0

[1] By cumulative WLM in underground uranium mines through 1963 (par. 3.32).
[2] Par. 3.16.
[3] Average rates.

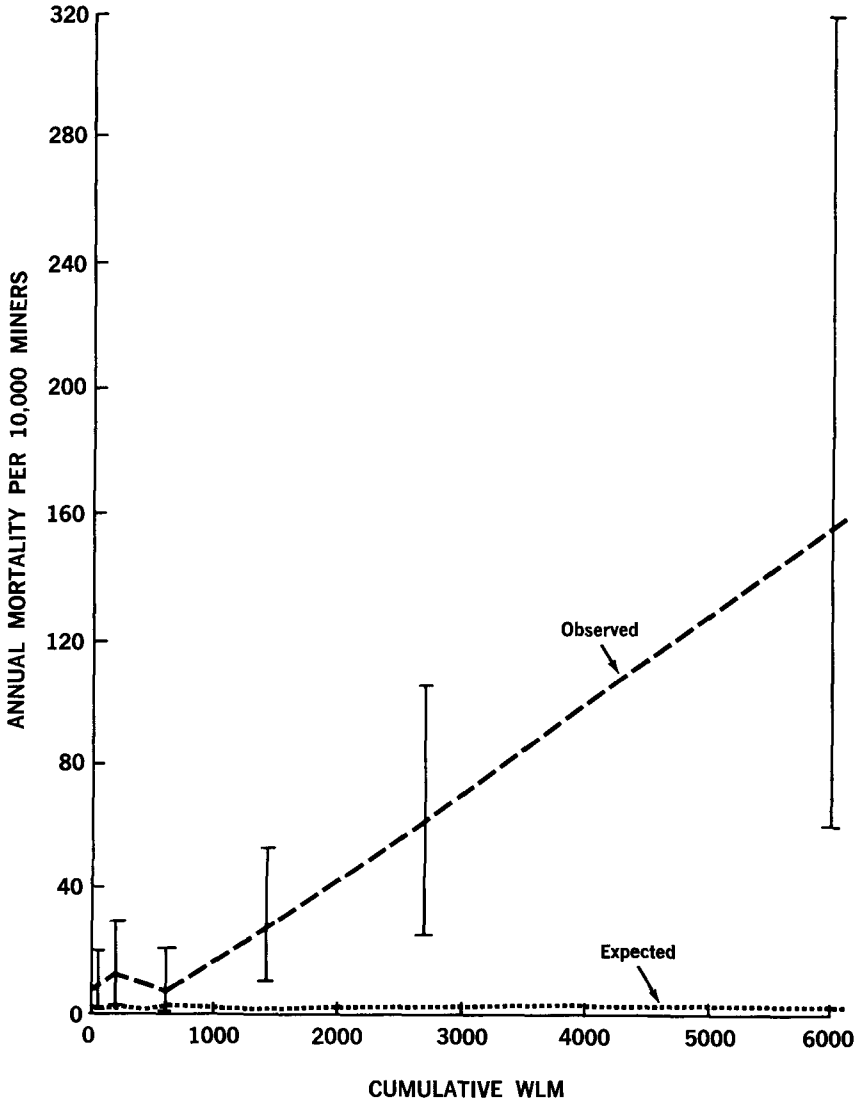

FIGURE 1.—Observed and expected annual lung cancer mortality per 10,000 miners and 95-percent-confidence limits in relation to exposure (see par. 3.13 and table 6).

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3.15 Lung cancer is not an immediate effect of exposure to radon daughters. The largest number of lung cancers observed in all exposure categories appeared 10 or more years after the individuals first started mining, even though several of the miners

worked underground only a few years in the uranium industry. For this reason, another subgroup of 1,434 miners who started mining after July 1, 1955 have not been included in the present analysis. The estimated exposures of 114 miners in this subgroup at the end of 1963 were 840 WLM or more. No lung cancers have been reported from this higher exposure group versus an expected 0.09, although 3 have been reported in the lower exposure group of 1,320 miners versus an expected number of 1.7.

3.16 The 34 observed deaths from lung cancer shown in table 6 are those that meet the requirements for group comparisons mentioned in paragraph 3.13 (*i.e.*, the underlying cause of death was recorded as lung cancer on the death certificate). Fifteen additional deaths from lung cancer make a total of 49 [a] observed in the subgroup of 1,981 miners who began mining before July 1955. These were not included in table 6 for one of two reasons: (1) the "cause of death" was not listed as respiratory cancer on the death certificate, or (2) the date of death was after June 1965, the cut-off date for the mortality analysis. Five of these additional 15 cases occurred in the group of 63 miners whose recorded exposures were greater than 3,720 WLM making a total of 12 in this small group. The remaining 10 were about evenly distributed among the other exposure groups. As related to the years since the beginning of underground uranium mining, but without regard to the exposure level, 3 appeared among miners with 5 to 9 years elapsed time after the start of mining, and 12 after 10 or more years had elapsed. Further evidence of a time factor is indicated by the death of 26 individuals with lung cancer by the end of 1963, and of 23 thereafter. The 49 cases may be considered as more indicative of the real incidence of lung cancer in the study group, although there is no generally accepted way to determine the expected value. Detailed information on the 49 cases will be found in the transcript of the hearings conducted by the Joint Committee on Atomic Energy between May 9 and August 10, 1967.

Cell Type of Uranium Miners' Lung Cancer

3.17 Although the malignant nature of the growths found at autopsy in miners was recognized as early as 1879, it was not until 1926 that they were established as carcinoma.(*47*) As pointed out by Gates and Warren,(*9*) the reason that they were initially thought to be a form of lymphosarcoma is probably that most of the cancers seen were of the small cell undifferentiated variety

[a] For the purposes of this discussion, the 34 deaths shown in table 6 will be referred to as "lung cancer deaths" and the 15 additional deaths will be referrd to as "cases."

which bears some resemblance to lymphosarcoma. Saccomanno *et al.*,(*48*) found that 57 percent of the lung cancers among United States uranium miners were of the small cell undifferentiated variety. The majority of these were considered by the authors to be of the "oat cell" type. The authors also showed that the proportion of small cell undifferentiated cancers among uranium miners increased with the estimated exposure to radon daughters. Small cell undifferentiated bronchial carcinoma rarely exceeds 20 percent of lung cancers found among nonminers.(*48 49*) Although small cell undifferentiated carcinoma or "oat cell" carcinoma of the lung is described as the morphological type representative of the lung cancers identified in uranium miners, it may be well to call atten-

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tion to the fact that bronchogenic (lung) cancers may vary appreciably in cell type in different parts of the tumor and the diagnosis of a specific cell type related to a specific causal agent is subject to some caution.

Base Metal Miners

3.18 An elevated incidence of lung cancer has been reported among miners of a sulfide ore that contained iron, copper, zinc, lead, manganese, arsenic, antimony, calcium, fluorine, and silver.(*39*) The uranium-thorium content is not known but it was probably about 1 percent of that in normal uranium ore. Wagoner, *et al.*, suggested several possible etiological factors, among which was radiation from radon decay products. While being followed for 25,033 person-years, this group experienced 47 lung cancer deaths, approximately three times the expected number. The radon daughter concentrations in those mines in 1958 were estimated to have been in the range of 0.1 to 0.2 WL. The concentrations during earlier years before the advent of improved ventilation are not known but were estimated to have been possibly 5 to 10 times higher. The threefold increase in the observed numbers of lung cancers relative to those expected was attributed by the authors not to be an effect of age, smoking, nativity, urbanization, socioeconomic status, heredity, diagnostic accuracy, or silicosis. The authors concluded that it appeared likely that the mine air contained materials that singly or in combination could be carcinogenic. Wagoner *et al.*, also concluded that chronic exposure to radon or radon daughters alone is unlikely to account for the observed increase, although there appeared to be a higher percentage of undifferentiated cancers than in the comparison group.(*50*)

Fluorspar Mines

3.19 deVilliers, Windish, (*36*) and Parsons, *et al.*, (*51*) have made detailed studies on Newfoundland fluorspar miners. Although uranium minerals could not be identified in the surrounding rock, radon entered the mine in ground water. The average concentration of radon daughters in the mine air was estimated to range between 2.5 and 10 WL. The group studied by deVilliers and Windish contained 630 men who had worked 12 months or more in the mines over a 29-year period (1933–61). Of 69 deaths reported in the group, 26 were attributed to lung cancer. This number is 25 to 40 times the number that might be expected if the lung cancer rates in the study group were compared to those of the adult male population of Newfoundland. (*36*) Lung cancer deaths were not noted during the first 19 years of operation of the mines.

Joachimsthal and Schneeberg Miners

3.20 Although mines in the Joachimsthal and Schneeberg areas have been operated since about 1500 A.D., the excess mortality was not generally attributed to lung cancer until the 1920 decade. (*2 47 52*) The radon 222 concentrations in the mine air were estimated to have averaged between 3,000 and 15,000 pCi per liter of air (*53 54*) (*i.e.*, radon daughter concentrations of 30–150 WL at radioactive equilibrium). The percent of deaths attributed to lung cancer has been reported to vary between 30 and 70. (*55 56*) Although knowledge about the population size and age distribution of the miners is incomplete, it was estimated in the course of this review that the incidence was possibly more than 20 times what might have been expected.

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Relation to Other Agents and Disabilities

3.21 Analysis of medical histories of U.S. uranium miners examined in 1957 and in 1960 showed a greater prevalence of the following complaints which are also observed in other miners: (1) shortness of breath, (2) persistent cough, (3) history of wheezing or whistling sounds in the chest, and (4) history of chest pain or pressure in the chest. (*51 57*) Ventilatory function studies made during these examinations showed that cumulative exposure to the atmosphere in uranium mines contributes to a loss in ventilatory function in a manner similar to that observed in aging and from cigarette smoking. (*51 58*)

3.22 Since a relatively high percentage of United States uranium miners smoke cigarettes and since cigarette smoking has

been associated with an increased incidence of lung cancer, it is necessary to consider this agent in the etiology of the lung cancers of uranium miners.(*60 61*) Although United States uranium miners smoke more than the general population, they smoke no more than some other occupational groups whose lung cancer rate is not comparable to that of uranium miners.(*62*) Since smoking habits appear not to differ systematically among individuals assigned to the different cumulative exposure categories in table 6, this variable is not considered important to the comparisons drawn between groups in that table. The cigarette consumption of the most highly exposed group was about the same as that of the less exposed groups. Although cigarette smoking may affect the total occurrence of lung cancer among uranium miners (*i.e.*, cancers observed compared to expected), smoking alone does not explain the trend with cumulative WLM. An analysis made by the PHS led to the conclusion that the smoking history of the uranium miners might increase the expected number of lung cancers from 5.13 as shown in table 6 to about 7. The data neither prove nor disprove the existence of a relationship between cigarette smoking and radon daughter exposure in the etiology of lung cancer among uranium miners.

3.23 There is evidence that cigarette smoking contributes materially to nonmalignant pulmonary impairments to which uranium miners are subject.(*57 58*) Cigarette smoking can influence lung cancer development among uranium miners in other ways—by changing the radiation dose distribution (through alterations in ciliary motion or thickness of the mucus blanket). It might act as a mitotic stimulant to bronchial epithelium which could reduce latent periods or influence the cell type of carcinoma produced. Although cigarette smoking seems to increase the incidence of several cell types of carcinoma, the one most prominently increased is the epidermoid type. This is in contrast to the small cell undifferentiated type which has been reported to be most prominently increased among uranium miners.(*48*) The possibility that a synergistic relationship may exist between cigarette smoking and exposure to radon daughters needs further study.

3.24 Increased incidence of lung cancer among miners has at times been attributed to silicosis. However, a number of studies suggest that silicosis by itself does not necessarily predispose to lung cancer.(*56 63 64*) The prevalence of silicosis among United States uranium miners has been reported to be comparable to that among other United States metal miners,(*44*) but lung cancer rates of the two groups are quite different.

3.25 The observations described in the previous paragraphs are

consistent with the older observations from Schneeberg and Joachimsthal that many miners had silicosis and tuberculosis (*47 56 59*) although Pirchan and Sikl reported that no notable degree of anthracosis or silicosis was found in the lungs of Joachimsthal [p. 25] miners submitted to autopsy. (*52*) Miners have undoubtedly experienced parenchymal pulmonary damage from exposure to the atmosphere in uranium mines as well as in other types of mines, quite aside from induced lung cancer. What portion of this parenchymal damage is due to radiation and what portion is due to nonradioactive dust (such as free silica) cannot be determined at this time, but it seems possible that sufficient exposure to radon daughters may enhance and alter the fibrogenic response to silica, and may possibly exert a fibrogenic effect of its own.

3.26 Among the many items considered in assessing the etiology of the Schneeberg and Joachimsthal lung cancers was the possible role of heredity. (*56 59 63*) Since both mining areas were relatively isolated, it was felt that centuries of inbreeding might have resulted in a high lung cancer strain of people as has occurred among certain strains of mice. (*65–67*) Although this was a possibility, the development of such high rates of lung cancer has never been observed among isolated nonmining populations. The fluorspar miners mentioned in paragraph 3.19 also constituted a relatively isolated population, but it was noted that a nearby similarly isolated community at Grand Banks, which did no mining, had a low lung cancer rate. (*36*) It has also been noted that high lung cancer rates have been observed primarily in males of the population. Among U.S. uranium miners, where marked differences in lung cancer rates have been shown between different cohorts, (*46*) and different exposure groups, (*60*) there is no reason to believe that hereditary factors were significantly different among the groups. There is no basis on which to implicate a common genetic factor as an important contributor to lung cancer in United States uranium miners.

3.27 The presence of long-lived radioactive materials in the dust of uranium mines (*68*) has given rise to speculation that these may contribute to the lung cancer rate of uranium miners. The various isotopes of uranium, thorium, and radium have been the principal radionuclides considered. In uranium ores, the relative abundance of these nuclides is generally low. Their concentration in mine dust is therefore a function of the richness of the ore. Uranium determinations on miners' urine have indicated that uranium is not absorbed in sufficient amounts to present a toxic hazard. (*69*) Thorium isotopes might be expected to concentrate

in lymph nodes, spleen, liver, lung, and bone.(*73*) Radium isotopes would be expected to concentrate in bone. However, no radium could be detected by whole-body counting in several uranium mill workers who had been heavily exposed to ore dust.(*70*) All the radionuclides in the uranium decay series undoubtedly contribute something to the radiation dose of uranium miners, and there is some indication that thorium 230 may have a longer pulmonary retention than its parent uranium.(*71 73*) However, the contribution by the immediate daughters of radon is so great that the contribution by other radionuclides to the lung dose during the working years is probably negligible by comparison.

3.28 Since carcinogenic hydrocarbons have been observed to be present in the exhaust from diesel engines,(*72*) there is the possibility that exposure to the exhaust gases might increase the incidence of lung cancers in uranium miners. There were no diesel engines in the Schneeberg and Joachimsthal mines during the periods when high lung cancer rates were noted. Beginning about 1952 a substantial part of United States production of uranium ore has involved underground diesel equipment. Many of the United States uranium miners in the present study who developed lung cancer had relatively little exposure to diesel fumes in their early work experience. In many nonuranium mines diesel equip-

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ment has been used underground for as long as, or longer than in uranium mines. Gasoline engines are rarely, if ever, used underground.

3.29 Circumstantial evidence appears to rule out diesel exhaust as an important agent responsible for the observed increase of lung cancer rates among uranium miners. However, since diesel exhaust contains the same type of carcinogens as cigarette smoke,(*72*) it is entirely possible that diesel smoke might contribute in the manner discussed above with respect to cigarettes (pars. 3.22 and 3.23).

Discussion and Conclusions

3.30 Respiratory impairment of several varieties has, for many years, been a recognized hazard of underground mining. Analysis of available evidence permits the conclusion that sufficient exposure to radon 222 and its short-lived radioactive daughters in the mine atmospheres is associated with an increased incidence of lung cancer. The highest incidence of lung cancer is occurring now in the group of miners (1) who worked in mines in which the average concentration of radon daughters was usually higher than 10 WL;

(2) whose total cumulative exposures ranged upward from about 1,000 WLM; (3) who started mining uranium ore more than 10 years ago; and (4) who were moderate to heavy cigarette smokers. These observations suggest that additional cases of lung cancer can be expected to develop in the study group.

3.31 The USPHS epidemiological study was designed to identify possible etiologic agents that might be implicated as a reason for the high incidence of lung cancer observed among the uranium miners. Observations on the United States uranium miners who started underground mining before July 1955 clearly demonstrate that an association exists between exposure to radon daughters and a higher than expected incidence of lung cancer when cumulative exposures are more than about 1,000 WLM. The degree of risk at lower levels of cumulative exposure cannot be determined from currently available epidomiological data. It is prudent to assume, however, that some degree of risk exists at any level of exposure, even though effects may not now be evident at the lower levels of cumulative exposure.

3.32 A review of the epidemiological data conducted by the USPHS after the preliminary report 8 was issued in May 1967, and testimony provided to the Joint Committee on Atomic Energy, amplify the previously described uncertainties in the exposure data and their interpretation.(74) These include:

1. The early measurements were very infrequent (sometimes less than once a year) and sampling sites were selected for purposes of control.

2. Information about the mines in which each individual had worked, including the year and the number of months in each, was obtained from an interview with each miner several years later.

3. The information in table 6 is based on estimates of the months worked in underground uranium mines only. Many of the miners also had extensive experience in other underground mines where radon daughters were present, but at lower concentrations. Present evidence suggests that underground uranium mining may account for less than one-half of the total exposure to radon daughters that might be associated with the complete mining experience of the individual when the WLM assigned to underground uranium mining is

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in exposure categories A or B (*i.e.*, less than 360 WLM).[74] The addition of exposure experience in other underground mines could result in some redistribution of the 34 lung cancer cases in table 6.

4. The miners in the study group started underground uranium mining before 1955, when radon daughter concentrations up to several hundred WL were commonly found in individual samples. Other factors taken alone (*i.e.*, ore dust, blasting gases, and other noxious agents) do not seem to be implicated as etiological agents for the lung cancers found in underground uranium miners. However, these factors, together with smoking, can influence any quantitative relationship between exposure to radon daughters and the prob-

ability of developing lung cancer by their individual or collective effects on lung tissue.

3.33 Several dosimetry models have been developed in an attempt to derive a numerical estimate of the effective radiation dose to the lung that might result from exposure to a given concentration of radon and radon daughters. Details of some of these models are presented in the appendix of this report. The differences among the various models and the uncertainties in the basic radiological parameters that must be used are too large for the models to be acceptable at the present time as a basis for estimating the risk of radiation-induced carcinogenesis. Inference of risk drawn from epidemiological studies of lung cancers associated with exposure to various concentrations of radon and its daughter products appears to be the most satisfactory basis for evaluating the associated lung cancer risk at the present time, although no reliable quantitative statement can be made if cumulative exposures are less than about 1,000 WLM.

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SECTION IV

CONTROL CAPABILITIES IN URANIUM MINES

4.1 Several procedures are available to control exposure of miners to radon and its radioactive daughters in mine atmospheres. These include: (1) removing radon and its radioactive daughters from mine areas by air replacement, (2) inhibiting the diffusion of radon into the air of the work areas from the surrounding rock or from abandoned workings, (3) limiting the time individuals can work in areas with an excessive air concentration of radon-radon daughters (work force management), and (4) reducing the concentration of radon daughters in the inspired air from that prevalent in the mine atmosphere.

4.2 Ventilation of underground work areas is the most common procedure. Natural draft ventilation is rarely adequate to provide the needed rate of air supply. Therefore, mechanical movement of the large volumes of air needed into or out of uranium mines is now the general practice. Portable air ducts and auxiliary fans are commonly used to conduct fresh air from its supply source through passageways to deliver the air to work areas in all types of underground mining. The incoming air dilutes and removes air fouled by dust, drill exhaust, blasting fumes and gases, and exhaust gases and heat from internal combustion engines. Ventilation is also necessary for comfort and health in underground mines of all kinds. In uranium mines these same considerations hold, but in addition ventilating air serves to remove radon and radon daughters as well as the dust and noxious gases.

4.3 Currently the most practical means for removing radon and its daughters from mines is to remove the contaminated air to the outside and replace it with fresh air. Mine ventilation procedures

must take into account the size, number, and complexity of mine workings and the level of radon and its daughter products present within these workings. The concentration of radon and its daughters in mine atmospheres, if not diluted and carried away, can build up to very high levels (*i.e.*, hundreds of WL). Continuous planned ventilation is much more effective than an intermittent supply or exhaust of air, or solely relying on ventilation by natural means.

4.4 The general considerations involved in ventilation control include:

1. Fresh air supply should be channeled through the mine passageways in such a manner that it would avoid mixing with contaminated air. The displaced air should be promptly exhausted aboveground at a distance from the air intake.

2. Old workings not needed for other purposes should be sealed off to inhibit the release of radon into the work areas. This will also decrease the concentration of radon daughters that can build up in the work areas.

3. Ventilation systems must be promptly altered or modified as development proceeds.

4. Air velocities through mine areas where men work must be kept within practical comfort limits.

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4.5 The volume of fresh air that can be supplied to underground mine workings is subject to physical limitations on the air velocity and pressure within the portable air ducts, and the velocity of the displaced air through exhausting passageways. In regard to the former, the power requirements to move a unit volume of air through a duct of a given cross-sectional area are reported to increase with the third power of the volume. The air velocity in passageways directly affects the miners.(*1*) There are valid objections to working in a high velocity air flow, especially when the temperature is low. Underground work crews, particularly those working continuously in passageways, object to being subjected to uncomfortably high air flow rates, even though the air temperature is maintained at a reasonable level.

4.6 Mines that are developed with foreknowledge of the ore body extent and with engineering design for mining and ventilation generally provide mechanical equipment to move air into and out of the mine through multiple openings with the least possible dilution or recirculation. A Bureau of Mines survey(*2*) has related radon daughter levels in underground uranium mines to the various ventilation practices; that is, with fans blowing or exhausting, with fresh air intake via the main mine entrance, or with auxiliary ventilation holes and the total volume of fresh air supplied. The results do not indicate any systematic differences

among these procedures. Regardless of the system, however, multiple exits are advantageous in shortening air retention time.

4.7 Prior to 1960 mine surveys were infrequent and in many cases the results were not representative of the average concentration of radon daughters in the mine air. Since 1960 State agencies and the major mining companies have conducted systematic monitoring in underground mines. Tables 4 and 5 (sec. II) show that a significant reduction in the higher concentrations of radon daughters in mine air has been achieved since 1960. (*3*) Although the number of mines reporting average concentrations of 1 WL or less is unchanged, average concentrations of 10 WL or more in mines have been virtually eliminated. The percentage of mines reporting average radon daughter concentrations in the range of 1 to 3 WL has increased. Public statements by mine association and company officials in States having most of the underground uranium mines suggest that the improvement is continuing. (*4–6*)

4.8 A meaningful comparison of mine ventilation cost from mine to mine is difficult because the evolution of ventilation systems is intimately associated with and conditioned by individual mine development. While it might be supposed that the cost of ventilation in uranium mines would be greater than the cost for ventilation in nonuranium mines, or that the cost of ventilation in mines with a lower grade ore would be less than that for those with a higher grade ore, this is not necessarily the case. Many other cost-affecting features may be of greater significance than air supply alone. These include such factors as depth below surface, lateral extension of workings, arrangement of passageways, number and size of mine openings, and so forth. Because of the general lack of specific information in this area, special analyses were necessary to evaluate the cost-effect of ventilation rate. A number of uranium mining companies have carried out and reported on mine ventilation cost studies at the request of FRC staff (see tables 7 and 8). These estimates are intended to illustrate the general magnitude of cost in a few selected mines and are not applicable to the industry as a whole.

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4.9 One study concerns 11 of the larger underground mines that produced more than 20 percent of the national total of uranium ore. These mines have all been in operation for 6 to 7 years, and it seems likely that they could continue in operation for several more years if, after the end of the Government procurement program in 1970, there is a continuing favorable market. These mines are individually profitable enterprises and, in general, they exemplify predevelopment planning for advantageous operation,

including the extra ventilation necessary for radon daughter control. They are similar in operation and depth from the surface. The reported estimates are for the group as a whole.

4.10 To obtain a general estimate of an "exposure index" in these 11 mines the following procedures were used. The concentrations of radon daughters in the ine air were determined by taking 10-minute air samples at about monthly intervals at underground work locations. The results of these determinations were then correlated with the time of occupancy by various categories of mine workers to give approximate time-weighted average exposures. In this way, an "exposure index" related to the WL was derived for each of the various work categories. These average exposures were then weighted by the number of persons involved in the respective categories to reach a "mine index" value representing the average exposure in the mine. The average mine index value for the 11 mines was reported as about 2 WL in 1965.

4.11 Total costs are reported for the 11 mines collectively in terms of "investment costs" and "annual operating costs." Based on this cost experience covering 6 or 7 years, the mining companies have also derived estimates of what these costs might be for two hypothetical cases: (1) the investment cost and operation expense necessary to provide the nominal ventilation that would have been needed for these mines without considering radon control (the prevailing mine index value would have been about 10 WL), and (2) the investment and operating costs that would be entailed in the further reduction of the prevailing mine index to 1.0 WL.

4.12 With these estimated costs, the extrapolated "10-year" cost of mining for operation of mine indexes of 10 WL and 1 WL were estimated. This extrapolation is intended to provide some appreciation of the way total cost might vary under progressively more stringent control requirements. These figures will differ from the actual costs as follows:

1. Ore bodies that do not last for 10 years will have less than the extrapolated 10-year operating cost and more than the stated investment cost, since the investment would have to be repeated when a new ore body is opened.

2. Ore bodies that do allow operation for 10 years will require additional investment and operating costs as the present operations are extended: These costs cannot be estimated at the present time because the rate of new development in particular locations cannot be predicted that far in advance. The relationships are shown in table 7.

4.13 Another study concerns estimates for each of 3 mines where conditions differ from the group of 11 mines as to geology, depth, extent of workings, productive capacity, arrangement of

passageways, number of openings, and so forth. Furthermore, the economy of operations is so different that the data reported for these 3 mines are not comparable to the group of 11 mines discussed above, and perhaps not even comparable among themselves. Collectively, the annual production of uranium ore of the three mines has been at a rate of about 2 percent of the national total. This study presents ventilation investment costs and venti-

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lation operating costs over a 6-year period of continual improvement effort together with current concentration values of radon daughters in all mine areas of concern. It should be noted that air concentration values are reported rather than a mine index. The WL values reported in table 8 are averages for 1965 and represent the present state of control development. The costs are then compared with corresponding costs that would have been incurred if the ventilation had been limited to that which would have been needed in these mines without considering radon control. It has been estimated that the radon daughter concentrations would then have been in the range of 5 to 20 WL with this limited ventilation.

TABLE 7.—VENTILATION COST ESTIMATES—11 MINE STUDY

	Investment cost	Oper. cost (10-yr. est.)	Total cost (10 yrs)	Estimated mine index WL
	Millions of dollars			
Past experience	3.9	7.9	11.8	[1]2
Estimated ventilation costs without radon control	2.0	2.8	4.8	[2]10
Additional cost radon control from 10 WL to 2 WL	1.9	5.1	7.0	
Estimated additional cost to reduce from 2 WL to 1 WL	1.5	6.0	7 5	1
Total cost to control at 1 WL—10 years			19.3	

[1] Composite mine index for 1965.

[2] Estimate of what the composite mine index would be with normal ventilation practices.

TABLE 8.—VENTILATION COST ESTIMATES—3 MINE STUDY

	Investment cost	Oper. cost (6-yr. est.)	Total cost (6 yrs.)	Average concentration WL
	Thousands of dollars			
Past experience				
Mine A	361	120	481	[1]1.4
Mine B	321	85	406	[1]1.5
Mine C	75	50	125	[1]1.5
Total	757	255	1,012	
Estimated for case of minimum ventilation				
Mine A	63	21	84	[2]5 to 20
Mine B	66	18	84	
Mine C	06	04	10	
Total	135	43	178	

[1] Average WL concentrations in 1965.
[2] Estimate of what the average WL concentrations would be with normal ventilation practices.

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4.14 This study indicates that radon daughter control at 1.5 WL in these mines is being achieved at a total cost of about $834,000 over a 6-year period. The relation of ventilation cost to tons of ore produced for the group of three mines is about 1.5 times the corresponding relation in the 11 mine group because of differences in size and other factors.

Inhibiting the Diffusion of Radon

4.15 Sealing off old workings not needed for other purposes is common practice and is effective, but the use of various types of coatings sprayed on the mine walls has proved to be ineffective in reducing the diffusion of radon from the walls into the work areas. Variations in barometric pressure have been shown to have an inverse effect on the rate of radon emanation into mines and, therefore, on the concentration of radon and radon daughters in mine air. (*7*) This suggests that an applied overexposure might be used to advantage in some mines for reducing the release rate of radon into mine air. Experiments designed to augment the normal atmospheric pressure in mines with an overpressure approximately equal to the usual range of atmospheric pressure variation have been performed. A pressure of 0.6 cm of mercury above normal reduced the rate of radon release to mine air by a factor of about 5. It has also been reported that if the pressure can be lowered in a nearby underground area—removed perhaps a hundred feet from the mine workings—the resulting flow of air into the rock can induce a flow of radon away from the work spaces. The prac-

tical value of these suggestions for mine application remains to be demonstrated on an engineering scale. However, an electrical analog system that permits analysis of the air flow in various mine configurations at different simulated air pressures has been developed.(*8*) Many of the primary factors can be investigated cheaply without the necessity of large scale engineering experimentation.

Work Force Management

4.16 Although limiting a miner's occupancy time in relatively high concentrations of radon or its daughter products has not been a normal practice in uranium mining, this procedure has been used in various activities of the nuclear industry when men routinely work in radiation fields of varying intensities. Since the concentrations of radon daughters vary widely with location and with time at a single location in a mine (from 1 WL in well ventilated areas to several hundred WL in stagnant areas), it has been difficult to establish an accurate record of the time-weighted average exposure for each worker. However, reasonable estimates of the average values are possible, and improvement in the evaluations can be expected in the future. Controlling a miner's exposure to radon daughter concentrations by controlling the time he is allowed to work in different atmospheres should generally be feasible and not too restrictive, provided the radon daughter concentrations are known and are not too high.

4.17 It is normal practice to control mine operations primarily on the basis of estimated exposures to radon daughter concentrations found in a working area at the time of sampling. The Colorado Bureau of Mines, for example, assumes that in a small mine with less than 15 men an individual miner will not spend more than 50 percent of his time in areas with significant concentrations of radon daughters. In larger mines, where most of the men stay underground for a full working shift, the men are assigned an exposure value of 75 percent of the average value for the mine.

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4.18 The basic philosophy of control in Colorado is that if the maximum radon daughter concentration in working areas is kept within acceptable limits, the individual worker will be adequately protected without reference to mine averages or time-weighted exposure calculations. New Mexico also limits maximum concentrations in mines, but places more emphasis on estimates of time-weighted exposures in its control program. Both regulatory

programs are derived from recommendations made in 1960 by Committee N-7 of the USA Standards Institute. Acceptable limits, as recommended in the Institute's standard are:

(a) "If the 13-week weighted average exposure of the workers to radon daughters, is less than the MPC, the conditions may be considered to be controlled and no action is necessary.

(b) "If samples in any working area show a concentration of radon daughters exceeding the MPC, but less than three times this level, sufficient additional measurements shall be taken to determine the worker's weighted average exposure for 13 weeks.

(c) "If samples show a concentration of radon daughters more than 3 times the MPC, but less than 10 times this value, corrective action shall be initiated.

(d) "If samples show a concentration of radon daughters greater than 10 times the MPC, immediate action shall be taken to reduce the worker's exposure and correct the condition."

The MPC referred to in the Institute's recommendations is equivalent to 1 WL of radon daughters in the mine atmosphere.

4.19 Integrating personnel exposures to a varying radiation field by providing a personal dosimeter, such as a film badge, is standard practice for controlling exposure to external sources in the nuclear industry. A film badge capable of recording the alpha particles emitted from nuclides in mine air has been developed by the mining industry and its reliability is being tested. With proper calibration, such a device may have utility as an integrating dosimeter. The availability and use of a reliable integrating dosimeter may permit more effective estimates of exposure than can be achieved by calculation of time-weighted average exposures. In addition, a detection system permitting continuous measurement and remote readout of radon daughter concentrations in various mine areas are under development.

4.20 The possibility that the quantities of the longer-lived lead 210 (RaD) or polonium 210 (RaF) in various body tissues could serve as an index of the total quantities of radon and radon daughters taken in has been investigated. Concentrations of these radionuclides in blood, excretion in urine, and deposition in hair, teeth, and bone have been examined; however, present information does not permit correlation of these quantities directly to lung dose.

Respirators

4.21 Reducing the concentrations of radon daughters in inspired air, as compared to the concentrations in the mine air by the use of respirators, is an obvious exposure control technique. Available estimates suggest that an ordinary surgeon's mask could give a 2- to 5-fold reduction. More efficient filters with low impedance might achieve a 5- to 100-fold reduction. Respirators would be

primarily effective for the partial removal of radon daughters. Radon concentrations would not be affected. Therefore, respira-

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tors can be useful as ancillary devices to reduce exposure when the radon daughter concentrations in the mine atmosphere are relatively high. The primary problem with respirators now in use is that it is very difficult to assure that they are used and that they are worn properly, even if the design of the respirator is appropriate to mining operation.

4.22 The use of respirators or self-contained breathing devices in United States uranium mines has been generally reserved for emergencies or control of silica dust. It has been reported that respirators that reduce the radon daughter products in inhaled air are worn by uranium miners in some other countries. (*9*) Since it is accepted that there should be more stringent control over the internal radiation exposure received by uranium miners, the Council staff strongly recommends that there be a concerted effort to improve respiratory devices. It is imperative that they be reliable and that they be acceptable to the miners. In most cases, underground uranium miners wear additional equipment, such as the hard hat, miners' lamp and battery (which may weigh up to 6 pounds), safety boots, and in some cases safety lines. In addition to his regular equipment a miner may also have to carry many different pieces of equipment and tools. His work sometimes requires overhead work, barring of loose rock, crawling in cramped spaces, and climbing ladders. If a respiratory device is to be imposed as an additional requirement it must not interfere with the miner's vision or with his freedom of motion to such an extent that it results in a net increase in his probability of incurring a serious accident. Furthermore, since oral communication is of major importance in mines, any respirator design should take this into account.

4.23 Use of respirators by miners should not deter mine management from providing adequate ventilation in their mines. Ventilation remains the primary means by which radon daughter concentrations can be controlled. If the basic principles of ventilation engineering and design are closely followed, radon daughter concentrations in mines can be significantly reduced.

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SECTION V

SUMMARY AND RECOMMENDATIONS

5.1 To provide a Federal policy on human radiation exposure, the Federal Radiation Council was formed in 1959 (Public Law 86–373) to "... advise the President with respect to radiation matters, directly or indirectly affecting health, including guidance for all Federal agencies in the formulation of radiation standards and in the establishment and execution of programs of cooperation with States." The present report fulfills this responsibility with regard to a Federal policy relating to the protection of underground uranium miners against deleterious health effects resulting from the inhalation of the radioactive daughters of radon 222. Although primary emphasis has been placed on underground uranium mining, the guidance contained in this report may be applied, as necessary, to any type of mine where similar concentrations of radon daughter products may be found.

5.2 This report emphasizes the radiation hazard associated with the inhalation of radon daughters as they occur in the air of underground uranium mines. Although other sources of radiation exposure occur in connection with underground mining, and potential radiation effects are not necessarily confined to the respiratory

system, they are considered of secondary importance as compared to the possible effects resulting from the inhalation of radon daughters.

5.3 In prior reports the Federal Radiation Council has expressed the philosophy that guidance for radiation protection involves achieving a balance between the risk of radiation-induced injury and the benefits derived from the practice causing the exposure to radiation. An implicit part of such a balance is a necessity for considering the relation between the difficulties involved in reducing the radiation exposure by a given amount and the risk that might be associated with that amount of exposure.

Evidence of Radiation Hazards in Underground Uranium Mines

5.4 Available information on the radiological factors involved in the underground mining of uranium ore has been carefully examined. The findings of immediate interest for establishing radiation protection guidance are:

1. It has been observed that underground uranium miners have a higher incidence of lung cancer than is found in the male population in the same geographic area. Continued exposure to the radioactive decay products of the naturally occurring gas radon 222 has been implicated as an important cause of this increased incidence. The decay products of radon 222 (radon daughters) of interest are: polonium 218, lead 214, bismuth 214, and polonium 214. For purposes of this report, the radiation dose from radon itself is not considered.

2. The principal radiation hazard is associated with the inhalation of mine air containing radionuclides that irradiate lung tissue nonuniformly. The most serious result is the development of lung cancer, which generally does

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not appear for 10 to 20 years after the individual started uranium mining.

3. In most domestic underground uranium mines the measurement of radon daughter concentration is obtained by using a specific field method. The results are then compared to the "Working Level" (WL), a unit defined as any combination of radon daughters in 1 liter of air that will result in the ultimate emission of 1.3×10^5 MeV of potential alpha energy. The concentration of radon daughters in air of unventilated underground uranium mines ranges from a fraction of a WL to several hundred WL. Exposure to radon daughters over a period of time may be expressed in terms of cumulative "Working Level Months" (WLM). Inhalation of air containing a radon daughter concentration of 1 WL for 170 working hours results in an exposure of 1 WLM.

4. Observations on United States uranium miners who started underground mining before July 1955 clearly demonstrate that an association exists between exposure to radon daughters and a higher than expected incidence of lung cancer when the cumulative exposures are more than about 1,000 WLM. The degree of risk at lower levels of cumulative exposure cannot be determined from currently available epidemiological data. As discussed in paragraph 3.14, the data do not suggest or exclude the existence of a threshold. It is prudent, however, to assume that some degree of risk exists at any level of ex-

posure, even though possible effects may not now be evident at the lower levels of cumulative exposure.

5. The highest incidence of lung cancer is now occurring in the group of miners: (1) who worked in mines in which the average concentration of radon daughters was usually higher than 10 WL; (2) whose total cumulative exposures were estimated to range upward from about 1,000 WLM; (3) who started mining uranium ore more than 10 years ago, and (4) who were moderate to heavy cigarette smokers. These observations suggest that additional cases of lung cancer can be expected to develop in the study group.

Factors Related to the Evaluation of Benefit and Control Capabilities

5.5 Available information on benefits to be derived from the mining of uranium ores, difficulties encountered in reducing radon daughter concentrations from previous levels to current levels, and the additional difficulties that can be anticipated if further reductions in radon daughter concentrations are required has also been reviewed. The findings of immediate interest to the derivation of guidance for radiation protection in uranium mining are as follows:

1. Uranium is currently the basic fuel needed for the development of nuclear energy, and all projections point to an increasingly important role for nuclear energy in meeting national electric power requirements.

2. Uranium mining is an important economic asset to the States in which the ore is mined. In addition to the value of the ore, mining provides important opportunities for employment. It is estimated that the work force will vary between 2,000 and 5,000 men in the next decade.

3. A significant reduction in the concentration of radon daughters in the air of underground mines has been achieved by the industry since 1960. Estimates of probable exposures of 2,177 miners in a five-State area during the third quarter of 1966 indicate that about 31 percent of miners were exposed to levels of 1 WL or less; 55 percent were exposed in the range of 1–3 WL; and about 14 percent were exposed to levels higher than 3 WL.

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4. Ventilation with fresh air is presently considered the most feasible technique for controlling the concentrations of radon daughters in mine air. The highest concentrations are usually found in the stope areas where some work must be done before ventilation can be brought directly to the miner's working area. This suggests that there are practical limits to the degree by which radon daughter concentrations in mine air can be controlled by ventilation alone. Available information suggests that it may be physically impossible to maintain radon daughter concentration in all parts of the mine to as low as 1 WL at all times.

5. Research studies have been made on possible procedures that might be used to block the diffusion of radon from rock into mine air. Positive pressure ventilation can be useful if the rock is porous enough to permit air to flow into it. Coating the rock surface might be useful if it is capable of blocking the diffusion of radon.

6. The effectiveness, feasibility, and safety of various types of auxiliary

respiratory protective equipment, as they might be used in underground uranium mining, deserve the most thorough study.

7. It is common practice to limit the highest radon daughter concentrations in which normal mining operations are allowed without determining the radiation exposure at lower concentrations. This procedure makes it possible to estimate the maximum exposure rate, but does not provide the information necessary for estimating a true average exposure, and hence the radiation risk for any one individual or group.

Guidance for Radiation Protection in Underground Mines

5.6 On the basis of the preceding findings, the Federal Radiation Council has concluded that radon and its radioactive daughter products occur in sufficient concentrations in underground uranium mines to require actions to control the potential radiation exposure associated with working in such environments. Although primary emphasis has been placed on underground uranium mining, the guidance contained in this report may be applied, as necessary, to any type of mine where similar concentrations of radon daughter products may be found.

5.7 The Council has considered: (1) the apparent relationship between cumulative exposure to radon daughters and the risk of subsequent development of lung cancer as shown by presently available epidemiological data; (2) the range of annual exposures received by various categories of miners now engaged in uranium mining; (3) the technological problems involved in achieving control to various levels of annual exposure, and the ability of present technology as practiced by the industry to reduce radon concentrations to different levels; (4) improvements that might be introduced by application of a more advanced technology, and the length of time such improvements might take; and (5) the magnitude of the radiation risk in the light of the other risks that are faced in underground uranium mining, and the impact the Council's recommendations might have on efforts to reduce these risks simultaneously.

5.8 The selection of the proposed standard for the control of radon daughters in underground mine air must necessarily involve a judgment based on all relevant information. In selecting the standards the Council has also considered: (1) the possible magnitude of the cumulative radiation exposure that individuals might receive under the practical application of the proposed standard; (2) the range of individual risk that might result; (3) the prac-

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tical difficulties and feasibility of reducing exposures; (4) the change in individual risk that could be associated with such reduced exposures; and (5) various control standards used by

different countries for control of radon and radon daughter concentrations in underground uranium mines.

5.9 On the basis of the information presented in the preceding sections, the following guidance is recommended:

1. Occupational exposure to radon daughters in underground uranium mines be controlled so that no individual miner will receive an exposure of more than 6 WLM in any consecutive 3-month period and no more than 12 WLM in any consecutive 12-month period. Actual exposures should be kept as far below these values as practicable.

2. Areas in underground uranium mines, whether normally or occasionally occupied, be monitored for the concentration of radon daughters in the mine air. The location and frequency of taking samples should be determined in relation to compliance with recommendation 1.

3. Appropriate records of the exposure from radon daughters in the mine air received by individuals working in uranium mines be established and maintained.

5.10 The Federal Radiation Council recognizes that current mining conditions are much better than those prevailing 10 years ago. However, it also considers that more improvement is needed to provide proper control of exposure to radon daughters. Steps to make improvements should be initiated immediately and made operational as soon as possible.

Research and Development Needs

5.11 The Federal Radiation Council recognizes that present regulatory procedures and the presently used technology are not adequate to insure compliance with the foregoing recommendations. The development of the appropriate technology and the modification of existing regulatory procedures needs to be supported by an applied research and development program. The general areas deserving attention include: (1) the development of the technology directed to the control and more reliable estimate of individual exposures to radon daughters; (2) registration and compilation of individual exposure records; (3) causal relationships between varying exposures to radon daughters and subsequent development of disability; and (4) improvement of mining practices. In addition, continued attention needs to be given to the development of adequate compensation procedures and the provision of educational opportunity and training programs wherever needed.

5.12 The technology concerned with the control and estimate of individual exposure to radon daughters include: (1) the development of more sensitive and more rugged equipment for the measurement of radon daughter concentrations in mine air; (2) the development of continuous air monitoring equipment; (3) the

development of devices permitting measurement of integrated exposures (personnel dosimetry); (4) the development and testing of low impedance respiratory protective devices; and (5) a more precise definition of the composition of the mine atmospheres, including (a) a measurement of radon 222 and each of its first three daughters separately in representative mine air, (b) the distribution of the three daughters between ions, nuclei, and various larger particle sizes, and (c) the conditions under which these may be altered by varying modes of ventilation, or by various designs of respirators.

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5.13 The practical determination of what is needed to implement the recommendations should take cognizance of the following: (1) data needed to indicate compliance with recommendation 1; (2) an evidentiary record needed to support or deny claims for occupational disability; (3) studies to evaluate possible causal relationships between exposure to radon daughters and the incidence of lung cancer at the lower cumulative exposure levels; and (4) development of a basis for estimating cumulative occupational exposure that the average miner might receive in the future under this guidance.

5.14 In regard to causal relationships, epidemiological studies should be continued on uranium miners and expanded to include other miners who could serve as appropriate comparison groups. Such studies should include, with proper categorization, low, intermediate, and high radon—radon daughter exposure groups as well as a health history followup.

5.15 The development of improved mining practices should place the emphasis on mine-planning as it relates to ventilation, removal of radon daughters from underground mine air, and reduction of radon emission from the rock into the mine. This program is primarily directed to the control of the mine air environment.

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4.1(h)(1) RADIATION PROTECTION GUIDANCE FOR FEDERAL AGENCIES (MEMORANDUM TO THE PRESIDENT), FEDERAL RADIATION COUNCIL

August 1, 1967, 32 Fed. Reg. 11183 (1967)

MEMORANDUM FOR THE PRESIDENT

JULY 21, 1967.

Pursuant to Executive Order 10831 and Public Law 86–373 the Federal Radiation Council transmits to you its findings and recommendations for the guidance of Federal agencies in the conduct of their radiation protection activities as they apply to the underground mining of uranium ore.

In prior memorandums and reports the Council has expressed the philosophy that guidance for radiation protection involves achieving a balance between the risk of radiation-induced injury and the benefits derived from the practice causing the exposure to radiation. An implicit part of such a balance is a necessity for considering the relation between the difficulties involved in reducing radiation exposures by a given amount and the risk that might be associated with that amount of exposure.

Assessment of radiation hazards in underground uranium mines. The Council has reviewed available information on the radiological factors involved in the underground mining of uranium ore. The findings of immediate interest for establishing radiation protection guidance for this activity are:

1. It has been observed that underground uranium miners have a higher incidence of lung cancer than is found in the male population in the same geographic area. Continued exposure to the radioactive decay products of the

naturally occurring gas radon 222 has been implicated as an important cause of this increased incidence. The decay products of radon 222 (radon daughters) of interest are: Polonium 218, lead 214, bismuth 214, and polonium 214. For purposes of this memorandum, the radiation dose from radon itself is not considered.

2. The principal radiation hazard is associated with the inhalation of mine air containing radionuclides that irradiate lung tissue nonuniformly. The most serious result is the development of lung cancer, which generally does not appear for 10 to 20 years after the individual started uranium mining.

3. In most domestic underground uranium mines the measurement of radon daughter concentration is obtained by using a specific field method. The results are then compared to the "Working Level" (WL), a unit which is defined as any combination of radon daughters in one liter of air that will result in the ultimate emission of 1.3×10^5 MeV of potential alpha energy. The concentration of radon daughters in the air of unventilated underground uranium mines ranges from a fraction of a WL to several hundred WL. Exposure to radon daughters over a period of time may be expressed in terms of cumulative "Working Level Months" (WLM). Inhalation of air containing a radon daughter concentration of 1 WL for 170 working hours results in an exposure of 1 WLM.

4. Observations on U.S. uranium miners who started underground mining before 1955 clearly demonstrate that an association exists between exposure to radon daughters and a higher than expected incidence of lung cancer when the cumulative exposures are more than about 1,000 WLM. The degree of risk at lower levels of cumulative exposure cannot be determined from currently available epidemiological data. It is prudent to assume that some degree of risk exists at any level of exposure, even though possible effects may not now be evident at the lower levels of cumulative exposure.

5. The highest incidence of lung cancer is occurring now in the group of miners: (1) Who worked in mines in which the average concentration of radon daughters was usually higher than 10 WL; (2) whose total cumulative exposures were estimated to range upward from about a thousand WLM; (3) who started mining uranium ore more than 10 years ago; and (4) who were moderate to heavy cigarette smokers. These observations suggest that additional cases of lung cancer can be expected to develop, even in individuals who may have already left underground mining.

Factors related to the evaluation of benefit or control capability. The Council has also reviewed available information on the benefits to be derived from the mining of uranium ores; on the difficulties that have been encountered in reducing radon daughter concentrations from previous levels to current levels, and the additional difficulties that can be anticipated if further reductions are required. The findings of immediate interest to the derivation of guidance for radiation protection in uranium mining are as follows:

1. Uranium is currently the basic fuel needed for the development of nuclear energy, and all projections point to an increasingly important role for nuclear energy in meeting national electric power requirements.

2. Uranium mining is an important economic asset to the states in which the ore is mined. In addition to the value of the ore, mining provides important

opportunities for employment. It is estimated that the work-force will vary between 2,000–5,000 men in the next decade.

3. A significant reduction in the concentrations of radon daughters in the air of underground mines has been achieved by the industry since 1960. Estimates of probable exposures of 2,177 miners in a five-state area during the third quarter of 1966 indicate that about 31 percent of the miners were exposed to levels of 1 WL or less; 55 percent were being exposed to the range of 1–3 WL; and about 14 percent were exposed to levels higher than 3 WL.

4. Ventilation with fresh air is presently considered the most feasible technique for controlling the concentrations of radon daughters in mine air. The highest concentrations are usually found in the stope areas where some work must be done before ventilation can be brought directly to the miner's working area. This suggests that there are practical limits to the degree by which radon daughter concentrations in mine air can be controlled by ventilation alone. Information made available to the Council indicates that it will probably be physically impossible to maintain the radon daughter concentration in all parts of the mines to as low as 1 WL at all times.

5. Research studies have been made on possible procedures that might be used to block the diffusion of radon from the rock into mine air. The use of positive pressure ventilation can be useful if the rock is porous enough to permit air to flow into it. Coating the rock surface might be useful if it is capable of blocking the diffusion of radon.

6. The effectiveness, feasibility, and safety of various types of auxiliary respiratory protection equipment, as they might be used in underground uranium mining, deserve the most thorough study.

7. It is common practice to limit the highest radon daughter concentrations in which normal mining operations are allowed without determining the radiation exposure at lower concentrations. This procedure makes it possible to estimate the maximum exposure rate, but does not provide the information necessary for estimating the true average exposure, and hence radiation risk for any one individual or group.

Guidance for radiation protection in underground mining. On the basis of the preceding findings, the Federal Radiation Council has concluded that radon and its radioactive daughter products occur in sufficient concentrations in underground uranium mines to require actions to control the potential radiation exposure associated with working in such environments. Although primary emphasis has been placed on underground uranium mining, the guidance contained in this memorandum may be applied, as necessary, to any type of mine where similar concentrations of radon daughter products may be found.

In reaching its recommendations the Council has considered: (1) The apparent relationship between cumulative exposure to radon daughters and the risk of subsequent development of lung cancer as shown by presently available epidemiological data; (2) the range of annual exposures received by various categories of miners now engaged in uranium mining; (3) the technological problems involved in achieving control to various levels of annual

exposure, and the ability of present technology as practiced by the industry to reduce radon concentrations to different levels; (4) improvements that might be introduced by the application of a more advanced technology, and the length of time such improvements might take; and (5) the magnitude of the radiation risk in the light of the other risks that are faced in underground mining, and the impact the Council's recommendations might have on efforts to reduce these risks simultaneously. In balancing these considerations, it is recommended that:

1. Occupational exposure to radon daughters in underground uranium mines be controlled so that no individual miner will receive an exposure of more than six WLM in any consecutive 3-month period and no more than 12 WLM in any consecutive 12-month period. Actual exposures should be kept as far below these values as practicable.

2. Areas in underground uranium mines, whether normally or occasionally occupied, be monitored for the concentration of radon daughters in mine air. The location and frequency of taking samples should be determined in relation to compliance with recommendation number 1.

3. Appropriate records of the exposure from radon daughters in the mine air received by individuals working in uranium mines be established and maintained.

The Federal Radiation Council recognizes that current mining conditions are much better than those prevailing 10 years ago. However, it also considers that more improvement is needed to provide proper control of exposure to radon daughters. Steps to make improvements should be initiated immediately and made operational as soon as possible.

The practical determination of what is needed to implement the recommendations should take cognizance of the following reasons for making the necessary measurements and the compilation of appropriate records: (1) Data needed to indicate compliance with recommendation number 1, (2) the evidentiary record needed to support or deny claims for occupational disability, (3) permit future evaluation of possible causal relationships between exposure to radon daughters and respiratory cancer at the lower cumulative exposure levels, and (4) to develop a basis for estimating the cumulative occupational exposure that the average miner might receive in the future under this guidance.

The control of an airborne hazardous agent, such as radon and its radioactive daughters, can be achieved either by controlling the environment by appropriate ventilation or by providing auxiliary procedures and equipment to offset exposure from the environment. Examples of such procedures are limiting the time individuals are allowed to work in the environment, or the use of

respiratory protection devices capable of removing most of the radon daughters present in the mine air.

These procedures should also be accompanied by an educational program under the direction of mine management so that the miner may be advised on the necessity for taking these precautionary measures and to emphasize the miner's responsibility in reducing his exposure to radioactive materials.

The Council urges the appropriate Federal agencies to cooperate fully with the states and the uranium mining industry in providing realistic and coordinated programs in the following areas:

1. The development of technology directed to the control and more reliable estimates of individual exposures to radon daughters.
2. The registration and compilation of individual exposure records.
3. Research on causal relationships involving varying exposure to radon daughters and the subsequent development of disability.
4. Research and development directed toward better mining practices.
5. Development of adequate compensation procedures.
6. Educational opportunities and training programs wherever needed.

In approximately 1 year the Federal Radiation Council intends to review its guidance for radiation protection in uranium mining. At that time, if it is indicated, the recommendations in this memorandum will be changed accordingly.

If the foregoing recommendations are approved by you for the guidance of Federal agencies in the conduct of their radiation protection activities, it is further recommended that this memorandum be published in the FEDERAL REGISTER.

JOHN W. GARDNER,
Chairman.

Recommendations 1, 2, and 3 in the preceding memorandum are approved for the guidance of Federal agencies, and the memorandum shall be published in the FEDERAL REGISTER.

LYNDON B. JOHNSON.

4.2 SELECTED REPORTS:

4.2a PATHOLOGICAL EFFECTS OF THYROID IRRADIATION, FEDERAL RADIATION COUNCIL, REVISED REPORT—DECEMBER 1966

FOREWORD

A special subcommittee of the National Academy of Sciences-National Research Council Advisory Committee to the Federal Radiation Council met on September 19, 1966, to consider and update the July 1962 report on Pathological Effects of Thyroid Irradiation. The conclusions reached at this meeting, and by sub-

sequent correspondence, are presented in this report and are based on information available through November 1966. The members of the subcommittee acted as individuals, not as representatives of their organizations.

Shields Warren, Chairman
Subcommittee on Effects of
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This report was approved by the Advisory Committee to the Federal Radiation Council at its meeting on December 10, 1966.

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PATHOLOGICAL EFFECTS OF THYROID IRRADIATION

INTRODUCTION

The constituent groups of the National Academy of Sciences—National Research Council Committees on the Biological Effects of Atomic Radiation (now disbanded) had met periodically since their formation in 1955 to consider various aspects of the general problem. In 1961 a report on Internal Radioactive Emitters [1] was issued, which included a discussion of the effects of iodine 131 on the human thyroid gland. A special report on the Pathological Effects of Thyroid Irradiation was issued by the Federal Radiation Council in July, 1962.[2] Enough new evidence on the effects of

[1] Publication No. 883, "Internal Emitters," 1961, of the National Academy of Sciences-National Research Council.

[2] "Pathological Effects of Thyroid Irradiation," Federal Radiation Council, Washington, D.C., July 1962.

irradiation of the thyroid has come to hand to warrant consideration by the Advisory Committee to the Federal Radiation Council; for this purpose, there was established a Subcommittee on the Effects of Radiation on the Thyroid Gland augmented by consultants with special knowledge of the field. Although parts of the available data are unpublished and incomplete, some investigations have reached a point where certain conclusions can be safely drawn.

Some of these data come from long-term studies on the effects of medically indicated irradiations involving the thyroid gland of man. Other data come from long-term animal experiments using either iodine 131 or X-rays as the source of radiation.

The human thyroid gland may be exposed to radiation from a variety of sources. Medical and dental requirements can lead to an X-ray exposure, either from a direct beam or as scatter from the irradiation of adjacent areas. Radioactive iodine may be administered for either diagnostic or therapeutic purposes. Substantial quantities of iodine 131 are produced in nuclear fission and may be released to the environment, principally during nuclear testing in the atmosphere or from some types of reactor accidents.

The most important radionuclide of iodine, iodine 131, has a very short half-life of 8 days which limits the quantities that can gain entrance into the body. Fallout from nuclear detonations or from a nuclear reactor accident may deposit iodine 131, as well as other radionuclides, including very short-lived radioiodines, on vegetation and in water supplies downwind from the point of release. The absorption of iodine 131 by inhalation will be unimportant except possibly in fallout intensities, which are intolerable for other reasons or immediately following a reactor accident. Direct absorption through the skin has not been demonstrated to be an important mode of entry of radioiodines in fallout. In sources of drinking water for major urban populations the relay between rainfall and consumption usually assures decay of iodine 131 to an insignificant level. In addition, dilution and other factors are effective in reducing the fallout concentration.

Fresh food becomes, then, the main source of iodine 131 from the environment. For most foods the time delay between harvest and consumption is sufficient to reduce iodine 131 to an insignificant level. This is not generally the case with fresh milk for which the time between production and consumption averages about 3 days in the United States. There is some evidence suggesting that consumption of some locally grown vegetables and produce, even after washing and normal home preparation, could conceivably contribute to the diet amounts of the order of those from fresh

milk.[3] However, there is no question that fresh milk is by far the major contributor of iodine 131 to the United States population as a whole.

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Relatively little information is available on the consumption of fresh cow's milk by people in various age groups. The most detailed study now available was completed in 1962 and presents per capita consumption by age and sex.[4, 5] During the first few months of life the intake of fresh cow's milk may be zero for infants who are breast-fed or given formulas based on processed products. From the survey study the average for children under one year of age was about 0.5 liter per day which was maintained until late teenage, after which a gradual decline occurred. For adult males and females in the population-at-large averages were 0.35 and 0.25 liters per day respectively. The range extended from persons consuming no milk to a group comprising 1 to 10 percent who consumed more than 1 liter per day. Large individual differences were found at all ages.

The thyroid gland is unique in its relation to the metabolism of iodine in either stable or radioactive form. Weighing only about 1 to 2 grams at birth, and 15 to 20 grams in the adult, this gland has a high affinity for iodine. A normal thyroid will absorb and retain 15 to 30 percent of a small quantity of ingested iodine. The exact amount retained will depend, among other things, upon the amount of stable iodine ingested during the preceding few days or weeks. Iodine not absorbed by the thyroid will be rapidly excreted, primarily in the urine. Thus, in a short time after a single intake, the gland will contain the highest concentration of the iodine remaining in the body. Because of its great avidity for radioiodine the thyroid will receive the largest radiation dose, particularly if the form is iodine 131.

The radiation dose delivered to other tissues will be, at most, a few percent of that received by the thyroid gland. A concentration of 1 microcurie of iodine 131 per gram of thyroid tissue will produce a time-integrated dose of about 113 rads,[6] ranging from 90

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[3] R. H. Wasserman, F. W. Lengemann, J. C. Thompson, Jr., and C. L. Comar. "The Transfer of Fallout Radionuclides from Diet to Man," Chapter 9, in Radioactive Fallout, Soils, Plants, Foods, Man edited by E. B. Fowler, Elsevier, 1965.

[4] Bureau of the Census, Department of Commerce and Division of Radiological Health, Public Health Service, "National Food Consumption Survey: Fresh Whole Milk Consumption in the United States." Radiological Health Data 4:15, No. 1, 1963.

[5] Bureau of the Census, Department of Commerce and Division of Radiological Health, Public Health Service, "Consumption of Selected Food Items in U.S. Households." Radiological Health Data 4:124, No. 3, 1963.

[6] Report of the International Commission on Radiological Units and Measurements (ICRU), 1959. National Bureau of Standards Handbook 78, January 16, 1961, Washington, D.C.

to 130 rads.[7] About 10 percent of this dose will be received in the first 24 hours, probably over 25 percent in the first 2 days.

When the thyroid is included in the beam from an external radiation source, such as an X-ray tube, a considerable amount of surrounding tissue will necessarily receive doses equal to or even greater than that received by the gland itself.

Differences in growth rate and histology of the thyroid from birth through early childhood have led some to believe that the infant thyroid is more vulnerable than that of the adult to injury from ionizing radiation. In addition to differences in size and proportion of proliferating cells of the thyroid in infants, children, and adults, there may be significant alterations in absorption, metabolic turnover, and cell sensitivity with advancing age. Any of these factors might affect the amount of biological damage resulting from a given radiation dose. Neither the relative importance nor the aggregate effect of these variables is known.

HUMAN EXPERIENCES

1. *Direct Effects of Iodine* 131

It has been pointed out that iodine 131 entering the body is promptly and selectively concentrated in the thyroid gland, or is

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excreted. The direct radiobiological effects are thus confined to the gland itself. The principal effects, which have been observed only after high doses of radioactive iodine, include a decrease in the metabolic activity of the gland, and at still higher doses, an atrophy of epithelial cells, and the appearance of numbers of atypical cells. These changes in function and structure are seen only after doses of thousands of rads. Thyroid cancer is an uncommon result, described with certainty to date only in animals.

2. *Indirect Effects Mediated Through the Endocrine System*

The thyroid gland is one of the several endocrine organs of the body whose activity is interdependent upon and responsive to disturbance in the functions of other members of the system. For example, when thyroid function is suppressed there is characteristically an increased production by the pituitary gland of a hormone that stimulates the cells of the thyroid. This mechanism is the basis of an hypothesis that has been advanced to explain the production of thyroid cancer by agents whose primary effect is to

[7] Silver, S.: Radioactive Isotopes in Medicine and Biology. Medicine. Lea and Febiger, Philadelphia, 2nd ed., 1962, page 117.

impair thyroid function. The resulting over-stimulation of unimpaired or slightly damaged cells by pituitary hormone is presumed to first induce hyperplasia or other effects which may then occasionally progress to true neoplasia.

In the case of human beings irradiated as infants or children, the incidence of thyroid neoplasms rises sharply during puberty and adolescence. The high requirement for thyroid function during this period of life presumably plays a powerful secondary role in inducing neoplastic transformation of the irradiated gland. The incidence of radiation-induced thyroid disease in this group appears to fall off after age 20 to 25 years.

3. *Other Indirect Effects in Cancer Induction*

In the last report of this group it was stated that the probability of developing thyroid cancer after irradiation is influenced by factors other than endocrine effects or the direct action of radiation absorbed in the thyroid gland itself. The reasons for this statement were twofold: first, the apparent absence of a dose response in thyroid cancer in persons treated with a wide range of dosage; and, second, the remarkable variation in thyroid cancer incidence in selected groups of children who received comparable doses of X-rays to the thyroid but different doses to tissues other than thyroid.

In the past four years the data on which these conclusions were based have been reconsidered in the light of new estimates of thyroid doses in these cases under study. The radiation dose to the thyroid depends strongly upon the exact location of the gland with respect to the primary beam, as well as upon the air dose. By estimating thyroid dose using reasonable assumptions as to beam port placement, it is possible to show a strong dose response for radiation-induced thyroid neoplasms. Furthermore, the remarkable variation in incidence of thyroid cancer in selected groups of persons who received comparable air doses of X-rays can be explained by the variation in thyroid dose resulting from variations of the geometrical relations to the primary beam. Although the possibility that irradiation of other tissues may have influenced thyroid tumor induction cannot be excluded, it is not necessary to invoke this hypothesis to explain the observations.

4. *Diagnostic and Therapeutic Exposure to X-ray*

a. *Diagnostic X-ray*

In various diagnostic procedures such as radiography of the teeth, cervical spine, or larynx, and fluoroscopy of the larynx or

esophagus, the thyroid gland may be exposed to a fraction of a roentgen up to several roentgens. These are frequent procedures, and to date no examples of cancer of the thyroid have been attributed to such exposures. However, systematic effort to determine such a relationship has not been made to our knowledge.

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b. *Therapeutic X-ray*

In radiation treatment of hyperthyroidism the thyroid gland may be exposed to doses of several thousand roentgens. This procedure has been carried out on thousands of patients, and carcinoma of the thyroid is an extremely rare complication.

Another practice, no longer in common use, is to treat supposedly enlarged thymus glands in infants and children by exposing the upper chest and neck to doses of 100 R to 600 R or more of X-ray. When large treatment ports, particularly those placed posteriorly, were used the thyroid gland often received the full depth dose from the primary X-ray beam. Similar exposures of the thyroid may result from X-ray treatment of enlarged cervical lymph nodes or skin diseases. Subsequent studies of these patients, both retrospective and prospective, by several authors have disclosed a small but significant incidence of thyroid cancer in excess of the expected rate as determined by comparison with control groups of siblings. This indicates that the thyroid gland in children is susceptible to cancer induction by radiation at relatively high doses. Evidence at low doses is incomplete.

5. *Exposure to Iodine* 131

a. *Diagnostic Procedures*

The use of iodine 131 was introduced into clinical medicine about 25 years ago, and for 15 years it has been widely used in a variety of diagnostic procedures. Most of these diagnostic procedures utilize between 5 to 100 microcuries of iodine 131, and most of the retained dose concentrates in the thyroid. No cases of thyroid cancer induction have been reported in the patients who have undergone these procedures.

b. *Therapeutic Procedures*

The principal uses of iodine 131 are in the treatment of hyperthyroidism and in the management of some cases of thyroid cancer. The latter cases must be excluded from present consideration since the radiations were acting on tissues already cancerous.

There is little evidence [8] at hand that any of the treatments for hyperthyroidism has produced a thyroid cancer, although doses have ranged from a few thousand rads upward. Ablative doses would in effect rule out the possibility of tumor induction.

From this and other evidence it appears that iodine 131 is considerably less effective than comparable doses of externally applied X-rays in producing thyroid cancer. The magnitude of this difference cannot be stated since not a single confirmed case ascribable to iodine 131 is known. In making a comparison it must be kept in mind that X-rays are ordinarily delivered at a high dose rate in a single sitting or in a few divided doses; and the thyroid as well as the blood vessels supplying it and the adjoining tissues are uniformly exposed. In addition, the age of the patients treated and their clinical conditions are rarely the same in the two types of treatment. If the radiation were administered at the same low dose rate of both iodine 131 and X-ray, the ostensible difference might not be as great.

6. *Reactor Accident*

In a reactor accident radioactive iodine was released to the environment [1], and control measures were instituted to prevent human thyroid doses from exceeding 20 rads. No increase in the incidence of thyroid neoplasia in this area has been reported, but it must be remembered that the new complete effects of this episode will not be known for many years.

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7. *Total Radiation Doses in Childhood Cancer of the Thyroid*

Although thyroid cancer occurs in children who are not known to have been exposed to artificially produced radiation, some history of X-ray exposure has been obtained by several workers in well over half the cases in which careful inquiry has been made. The X-ray doses received by most of these subjects are difficult to determine, but by tracing the records of radiologists it appears that the smallest doses associated with subsequent cancer range upwards from about 100 R measured in air. Only a very small number at these low levels have been reported.

8. *Thyroid Abnormalities in a Marshallese Population Exposed to Radioactive Fallout*

The development of thyroid nodules and hypothyroidism has been noted in a number of Marshallese people of Rongelap Island

[8] Staffurth, J. S.: Thyroid Cancer After 131-I Therapy for Thyrotoxicosis. Brit. J.Radiol. 39:471–473, 1966.

in the Pacific who had been exposed to radioactive fallout in 1954.[9] This development is believed to be a late effect of irradiation of the thyroid gland from internal absorption of radioiodines and from external gamma radiation at the time of the fallout. A total of 64 Rongelap people (54 living in 1966) received a whole body dose of gamma radiation of 175 rads, extensive direct irradiation of the skin from deposition of fallout thereon, and internal absorption of radionuclides in the fallout. Eighteen other Rongelap people (14 living in 1966) received a lesser exposure of about 70 rads of gamma radiation along with a smaller dose to the skin and internal absorption of less amounts of radioelements. A total of 157 individuals on the island of Utirik received a whole body gamma dose of approximately 14 rads.

During the two-day period following the accident before the evacuation of the people occurred, the inhabitants absorbed radionuclides in the fallout by inhalation and ingestion of contaminated food and drinking water. Based on radiochemical analyses of pooled urine samples taken several weeks after the accident it was estimated that the adult thyroid gland in the main Rongelap group received about 160 rads from the radioiodine plus another 175 rads from the external gamma radiation. Taken into consideration in those calculations were the time and length of the fallout period, the isotope energies and half-lives of the various iodine nuclides, and the yield of the isotopes. Similar estimates for the smaller thyroid glands of the young children ranged from 700 to 1400 rads in the more heavily exposed group. Though "beta burns" were prevalent in the neck region, it is believed the beta energies were too weak to have contributed significantly to the thyroid dose. The thyroids of the Utirik children received an estimated 55 to 125 rads from iodine, plus the 14 rads from external gamma radiation.

In 1963, nine years after exposure to fallout, the first thyroid nodule was detected in a 12-year-old girl in the more heavily exposed group, and 2 further nodules were detected in 1964. In March 1965, five other cases were noted, and in addition hypothyroidism was diagnosed in two boys who had shown growth retardation. Five further cases were detected in September of 1965 and 5 more in March 1966, making a total now of 16 cases with nodules, plus two cases of hypothyroidism; [10] only one nodule was

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found to be malignant. These cases are described in table I. Table II summarizes the incidences of thyroid abnormalities in the

[9] Conard, R. A., Rall, J. E., and Sutow, W. W.: Thyroid Nodules as a Late Sequela of Radioactive Fallout. New England J. Med. 247:1392–1399, 6/23/66.

[10] Conard, R. A.: Personal Communication.

various populations examined. Note that 79 percent of children less than 10 years of age at time of exposure in the more heavily exposed group developed thyroid abnormalities, in comparison with no thyroid pathology noted in children of the same age range of the non-exposed population or in the lesser exposed populations. The incidence in those exposed at a greater age is considerably lower, and only slightly above that seen for the unexposed or less exposed populations. It should be noted that the only nodules noted in the unexposed population were in the older age group, that is, greater than 50 years of age.

In most cases the thyroid glands contained multiple nodules ranging in diameter from a few millimeters to a few centimeters. All were non-tender, some firm, others cystic, and sometimes even hemorrhagic. No lymphadenopathy was noted. The microscopic sections of the benign lesions showed quite bizarre appearance with a wide variety of different sized follicles, some small and atrophic, others large with hyperplasia or cystic formation. The hyperplastic changes were characterized in some cases by infolding of the epithelium giving an arboreal appearance. These changes resemble those seen in iodine deficiency goiter (adenomatoid goiter). The one case of cancer of the thyroid occurred in a 42-year-old woman and was of the mixed papillary and follicular type.

A hypothyroid etiology for growth retardation noted in children in the exposed group is strongly suggested by the findings of definite hypothyroidism in two of the most retarded boys who had atrophic glands but no nodules, and had a positive growth response to thyroid hormone therapy. Their protein bound iodine levels were below 2 microgram percent. Two other children with thyroid nodules showed low values also.

The radiation etiology of these thyroid lesions appears to be reasonably certain in view of the following facts: (1) The thyroid glands received a substantial dose of radiation from radioiodines and external gamma radiation. (2) Only a few older people in the unexposed or low exposure groups have shown any nodules of the thyroid gland. (3) the diet is not lacking in iodine and there are no known goitrogenic foods.

9. *Atomic Bomb Casualty Commission—Adults*

The Atomic Bomb Casualty Commission has reported 14 cases of thyroid cancer among survivors less than 1400 meters from the hypocenter; 12 were found in the Hiroshima group, 2 in the Nagasaki group. These survivors had received external radiation; radioactive iodine probably was not a contributory factor. The

frequency of thyroid cancer appears greater in the Japanese population than in the United States. The estimates of thyroid cancer range from 4.7 percent among all cases of thyroid disease in Japanese hospitals,[11] 3.1 percent in a study made at the Kyoto University Medical School,[12] to 13 percent at the University of Hiroshima.[13] Socolow [14] points out that although the over-all incidence of thyroid cancer may not differ greatly among the atomic bomb survivors, the age incidence does differ. Eight of his 21 cases were under 35 years of age, whereas at Kyoto [12] 85 percent of the cases were diagnosed after the age of 40. Three of Socolow's cases at Hiroshima were between 3000 and 3500 meters from the hypocenter. These probably received little or no radiation on the basis of the most recent recalculations of dose.[15] The estimates of doses given by Socolow for his cases range from 33 rads to 2620 rads.[14] Seven of the thyroid cancers found in the two cities developed in persons under 20 years of age at the time of the atomic bombing. The estimated thyroid dose received by them ranged from 256 to 2620 rads.

10. *Fallout in Utah*

In May 1953 Washington County, Utah, was thought to have received an unusual amount of radioactive fallout from a nuclear test at the Nevada test site. The exact dosage of iodine 131 from

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this fallout is not known, but estimates for the dose from iodine 131 to the thyroid gland range from less than 10 to above 400 rad. Examination conducted in 1965 of school children in Washington County, Utah, revealed several thyroid abnormalities, but nothing which can be specifically ascribed to radiation as an etiological agent. Because of the fact that Washington County residents seem, historically, to have had a relatively high prevalence of thyroid disease and because children in Utah outside Washington County and in Northern Arizona at the time of fallout showed the same frequency of the more severe thyroid abnormalities as

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[11] Sano, S. Konoe, K., and Iokawa, N.: Statistics on thyroid diseases in Japan. *Nihon Naibunpi Gakkai Zasshi* 34 (3):230, 1958.

[12] Miyake, T., Torizuka, K., and Kusakabe, T.: Epidemiology of thyroid disease in Japan. *Shindan lo Tiryo* 50:783–796, 1962.

[13] Kusunoki, N., Aoki, M., Nakagawa, S., and Masuda, T.: Diseases of thyroid gland. *Hiroshima Igaku Gencho* 7 (6):1461–1467, June 1959.

[14] Socolow, E. L., Hashizume, A., Neriishi, S., and Niitani, R.: Thyroid carcinoma in man after exposure to ionizing radiation. A summary of the findings in Hiroshima and Nagasaki. *New England J. Med.* 268:406–410, February 21, 1963.

[15] Auxier, J. A., Cheka, J. S., Haywood, F. F., Jones, T. D., Thorngate, J. H.: Free-field radiation-dose distributions from the Hiroshima and Nagasaki bombings. *Health Physics* 12:425–429. March 1966.

did the children who were in residence within the County, it is not possible, from this particular study, to ascribe any degree of significance to radiation exposure.

ANIMAL DATA

Data from animal experiments indicate that thyroid tumors originate spontaneously less frequently and may be less easily induced by radiation than tumors of some other organs. Thus leukemia is frequent in numerous strains of mice, breast tumors common in rats, squamous cell carcinoma in white-faced cattle and mast cell tumor in dogs; whereas, thyroid tumors were infrequent in all except in regions where goiter is endemic. The two general types of thyroid tumors are: (1) rounded, circumscribed, benign nodules: adenomas; and (2) invasive, destructive growths: carcinomas. Adenomas do not necessarily develop into cancers but may precede them. Ionizing radiation, as well as a number of chemical agents, may induce either.

Most animal experiments with radiation have been done when the animals were young, though not in infancy. However, a limited number of sheep at Battelle-Northwest (formerly Hanford Laboratories) have been continuously exposed to various levels of iodine 131 from conception to death (up to 10 to 12 years of age). These animals have shown no thyroid tumors at dose levels giving 150 rads per year, but have shown adenomas after several years with accumulated thyroid doses of 5,000 to 40,000 rads.

Two cancers involving the thyroid gland were seen at cumulative doses of 10,000 and 30,000 rads. Thyroid exposures of 30,000 to 40,000 rads as a result of single doses of iodine 131 to young adult sheep also resulted in many adenomas after 4 to 5 years.

When rats were subjected to radiation combined with substances producing goiter (which act by reducing thyroid hormonal production and stimulating the pituitary), a few thyroid cancers were produced by 1,100 rads of X-ray. About 15,000 rads were required to produce a comparable tumor incidence when iodine 131 was used as the source of radiation.

When the head and neck are exposed to X-rays, up to 5 percent of exposed rats may develop thyroid cancer. Parabiont rats develop cancer of many organs readily when one of the pair is given 1,000 rads of X-ray, but cancer of the thyroid is rare.

Whole-body doses of X-rays that readily induce leukemia in most strains of mice very rarely produce thyroid cancer. Iodine 131 given to mice in large doses (delivering thousands of rads to the thyroid) will heavily damage the thyroid without causing cancer there, perhaps because of the many thyroid cells destroyed. How-

ever, this may produce adenomas or cancers of the pituitary gland, which is not itself significantly irradiated but is assumed to be stimulated to abnormal activity and hyperplasia by the absence of normal feedback from a functionally impaired thyroid.

The animal data are inadequate to permit firm conclusions, but available information suggests that cancers of the thyroid are not easily induced by radiation and that radiation from iodine 131, largely restricted to the thyroid, is an even less efficient carcinogen in laboratory animals than are X-rays.

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CONCLUSIONS

1. Therapeutic doses of X-rays to the thyroid region of children have been followed after some years by the development of thyroid neoplasms. Whereas the percent of cases of malignant neoplasms is small, the proportion of persons irradiated who develop nodular thyroid disease can be extremely high. The incidence of radiation-induced thyroid disease is strongly dose dependent above 100 rads (thyroid dose). The shape of the response curve below 100 rads is unknown.

2. X-rays are probably as effective if not more so than iodine 131 in producing thyroid lesions for equal, average absorbed doses delivered to the gland at similar rates. An apparent greater effectiveness of X-ray irradiation may be due to the higher dose rate used.

3. Whereas it was formerly believed that the induction of thyroid tumors was enhanced by irradiation of tissues other than the thyroid itself, it now seems possible to explain variability in tumor induction in children on the basis of whether or not the gland was in the primary X-ray beam.

4. Radioactive iodine in amounts sufficient to deliver several hundred rads to the thyroid of the infant or young child has been shown to produce a high incidence of thyroid nodules. Radioactive iodine has been shown to be carcinogenic in some animals. No case of thyroid cancer clearly ascribable to it has been reported in man.

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TABLE I.—THYROID ABNORMALITIES IN EXPOSED RONGELAP PEOPLE, 1966

[Abnormality noted]

Case No. and Sex	Present Age	Age at Exposure	Years	Age	Findings
3, M	13	1	1965	12	Hypothyroid, PBI less than 2 μg% March 1965; retardation of growth preceded these findings by a number of years. 3/66 growth spurt and improved appearance on hormone.
5, M	13	1	1965	12	Hypothyroid, PBI less than 2 μg% March 1965; retardation of growth preceded these findings by a number of years. 3/66 growth spurt and improved appearance on hormone.
17, F	15	3	1963	12	Adenomatous goiter, complete thyroidectomy, 1964. No recurrence.
21, F	15	3	1964	13	Adenomatous goiter, complete para- and thyroidectomy, 1964. No recurrence.
69, F	16	4	1964	14	Adenomatous goiter, partial thyroidectomy, 1964. No recurrence.
2, M	13	1	1965	12	Adenomatous goiter, partial thyroidectomy. 1965. No recurrence.
20, M	19	7	1965	18	Adenomatous goiter, partial thyroidectomy, 1965. No recurrence.
64, F	42	30	1965	41	Mixed papillary and follicular carcinoma, thyroidectomy—surgical and with radioiodine, 1965. No recurrence noted.
72, F	18	6	1965	17	3 mm. nodule left lobe. No exam 3/66.
42, F	15	3	1965	14	2 mm. nodule right lower lobe; 3/66—nodular enlargement entire gland; firm 5 mm. nodule right lobe. 7/66 subtotal thyroidectomy. Adenomatous goiter.
61, F	20	8	1965	19	6-8 mm. smooth nodule left lower pole; 3/66 1 cm. nodule left lobe. Subtotal thyroidectomy 7/66. Adenomatous goiter.
40, M	41	29	1965	40	2 mm. nodule right lower pole; 3/66 no nodules detected.
59,* F	46	34	1965	45	5 mm. nodule midline; 3/66 same. Subtotal thyroidectomy 7/66. Adenomatous goiter.
54, M	13	1	1966	13	Nodular enlargement left lobe and isthmus with 2 mm. firm nodule.
19, M	17	5	1966	17	Multinodular soft goiter—gland 1½ normal size; 1 cm. nodule right lower pole.
36, M	19	7	1966	19	About 1 cm. nodule—not clearly demarked—right lower pole. Many tiny nodules surface of gland.
33, F	13	1	1966	13	In 9/66 questionable irregular gland. 3/66 definite 5 mm. nodule left lobe. Subtotal thyroidectomy 7/66. Adenomatous goiter, Hürthle cell adenoma.
65, F	13	1	1966	13	In 9/65 questionable small nodule; 3/66 a 5 mm. nodule right lobe. 7/66 right subtotal thyroidectomy. Adenomatous goiter.

* Exposed to only 69 rads whole body radiation and presumably proportionately less thyroid dose.

TABLE II.—THYROID ABNORMALITIES (NODULES AND HYPOTHYROIDISM) MARSHALLESE POPULATIONS EXAMINED 1964–1966

	Age (1954) <10 yrs.			Age (1954) 10–19 yrs.			Age (1954) 20–40 yrs.			Age (1954)** >40 yrs.			All Ages	
Island Group	No. in Group	Estimated Thyroid Dose in Rads*	% Abnormalities	No. in Group	Estimated Thyroid Dose in Rads*	% Abnormalities	No. in Group	Estimated Thyroid Dose in Rads*	% Abnormalities	No. in Group	% Abnormalities	No.	% Abnormalities
Rongelap	19	I 700–1400	78.9	12	I 350–600	0.0	14	I 160	14.3	10	0.0	55	30.9
Ailingnae***		γ 175			γ 175			γ 175					
Utirik***	6	I 275–550	0.0	1	I 175–300	0.0	4	I 54	25 0	3	0.0	14	7.1
		γ 69			γ 69			γ 69					
Unexposed	40	I 55–110	0.0	16	I 25– 55	0.0	22	I 16	4.5	21	4.8	99	2.0
(Rongelap		γ 14			γ 14			γ 14					
Utirik)	61	—	0.0	36	—	0.0	48	–	0.0	49	6.1	194	1.5

*I = Dose from β and γ radionuclides; γ = dose from external γ radiation.

**Dosage in this group was the same as in the 20–40 year group.

***In estimating the thyroid doses to the Ailingnea and Utirik exposed group it was assumed that these doses were proportional to the corresponding thyroid doses of the Rongelap exposed group, based on relative whole body gamma dose received.

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4.2b RADIATION EXPOSURE OF URANIUM MINERS, REPORT OF AN ADVISORY COMMITTEE FROM THE DIVISION OF MEDICAL SCIENCES: NATIONAL ACADEMY OF SCIENCES—NATIONAL RESEARCH COUNCIL—NATIONAL ACADEMY OF ENGINEERING, FEDERAL RADIATION COUNCIL, AUGUST 1968

PREFACE

A special subcommittee of the National Academy of Sciences—National Research Council Advisory Committee to the Federal Radiation Council was appointed at the request of the Council staff to prepare this report on "Radiation Exposure of Uranium Miners." The report includes information available through July 1968 and is based on contributions of individual subcommittee members, a meeting of the subcommittee on May 2, 1968, a meeting of the full committee on June 25, 1968, and subsequent correspondence. The members acted as individuals, not as representatives of their organizations.

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RADIATION EXPOSURE OF URANIUM MINERS

SECTION I. INTRODUCTION

1.1 Increasing attention has been given, within recent years, to observations that extended exposure in some uranium mines is associated with an increase in lung cancer. Upon approval by the Federal Radiation Council (FRC), its staff carried out a study on the radiation hazards associated with the underground mining of

uranium ore. A preliminary draft of the staff report was prepared for use in hearings on "Radiation Exposure of Uranium Miners" held by the Joint Committee on Atomic Energy during the summer of 1967. The FRC staff report, Report 8 Revised, "Guidance for the Control of Radiation Hazards in Uranium Mining" (*1*), was issued in September 1967. The published two-part record and summary analysis of the hearings (*2*) and the FRC staff report constitute a most comprehensive collection of relevant data and viewpoints. The broad objectives were to determine whether uranium miners were being protected by adequate standards and to ascertain how low an exposure would be necessary to insure a proper level of safety for the miners. This necessarily led to considerations of risk versus benefit and to examination of the scientific basis for estimating the magnitude of risk associated with low levels of exposure.

1.2 It was apparent that the subject was most complex and that divergent viewpoints were held on many important issues.

1.3 Accordingly, it was intended that an interpretative report be prepared by persons competent in related areas of radiobiology, but not necessarily having intimate connection with specific aspects of uranium mining. This report has three major objectives: (a) evaluation of the degree of reliability that can be assigned to conclusions from present data, (b) indication of urgent problems that need to be answered to provide adequate reliability for future conclusions, and (c) clarification of the best possible basis for decisions that have to be made now before completely adequate information becomes available. There is included only such factual material as is necessary for understanding of the viewpoints presented. Reference can be made to previously mentioned reports for additional details.

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SECTION II. GENERAL CONSIDERATIONS IN ESTABLISHMENT OF GUIDANCE

A. Background

2.1 It has been known for centuries that numerous miners who worked for several years in mines in which pitchblende was present developed fatal pulmonary disease. This was recognized particularly in Schneeberg in the Erz Mountains in Saxony, and in Joachimsthal on the Bohemian side. The possibility was put forth first in the 1920's that lung diseases, particularly carcinoma, might be associated with high levels of radon in the mines. This theory was further developed in the thirties and forties, and now there

seems to be little question that inhalation of the mine air played an etiologic role in the development of cancer.

2.2 Epidemiologic studies during the 1950's on men working in uranium mines in the United States also indicated an increased incidence of lung carcinoma. Additional studies have confirmed this and have suggested an additive and perhaps synergistic effect between exposure in the mines and cigarette smoking. There thus seems to be no question that extended exposure in some uranium mines is associated with an increase in lung cancer. There is further evidence that the incidence may be correlated with the product of the length of time worked and the average concentration of radon and its daughter products during that time. There is no absolute proof that exposure to radiation is in fact the etiologic factor in the development of lung carcinoma under these circumstances; however, few, if any, would question the high probability that radiation exposure does play a definitive role.

B. The Problem of Guidance

2.3 A specific problem at hand is to decide on the most objective approach to determining the limits of exposure for uranium miners independently of any considerations of actual values that a given approach might yield. Many philosophies exist with respect to what should be the "allowable" exposure for any noxious agent. Broadly speaking, they range from the thesis of "zero" exposure and hence zero additional effect, to various figures for exposure that are presumed to result in some definite but "tolerable" increase in the probability of occurrence of harm. Short of barring all exposure and thus reducing the risk to zero, all philosophies, however lax or rigid they may be, involve implicitly or explicitly an evaluation of the degree of risk as a function of exposure to or dose from the noxious agent. The problem, then, is essentially to decide whether an objective basis can be found for evaluation of dose-effect relationships with respect to the uranium miners.

C. Approaches

2.4 There are two fundamental approaches to the problem—the "empiric," based on epidemiologic data, and the "theoretical," based on hypothesis and calculation.

2.5 With respect to the empiric approach, studies conducted in the United States have resulted in the accrual of a large amount of data on the incidence of lung carcinoma in uranium miners (*1, 2*).

Estimates of the degree of exposure, expressed in WLM,[1] have been made for such persons, even though physical measurements on which to base the estimates were not available in a large proportion of the cases. On the basis of these estimates, however, an attempt has been made to construct an exposure-effect curve (ref. (*1*), p. 22). By appropriate curve fitting, one can attempt to determine the nature of the exposure-effect relationship and can, in principle, then extrapolate to determine some exposure level that will result in some acceptable degree of risk.

2.6 The analogy to this approach is found in the use of human data on radium-dial painters and others who received radium internally, in establishing the present maximum permissible body burden (MPBB) for radium of 0.1 μCi total body burden. Epidemiologic studies on the persons so exposed to radium were conducted, and disease and mortality associated with the radium exposure were evaluated. Estimates of radium body burden were made. The primary data for establishment of the MPBB lie in the curve of degree of effect in human beings versus body burden of radium in microcuries (2*A*). The introduction of a suitable safety factor led to the 0.1 μCi MPBB, which is still extant and which is the prime standard for setting the MPBB for bone seekers. It should be noted that although large numbers of calculations of absorbed dose in rads and of dose equivalent in rem from the radium body burdens have been made, such calculations are not necessary for and are not used in establishing the body burden of 0.1 μCi of radium. The primary approach is to use dose-effect data from human beings, with dose in terms of μCi of radium.

2.7 The second approach (theoretical), which is in principle completely distinct from the first, involves the establishment of hypothetical dose-effect relationship; that is, the establishment of some exposure expressed in quantities of dose equivalent (units of rem), which will result in some presumably acceptable but unspecified increased individual risk. An acceptable risk to a person implies a high probability of escaping injury altogether. A

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[1] Working Level (WL): A level of concentration or burden of radioactivity in a given air environment. Related to environments containing radon and daughter products of radon, a WL is represented by any combination of short-lived radon daughters in 1 liter of air that will result in the emission of 1.3×10^5 MeV (million electron volts) of potential alpha energy from the radioactive decay of the radon daughters. This numerical value is derived from the alpha energy released by the total decay of the short-lived radon daughter products at radioactive equilibrium with 100 picocuries of radon–222 per liter of air.

Working Level Month (WLM): A unit of radiation exposure obtained from working in an environment of 1 WL for 1 month (170 hrs.). (For example, 12 months at 1 WL = 12 WLM; 12 months at 0.3 WL = 3.6 WLM.) Most standards provide a further restriction on exposure, that no quarter of the work year shall involve greater than half the permissible annual total; for example, in the first case above, 6 WLM; in the second, 1.9 WLM. The designation CWLM is often used to represent Cumulative Working Level Months.

variety of hypothetical dose-effect relationships can be invoked, but the one most commonly used is the "linear no-threshold" hypothesis because it is felt to be the "safest." In principle, one could establish an excess incidence of effect or increased individual risk that is deemed to be acceptable and determine the corresponding exposure in rem, on the basis of the hypothetical dose-effect relationship chosen. Actually, what appears to be more common is simply the establishment of an exposure (usually exposure rate), expressed in rem, with no incidence figures attached. With respect to the lung, a dose-equivalent rate of 15 rem/year is established (see pp. 642 and 643 of Part 1 of the hearing (*2*)). It must be emphasized that the 15 rem per year is not based on direct evidence (in the human being or in animals) that any ill effects or any particular degree of risk would be associated with this exposure rate. The number represents a "best estimate," arrived at in the absence of data on actual dose-effect relationships. It should also be emphasized that the 15 rem per year is a value for dose-equivalent rate averaged over some macroscopic tissue volume; no cumulative total dose equivalent that will result in an "acceptable" level of damage is given.

2.8 Once the "allowable" dose to the assumed critical tissues is established, it is necessary to calculate the exposure in terms of radioactivity in the mine atmosphere that would lead to this dose-equivalent rate. A number of assumptions are involved in the calculations, including:

(a) the value for the RBE (relative biologic effectiveness) for alpha emitters, for carcinoma of the human lung (this value is not

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shown and must be estimated);

(b) the "critical tissue" in which the tumor is formed (it is not certain in what tissue or in what portions of the lung these tumors arise);

(c) the effect of nonuniform dose distribution (the degree of influence of "hot spots," as contrasted to an "average" tissue or organ dose, is unknown but may well be important);

(d) the model that describes the kinetics of cell proliferation in the presumed critical tissue, commonly taken to be the bronchial epithelium (available models vary widely, and the dose and dose-rate to tissues are highly dependent on the model selected); and

(e) the amount of radioactivity deposited per unit time in the presumed critical tissue, for a given level of radioactivity in the atmosphere of the mine.

2.9 Both broad approaches, the empiric and the theoretical, involve many errors and assumptions. In an effort to decide whether

one has merit over the other, the following broad principles are offered.

(a) It is best, whenever possible, to work from actual dose-effect data relating to the organ and exposure conditions of interest.

(b) It is better, whenever possible, to apply available data on human beings than on animals.

(c) If data on the human being are not available, or are felt to be so scanty and poor as to be essentially unusable, then dose-effect relationships established for animals should be used, if available.

(d) The use of hypotheses of dose-effect relationships and necessary calculations to arrive at exposure levels should be reserved for situations in which the human or animal data are such that the relative error in the empiric approach is definitely greater.

2.10 In regard to the uranium miners, data on exposed human beings are available. The precedent exists, as already described for radium, for using epidemiologic data of this nature in establishing guidance. It is necessary to attempt to assess the relative error involved in the two approaches. With the empiric approach, as indicated, the error is large. It is possible, however, to place limits of error on the dose-effect relationship obtained (one can obtain a curve to describe the dose-effect relationship simply by obtaining a least-square fit of the data); alternatively, one can attempt to impress on the data a curve that fits some hypothesis. The theoretical approach also carries potentially large errors, to many of which no limits of error can be assigned. The largest uncertainty lies in the assumption that 15 rem per year will lead to some degree of effect that will be acceptable. There is no way of putting limits of error on this assumption because it is an "educated guess." The second largest assumption, again with no limits of error, involves the amount of radioactivity deposited in the critical tissue per unit of exposure to radiation in the atmosphere. Other sources of error include the particular lung model adopted, the effect of nonuniform exposure, translocation of radioactivity, and uncertainty as to the critical tissue.

2.11 We are thus faced with two approaches, each with a large uncertainty. The degree of error can be assessed in the empiric approach; it is essentially unassessable in the theoretical approach. Also, with the theoretical approach, a long chain of potentially large and unassessable errors are involved, which are multiplicative. In the absence of an absolute assessment of the degree of error in each approach, it is not possible to decide objectively, on the basis of degree of error, which approach is the more objective.

It is clear, however, that there is no compelling reason to use the theoretical approach on the basis of relative probable error. For the future, errors in the empiric approach may be reduced by the availability of more data on effects, but the errors may also be increased because of reductions in the levels of exposure that have gone into effect. Nevertheless, there are strong reasons at present for using and improving the empiric approach in arriving at guid-

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ance for exposure of uranium miners.

2.12 The above conclusion is in no way intended to discourage efforts to calculate dose or to downgrade the importance of understanding and quantitating dose-response relationships in radiobiology and in radiation protection. On the contrary, every effort should be made to improve dosimetry, so that more meaningful calculations can be made. Eventually, the theoretical approach may provide better understanding of the various factors involved and permit generalizations to other exposure situations.

2.13 Regardless of approach, it is necessary to inquire into the reliability of estimates of the dose and of the effect produced. As a starting point, it is usually assumed that the estimation of radioactivity in the ambient atmosphere bears a constant relationship to the radiation exposure. Further refinement and understanding come from consideration of physical and physiologic processes in the lung, although, with present information, it is doubtful that such considerations contribute practically to quantitation of radiation dosage. The status in regard to both atmospheric measurements and lung processes is presented in section III. The effects are discussed in sections V and VI.

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SECTION III. THE WORKING LEVEL CONCEPT

A. General

3.1 The Working Level [1] refers to a concentration level or burden of short-lived radon daughter products in a given air environment, and present epidemiologic data are based on the Working Level Months (WLM) as the unit of radiation exposure in the dose-effect relationship. It is evident that the Working Level was designed to represent the radiation exposure potential of uranium mines in the face of a variety of nonequilibrium conditions. It is unsatisfactory for two reasons. First, there are inherent dif-

[1] See footnote 1, p. 3.

ficulties in sampling methods and instrumentation; this is by no means unique to uranium mines nor to the Working Level concept, but occurs with all types of air-sampling programs. There are partial remedies based on proper decisions, such as those concerning the type and number of samplers and the number and duration of samples taken. Second, the Working Level, conceptually and in practice, gives no recognition to the relative contributions of the various radon decay products to the radiation dose and, in particular, fails to recognize the "free-ion" fraction. There is an appropriate and apparently successful instrument-development program underway in both area and personnel dosimeters; thus, much of the instrumental inadequacy soon may be eliminated.

3.2 Assuming that the problems other than instrumental can and will be overcome, we might reasonably expect that the Working Level measurements in combination with information about the worker's activity, respiratory physiology, and associated environmental factors can be amalgamated into a reasonable estimate of exposure in the future.

B. Methods and Measurement

3.3 Measurements of radon and airborne daughters are still being made by the methods described in Public Health Service Publication 494. This document originally appeared in 1957 and was submitted to the hearings (*2*) in 1967 as representing contemporary procedure. The methods are time-tested and satisfactory in competent hands, and there seems no reason to question the figures obtained by using them.

3.4 Some field measurements of radon concentration have been made with scintillation detectors, but these probably do not have the accuracy of the laboratory assays.

3.5 A sample for the radon daughter determination is obtained by pulling a known volume of air through a filter paper, which is subsequently assayed in the laboratory. The laboratory assays can be expected to have the usual random error distribution, above and below the true value, but this may not be the case for the sample collection. Most of the operational uncertainties will tend to reduce the amount of material collected, and hence lead to an underestimate of the airborne activity. If representative samples are to be obtained, the field personnel must be well trained.

3.6 Monitoring efforts have properly concentrated on radon daughters, because they are responsible for the greatest propor-

tion of the airborne hazard. Some 1,200 mines are under surveillance, in which about 12,000 determinations of radon daughters have been made over a 10-year period. This averages to about one sample per mine per year, but the distribution is far from uniform. In some mines where disturbingly high concentrations were found, series of closely spaced measurements may have been made as corrective measures were instituted. In some mines, no measurements have been made.

3.7 Uranium mines may be classified by a variety of characteristics, such as depth, degree of wetness, rock porosity, and character and extent of ore bodies. Correlations of these characteristics with measured values of airborne radioactivity permit an estimate of activity levels in unmeasured mines. Experienced workers have more confidence in these estimates than most outsiders would anticipate.

3.8 Exposure values assigned to the period before 1956 are highly unreliable, being based almost entirely on estimates rather than measurements of concentrations. The sampling frequency increased with time, but some of the 1956–1960 values may nevertheless be in error by an order of magnitude. Values for the period after 1960 are the most reliable, but even here many of the Working Level values reported are only estimates, no measurements having been made.

3.9 There is some uncertainty in the average Working Level values even in mines in which a number of measurements have been made. Each assay depends of necessity on a spot sample, representative only of the conditions existing at the time and place of sampling. The usefulness of spot samples in estimating average exposure levels has been evaluated (*3*) and found to be acceptable, if not ideal. Errors in the techniques of sampling and of field assay methods have been estimated to be less than 10 percent under favorable conditions (*4*). The conditions can vary widely with the nature of mine operations, such as blasting, ventilation, and amount of ore uncovered. The mine air may be almost free of dust and fumes, so that the radon daughters, created as individual nuclei, may exist in an essentially gaseous state for an appreciable period. However, Diesel engines may be running, producing soot particles that serve as condensation nuclei, hydrocarbon residues of various sorts, and carbon dioxide. The variable concentrations of these chemical contaminants introduce both physical and biologic uncertainties.

3.10 The physical uncertainties have been demonstrated by the finding of different particle size distributions and lung depositions between an operating and a quiescent mine environment. Vir-

tually nothing is known about any additive or synergistic effect of radiation and other common mine contaminants, such as arsenic, copper, germanium, lead, and zinc. Concentrations of these elements are detectable but are probably too low to be of biologic significance. Opinions on this point are by no means unanimous.

3.11 The problem of determining an individual uranium miner's radiation exposure is complicated by the fact that official mine records do not necessarily show his actual job assignment. Only the miner himself, and to a lesser extent his immediate supervisor, know the areas in which he has worked. Another problem is possible exposure from previous mining experience. Retrospective information of this type is of dubious validity.

3.12 The latent period for tumor induction makes the early values of exposure and dose particularly important. It is unfortunate that, of the present data on uranium miners, these important early exposure values are the least reliable.

3.13 In addition to uncertainty in the physical measurements, there are great variabilities in the actual radiation dosage as delivered to the critical tissues, depending mainly upon physiologic and physical processes in the lung. These are discussed below.

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The "Free-Ion" Controversy

3.14 In the evaluation of Working Levels, the concentration of free ions (RaA) is a key issue because of its presumably important contribution to the radiation dose and dose rate received by the bronchial tree. The controversy over what values to use for the free ion-fraction seems unresolvable at present and probably will remain so, in view of the wide range of free ion values reported in mine atmospheres. One possible solution to the problem is, of course, to avoid trying to settle on a "universal" value and, instead, to use measured values for each circumstance.

3.15 The deposition characteristics of free ions on small molecular aggregates of the radon decay products within the human respiratory tract have been studied by several investigators. (*5–10*). The average desposition value appears to be about 35 percent. Recent data obtained at the Beaverlodge mines by personnel from the NYO Health and Safety Laboratories (*11*) give a mean deposition value of 38 percent, with a standard deviation of about 15 percent. With large tidal volumes (> 1 liter), the total deposition for radon decay products generally exceeded 50 percent. Investigators at the Health and Safety Laboratories have also measured the nasal deposition of free ions; their reported values generally exceed 60 percent, and average about 65 percent. The

widely accepted value of about 25 percent nasal deposition for free ions, obtained experimentally by Chamberlain and Dyson (*12*), is lower than diffusion theory predicts, and lower than that determined in other studies with aerosols of comparable diffusivity. Increasing the free ion deposition in the nasal passages will correspondingly reduce tracheobronchial dose estimations.

3.16 A variety of papers (*5, 8, 11, 13, 14*) indicates that in uranium mine atmospheres the alpha activity derived from radon decay products is associated exclusively with particles below 0.5 μm in diameter. In most instances, the major part of the activity appears to be on particles well below 0.1 μm. Mine atmospheres, however, have quite different aerosol distributions; commonly, the mine aerosol has a mass median diameter greater than 1 μm and a count median diameter less than 0.5 μm. There is no evidence that the alpha activity is distributed on the mine (vector) aerosol distribution in a predictable way. Estimates of the surface area distribution (based on geometric configuration of particles and not specific surface-area measurements), for example, fail to give an activity distribution corresponding to actual measurements. It is, probable, therefore, that the activity is distributed more closely to the numerical distribution.

3.17 The Task Group Report on Lung Dynamics (*15*) dealt with this general topic in a limited way. It suggested, among other things, that the nasal efficiency is increasing for particles below 0.01 μm and that the graphic representations of size-deposition used in the report were not designed to handle aerosols composed primarily of such minute particles. In fact, the Task Group considered the whole area as a special problem. A second Task Group was later organized under ICRP Committee 2 to investigate this problem in detail. There has been no formal report from this group.

D. Lung Models

3.18 It now appears technically feasible to obtain suitable air-sampling information for assessment of exposure conditions in uranium mines. To evaluate this information more directly in terms of hazard potential to the worker, some knowledge of the intermediate processes is necessary. One approach is to draw on the established physical-chemical properties of the atmospheric contaminants and apply them to a physiologic and anatomic model of the respiratory system. The development of a lung model not only provides for expressing air-sampling information in terms of dose to the tissue, but also divides the relationship into its components. The significance of individual factors is thereby subject

to assessment, and the possibility of modifying these factors is [p. 8] brought into focus; in addition, recognition is given to areas for which information is lacking, uncertain, or controversial.

3.19 Several models have been developed specifically for the radon daughter problem; those of special merit have come from Altshuler and coworkers (*16*), Jacobi (*17*), Thomas (*18*), and Haque and Collinson (*19*). These epitomize the degree of sophistication currently possible, and it is considered that they cannot be improved on, in principle, to any important extent. There are, however, small but significant differences among these models, and these have rather important effects on the ultimate estimation of dose. One of the more significant distinctions has already been discussed; that is, the daughter ratios and the amount of free ions assumed present in the exposure. Other important distinctions include the anatomic dimensions of the bronchial tree, the thickness of the mucous and the bronchial cell layers, the presence or absence of effective mucociliary clearance, and the presumed deposition pattern. It is not productive to study these models and decide that this or that assumption is more likely correct, because these investigators have all drawn their ideas and assigned values from a body of information that lacks consistency and completeness. Perhaps in a few instances it would be possible to state preferences because of new information or information that might not have been known to the persons involved. Still, when the various models are used with the same kind of Working Level assumptions, they tend to give approximately the same kind of dose estimate to the bronchial tree; that is, they range within a factor of about 6, and this includes the effect of assuming that different areas of the bronchial tree receive the greater dose.

3.20 The effective half-life of radon daughter products was estimated, using several of the lung models, on the assumption of a 15-minute exposure. The theoretical elimination curves from the foregoing models predict an effective half-life around 15 to 18 minutes. Experimentally determined effective half-lives for radon decay products in the lungs have been found to average 37 minutes in subjects studied by external counting methods after inhalation exposures to mine atmospheres (*9*). This half-time value essentially corresponds to that of radium-C decay.

3.21 Although the data are limited, clearance measurements for radon decay products generally give effective half-times somewhat longer than those obtained in other human studies of tracheobronchial clearance using radioactively labeled aerosols (*20*). This is probably due to a more peripheral deposition pattern for the

smaller particles serving as a vector for the radon decay products; in addition, there is a possibility that, after deposition, the radionuclei rapidly dissociate from the aerosol particles (*21*) and later experience adsorption to and absorption by the bronchial epithelial cells. Whatever the explanation, there now seems to be ample information to substantiate the view that radon decay products (radium-A to radium-C) undergo negligible biologic clearance from the human bronchial tree.

3.22 In summary, existing lung models and dosimetry use different assumptions, but starting with a relatively uniform exposure basis (a similar ratio of daughter products and percentage of free ions), they give an exposure equivalent estimate of about 7 $\pm$ 5 rad per WLM (*1, 2, 18, 19, 22*).

E. Correlation of Bone Levels

3.23 A novel approach to the exposure-radiation dose relationship in uranium miners has been undertaken by Black and coworkers (*22*). They attempted to correlate the bone levels of lead-210 with estimated exposures (WLM). A key assumption in their development depends on the relation between the lung burden of lead-210 and the amount redistributed to bone; this apparently varies from about 10 percent to 65 percent. Black and coworkers selected 22.5 percent, and obtained approximately the same rad

[p. 9]

dose to the bronchial tissue per Working Level Month as is determinable by the various lung models, viz., about 2 rads. There are still large uncertainties involved in this interesting approach that require further substantiation.

F. Quality Factors

3.24 The published literature gives no adequate basis for assigning a quality factor for alpha particles where lung carcinoma is concerned.

[p. 10]

SECTION IV. DOSE-EFFECT RELATIONSHIPS

A. Considerations of Carcinogenic Mechanisms in General

4.1 To derive meaningful conclusions from the sparse data on uranium miners and to use experience from the clinical radium data, it is necessary to understand some of the general aspects of: (a) carcinogenic mechanisms, (b) time patterns of cancer induction, (c) wasted radiation, and (d) shapes of dose-effect curves,

particularly in regard to thresholds and the linear hypothesis (*2*, *23*).

4.2 Cancers caused by radiation cannot be pathologically distinguished from the same types of cancers resulting from other causes. They can be distinguished only statistically with respect to their incidence in irradiated populations, compared with control populations.

4.3 None of the many types of changes that radiation can cause in cells or tissues is specific or unique for radiation. These types of changes can be caused by a variety of agents or conditions, including many of those known or suspected to be carcinogenic or to promote carcinogenesis. Some of the effects of radiation seem to be additive to carcinogenic or promoting effects of other agents and conditions.

4.4 The precise mechanisms of carcinogenesis are not known completely. Available information indicates that most, if not all, types of cancer develop as a result of multistage or multievent mechanisms, including: (a) initiating cellular events that change the cells of origin of the potential cancer in a manner (chromosomal or other organelle aberrations, mutations) that confers on them neoplastic potential, and (b) promotional events, in which further changes in cells or in local or systemic environment act on the potentiated cells to change them or permit or stimulate them to proliferate as cancer cells. The precise number and nature of the cellular and environmental events for any type of cancer are not known.

4.5 Carcinogenic mechanisms can involve events occurring at any time from the prezygotic stage to the time of cancer appearance. They can involve: (a) prezygotic (inherited) cell mutations, which can spread during development to all kinds of cells; (b) postzygotic somatic-cell mutations acquired throughout life; (c) viral factors; and (d) changes in systemic factors (depressed immune competence, hormonal imbalances) and in local tissue (disorganization and damage), which result from the many pathologic or inherent processes that occur with time. These latter include the changes in cells and tissues caused by a variety of endogenous and exogenous carcinogenic initiating and promoting agents. The incidence of lung cancer, for example, tends to increase with advancing age.

4.6 Radiation can cause all the changes required to induce cancer; however, it may be only one of the causes. Even small doses of radiation can cause cellular changes, including chromosomal aberrations and cell mutations, some of which have been implicated as initiating cellular events in carcinogenesis. In large doses,

radiation can, in addition, cause tissue disorganization and physiologic changes that are essential or contributory to carcinogenesis. Although there is as yet no consensus as to the mechanism of radiation-induced carcinogenesis, the following have been sug- [p. 11]
gested: (a) production of ions and inorganic radons, with hydrogen peroxide formation in aqueous systems, (b) direct production of somatic mutations that predispose to the development of cancer, and (c) activation of oncogenic viruses (although virus-induced cancers have not yet been found to occur in man). With regard to the first hypothesis, it has been suggested that a number of organic peroxides have carcinogenic properties, and that peroxides in general may act by catalyzing the depolymerization of DNA and RNA.

4.7 As already implied, lung cancer is apparently preceded by considerable local tissue damage and disorganization. The experimental induction of lung cancer by irradiation of normal animal lung requires large radiation doses, but the required doses are reduced if local tissue damage and disorganization are caused by other means. In addition to radiation, other factors may play a role in the etiology of lung cancer in uranium miners, including: (a) cigarette smoking, (b) Diesel exhaust fumes, (c) uranium ore dust, (d) upper respiratory and viral infections, (e) nitrogen oxides derived from explosives, and (f) hydrocarbon mists from oil-lubricated pneumatic drills.

4.8 The relative contribution of any particular radiation exposure to the induction of a particular cancer and the radiation dose required to induce the cancer in a person (individual dose threshold) depend on the extent to which the rest of the carcinogenic mechanism will have been completed by changes caused by factors other than the exposure in question. Obviously, the age or life expectancy of the person at the time of exposure and relation to the required time for induction and development of the cancer is one of the determining factors in the individual dose threshold or susceptibility to radiation induction of the cancer. In this regard, there is ample experimental evidence, at least for cancers that increase in incidence with age, that the time between irradiation and the appearance of radiation-induced cancer increases as dose decreases.

4.9 The effect of a radiation exposure in radiation carcinogenesis in a population may be either (a) to cause earlier induction and development of cancers (temporal advancement) in persons who would have had the cancers eventually without the exposure, or (b) to cause cancers (absolute induction) in persons who would

not have had the cancers otherwise. The yield of cancers in any given period after exposure will be determined by which of these processes or what combination of them applies among the cancer cases, and by any changes in survival time caused by the exposure. The difference between temporal advancement of cancer and absolute induction of cancer by radiation exposure involves all grades of contributions of radiation to the total mechanism of the cancer. The difference between the two, at least on a statistical basis, cannot be fully appreciated without thorough determination of the differences in total lifetime incidence, as well as in the age-adjusted incidences between exposed and control groups.

4.10 Most of the available radiation information on man, and even much of the available information on experimental animals, is limited to a period after exposure that is considerably shorter than the survival time of the groups studied. Therefore, the total lifetime incidence of cancer can be estimated only by extrapolation that involves assumptions concerning the future incidence of cancer in both the exposed and the control groups.

B. Considerations of Radiation Dose Threshold in General

4.11 It is the distribution of the individual dose thresholds for a cancer in a population that determines the shape and intercept of a dose-effect curve.

4.12 The term "threshold dose" has real meaning only in terms of the radiation effect in an individual. If a population is being considered, it has meaning only in terms of the radiation effect in the most susceptible individual in that population; that is, the one with the lowest dose threshold for the effect.

4.13 Theoretically, there is a finite probability that exposure to the smallest quantity of ionizing radiation can cause a change in a

[p. 12]

cell—for example, a point mutation—that can contribute a part of the complex mechanism of carcinogenesis in a tissue. Whether this cellular change results in the induction of a cancer—that is, in a "no-threshold" individual—depends on whether the balance of the mechanism is provided by other means.

4.14 The more heterogeneous the population, with respect to factors influencing individual susceptibility or dose threshold for a radiation-induced cancer, the greater the probability of inclusion of individuals in whom the smallest amounts of radiation exposure could complete the required carcinogenic mechanism.

4.15 On logical or theoretical grounds, it is erroneous to assume the existence of an absolute threshold dose for cancer of any kind in all populations of any size or character. It is reasonable to

assume that no absolute dose threshold exists for radiation induction of a cancer in a highly heterogeneous population of great or unlimited size, even though the probability of a "no-threshold" individual is very low, and even though some samples of the population may show an observable or high threshold ("practical threshold").

4.16 The "practical threshold" dose is the largest dose that has been observed to be ineffective for causing an increased incidence of effect (persons with the cancer of interest) in the samples of the population that have been studied for this effect. The "practical threshold" may differ between different samples of a population according to differences in distribution of individual thresholds (and ages) at the lower exposure levels.

4.17 Different tissues (for example, lung and bone), in addition to their inherent differences in susceptibility to carcinogenesis (including radiation carcinogenesis), may differ also in the extent to which they are subjected to exogenous carcinogenic or damaging, cancer-promoting agents and conditions. This factor, among others, may result in differences in dose-effect relationships between tissues, and should be considered in any attempt to relate one tissue to another in this respect.

C. The Relevant Dose in Protracted Irradiation

4.18 With protracted, nonuniform exposure of tissue to alpha particles, there is uncertainty, not only as to the tissue component-dose that is relevant to carcinogenesis, but also as to the portion of the total accumulated exposure that effectively contributed to the induction of the cancer.

4.19 For each subject it takes a certain amount of time to accumulate the exposure (induction dose) required to ensure that cancer will be induced and appear within his remaining life span. After the induction dose has been accumulated, it takes some time (latent period) for the cancer to appear. In protracted irradiation, some of the total accumulated dose is "wasted" and irrelevant, as far as the induction of a cancer is concerned. 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.

4.20 When the individuals of an exposed population receive the protracted exposure at greatly different rates, a particular induction dose takes longer to accumulate at a low-dose rate than at a high-dose rate. This longer time would be taken at the expense of time available for the latent period even if dose rate did not influence the required size of the induction dose. However, be-

cause the available evidence indicates that dose rate does influence the carcinogenic effect, the required induction doses may be larger at the lower dose rates and take still more time to accumulate.

D. Dose-Effect Relationships—General

4.21 For cancer induced by local exposure of the tissue of origin of the cancer, there is, in general, an increase in incidence and a reduced latent period with increasing dose within a certain dose range. With further increasing dose, there may be a decline in the rate of increase in incidence. This decline at high-dose levels is represented first by a plateau in the dose-effect curve at peak incidence levels, and then by a fall in the curve at still higher dose levels. This fall in the curve at the highest dose levels has been

[p. 13]

attributed to degrees of tissue induction that eliminate cancer induction in some persons. Fractionation of such large doses (in the declining incidence range) can increase the incidence, presumably by reduction of the excessive tissue damage, but fractionation of a dose in the range of rapidly rising incidence may reduce the incidence.

4.22 For present purposes, several kinds of dose-response relationship should be considered. An observed dose-response relationship may be either linear or curvilinear (quadratic, sigmoid), and in either case with or without a well-defined threshold (practical).

4.23 A curvilinear relationship between dose and the probability of cancer induction would be expected for cancers, such as lung cancer, that depend greatly on localized tissue damage, which itself is characterized by a curvilinear dose-effect relationship with threshold. However, even under these circumstances, a linear relationship is possible in a group in which there is a range of individual thresholds distributed in a manner permitting a linear relationship.

4.24 On the basis of the above considerations and the limitations of dose-effect studies of radiation carcinogenesis at the lower dose levels, it must be expected that even an observed dose-effect curve with an apparently high- "practical" threshold may have in reality a poorly defined threshold or none at all at lower dose levels, owing to the presence of a small proportion of low-threshold individuals. This lower threshold may be represented by a long, low tail of the curve preceding the point of more rapid rise in the vicinity of the "practical" threshold point. The length and position of this tail and its relative practical importance would depend on the distribu-

tion of individual thresholds in one or another population, and this distribution can be skewed in various ways by variable influences.

4.25 As a basis for protective measures, an arbitrary decision may be made that the probable tail in this theoretical quasi-threshold curve represents so few individuals as to be regarded as negligible.

E. Dose-Effect Relationships—Assumptions

4.26 In the absence of data on cancer incidence related to low doses or dose rates of radiation, the extent to which such exposure has a carcinogenic effect and the shape of any dose-effect curve are matters of speculation and hypothesis, regardless of the observed shape of the dose-effect curve for larger or more intense doses. This becomes more true as the dose range to which the observed dose-effect relationship is limited or for which it is valid becomes higher.

4.27 The establishment of a well-defined dose-effect curve on the basis of a wide range of doses and dose rates is helpful in the arbitrary selection of a "practical" threshold or in the selection of a curve and its shape for extrapolation to lower levels of exposures for which there are no concrete data. Nevertheless, the relationship at the low-dose or dose-rate levels is still hypothetical and involves great assumptions concerning the dose-effect relationship, the carcinogenic mechanisms operating, the dose-rate dependence, the distribution of individual dose thresholds, and the latent period for the manifestation of the effect. When relationships (often based on the linear hypothesis) are used for purposes of radiation protection it is necessary to discourage the acceptance of such procedures as scientific dogma. There should be explicit qualification of the scientific validity of the arbitrary assumptions involved.

4.28 In the present state of data on man, which involve non-uniform exposure of tissue and individuals of heterogeneous groups, often with differences in dose rates, it is necessary for a particular risk estimate to select a single value of a quantity that characterizes the exposure of a group or subgroup, even though such a value may be of limited significance or accuracy. Mean accumulated tissue dose (or exposure) for the individual and for groups of individuals is the only criterion that can be used practically to estimate risks of cancer in such populations until adequate knowledge of more relevant criteria becomes available. [p. 14]

Furthermore, when the dose rate is not uniform and its influence in the exposed group is not known, it must be ignored until more adequate data are available. The linear hypothesis is the only one

that normally permits the use of mean dose or exposure as the significant dose factor under conditions of nonuniform exposure and exposure rate in an individual and among individuals, and that permits the neglecting of dose rate. The use of a nonlinear dose-effect relationship requires consideration of the individual dose and dose rate, and the distribution of doses and dose rates for purposes of estimating risk or setting dose limits.

4.29 If the slope (rate of increase in incidence with increasing dose) to be used for linear extrapolation to low-dose levels is obtained from observed dose-effect data that happen to be in the most rapidly rising segment of the total curve, it is likely that the risk per unit dose at the low-dose levels will represent an upper limit. However, if the slope for linear extrapolation is obtained from observed data that happen to be in the high-dose range of the dose-effect curve, where the doses exceed the maximum effective induction dose (plateau of constant incidence with increasing dose) or where the doses are associated with a decline below the peak incidence found at lower doses, the risk per unit dose at lower dose levels may be underestimated. In any case, such estimates of risk are reliable only in the range of observed dose-effect data from which they were validly derived and only under the associated conditions of the exposure and the exposed.

4.30 The presently available data on lung cancer and exposure to radon daughter products (expressed as Cumulative Working Level Months) in uranium miners do not permit reliable quantitative description of the exposure-effect relationship, or even identification of the general shape of the curve, because of: (a) uncertainties as to exposure and exposure rate, (b) limitations on numbers and followup time, and (c) inability to separate out the effects of combined factors, such as cumulative exposure, exposure rate, age at exposure, minimal and exposure-related latent periods, relevant induction exposure, and exposure to other agents. Therefore, it is not possible at present to select from these data a reasonably reliable or valid exposure-effect relationship for extrapolation to low-exposure levels on the basis of an arbitrary assumption of a hypothesis, linear or otherwise.

[p. 15]

SECTION V. PATHOLOGY

5.1 The most noteworthy feature of the pathology of lung cancer in the uranium miners of the study group is the great preponderance of the small-cell undifferentiated tumors in the higher exposure categories, as reported by Saccomanno and others (*24*); details are tabulated in reference (*2*) pp. 1062–1067. With esti-

mated exposures of less than 360 WLM, two of 11 neoplasms were of the undifferentiated type. This cannot be stated to be in excess of the expected incidence of this tumor type. With estimated exposure levels of 360 WLM or more, small-cell undifferentiated tumors accounted for 60 to 70 percent, whereas tumors of this type usually constitute 20 to 30 percent of all malignant bronchogenic neoplasms in males.

5.2 The small cell undifferentiated type is known to have predominated in the lung cancers among the cobalt miners of Schneeberg and Joachimstahl; in fact, it is understandable from morphologic similarities that these tumors were first considered to be lymphosarcomas and not identified as carcinomas until the late 1920's (*25*). It must be recognized, with the methods currently available, that it is not possible to determine whether any given lung cancer was caused by ionizing radiation. Thus, the etiologic role of ionizing radiation in the genesis of lung cancer of uranium miners at high exposure must be accepted as a high probability, on the basis primarily of epidemiologic evidence with suggestive support from histologic evidence. Among the miners of the Schneeberg district, it was not until after 1928 that evidence was presented that radioactivity of the ores was the principal etiologic factor (Sikil, 27). Hueper (*28*) has summarized data relating ionizing radiation to the pathogenesis of pulmonary tumors. Koelsch (*29*) reported, of 469 deaths among the miners of this district from 1875 to 1912, that 276 were due to pulmonary carcinoma. This extremely high mortality from cancer of the lung, first noted by Harting and Hesse (*30*) in 1879, suggests the existence of a special environmental factor or factors different from those of the general experience of the ordinary miner.

5.3 It has been established that the American uranium miners likewise have a mortality from lung cancer clearly in excess of that reported among other miners in the United States (*31*). Epidemiologic evidence of the etiologic role of radiation, rather than other possible factors, is summarized by Wagoner (*32*) and by Cooper (*33*), and is further discussed in relation to presumed exposure in section VI of this report.

5.4 The question of the possible potentiating or cocarcinogenic action of two or more agents in the development of pulmonary carcinoma may be raised. An excellent example in animal pathology is represented by the experiments of Kotin and Wiseley (*34*). They found that squamous metaplasia and invasive and metastasizing squamous carcinoma developed in C-57 black mice only if the animals were exposed to both mouse-adapted influenza virus and an aerosol of ozonized gasoline ("artificial smog"). Only

acinar atypical proliferation was observed if either agent was used alone. This study has special significance, in that spontaneous squamous cancers are exceedingly rare in rodents, and a cocarcinogenic effect of viral and chemical agents was demonstrated.

[p. 16]

5.5 In man, the relation and interstitial pneumonia, honeycombing, and atypical epithelial proliferation to cancer of the lung has been studied in considerable detail (*35*). It is of note that all the patients in the honeycombing-carcinoma group were male, and also that all the patients from whom a smoking history had been obtained were cigarette smokers. In the case of the cancer patients without a background of honeycombing, at least 16 percent were nonsmokers. It is known that the honeycombing itself is not necessarily associated with smoking. These observations suggest the possibility of some potentiating effect that is related to the combination of widespread pulmonary scarring with associated epithelial hyperplasia, and exposure to cigarette smoke. Selikoff, Hammond, and Churg (*36*) have recently reported a similar relationship between exposure to asbestos, smoking, and neoplasia. Of 87 nonsmokers in a group of 370 asbestos workers, none died of bronchogenic carcinoma during the study period, but of 283 of the workmen with a history of regular cigarette smoking, 24 died of bronchogenic carcinoma, although only three were expected to die of this disease.

5.6 There is evidence that pulmonary fibrosis and atypical proliferation are relatively frequent in uranium miners (as in other miners) in comparison with the general population (*32*). Exposure to ionizing radiation superimposed on such chronic pulmonary disease might have a potentiating effect in relation to development of bronchogenic carcinoma. This general relationship requires further study, and specifically the nature and extent of noncancerous (possibly precancerous?) pulmonary disease in the miners should be investigated in a systematic and detailed manner.

5.7 Also to be considered is the possible cocarcinogenic action of smoking and exposure to radon and its daughters. This hypothesis is supported primarily by epidemiologic evidence presented in section VI. It is evident, however, that there is a large excess of respiratory tract cancers among uranium miners, even when account has been taken of variability associated with age, smoking, and other factors (*37*). As emphasized by Kreyberg (*38*), epidermoid carcinomas, rather than small-cell undifferentiated neoplasms, predominate among cigarette smokers in general.

5.8 A number of features of the natural history of the respiratory tract neoplasms associated with uranium mining may have

relevance to pathogenesis, as well as etiology. Most of the tumors in these miners appear to originate in major bronchi, as is typical of the dominant small-cell undifferentiated type. The idea that such tumors are derived from reserve cells that are relatively deeply placed in the epithelial lining (*39*) is a hypothesis without firm foundation, and it must be admitted that the histogenesis is essentially unknown. Localization in the large bronchi may be related to the occurrence there of a cell type that is particularly sensitive to some factor associated with uranium mining, or possibly to maximal effective concentration of a responsible factor or factors in this distribution. The complexity and unresolved state of the problems relating ionizing radiation exposure to tissue dosage are considered particularly in section III of this report.

5.9 Cytologic examination of sputum has been suggested as a method of surveillance whereby precancerous lesions might be detected in uranium miners, as in other "high-risk" groups (*40*). Further exploration of this method under carefully controlled conditions, using the "blind" reading technique in correlation with long-term followup of patients, is needed to establish its validity.

5.10 Some conclusions that may be drawn at this time are:

(a) The reported dominance of small-cell undifferentiated bronchogenic carcinomas among uranium miners, especially in consideration of epidemiologic data, strongly suggests that radiation may be the most important determining factor in the excessive prevalence of lung cancer among uranium miners at the higher exposure levels. Reexamination of the pathologic material by a second experienced panel of experts is in progress and should

[p. 17]

provide valuable information and interpretation (*34A*).

(b) Granting the strong possibility of the cocarcinogenic effect of cigarette smoking, and perhaps also fibrosing pulmonary disease, the preeminence of the radiation factor is likely for the same reason; that is, predominance of the small-cell type.

(c) The following subjects are worthy of investigation as problems in pathology, as well as epidemiology:

(1) the nature of fibrosing pulmonary disease in these miners, with attention to intensity and duration of exposure in the mines, and

(2) sputum cytology as a clue to the development of precancerous lesions in the lung, as well as to diagnosis of manifest cancer.

(d) There is also a need for accurate information regarding the radiobiology of the lung exposed to inhaled radioactive gases of particles in relation to:

(1) the effects of the radioactive materials as a function of the physical decay process;

(2) pulmonary dynamics in terms of the transport or persistence of the radioactive materials in the various possible distributions within the lung; and

(3) the cellular response of the lung itself.

[p. 18]

SECTION VI. EPIDEMIOLOGY

6.1 Epidemiologic data on man must constitute the final court of appeal on questions of risks to man associated with environmental exposures. Despite uncertainties in dose categorization for uranium miners and despite the relatively small populations involved, epidemiologic data have been developed that have considerable bearing on two issues of primary concern:

(a) Is there a cause-effect relationship at 100 to 400 CWLM?
(b) Is there a synergistic effect on cigarette smoking on the production of lung cancer in uranium miners?

A. The Question of a Cause-Effect Relationship at 100 to 400 CWLM

6.2 We should separate this issue into two questions:

(a) Is there a statistical association between lung cancer and exposures at 100 to 400 CWLM?
(b) If so, is radiation the principal causative agent?

6.3 There have been several epidemiologic studies of lung cancer and other causes of death in uranium miners in Europe, in hard-rock metal miners in the United States and elsewhere, and in coal miners; however, none of these studies can be said to cast any light on the specific question posed here. In regard to the hard-rock metal miners, the variety of the associated exposures, which include radon, makes it difficult to assign causal roles to any particular item or combination of items. In regard to the coal miners, the data from different countries are conflicting and information on radon and other exposures is lacking. The U.S. Public Health Service study of U.S. uranium miners is the only study in which information on levels of exposure makes it at all feasible to attempt a description of the relationship between lung cancer rates and cumulative exposure to radon daughter products. It is also the only relevant study in which histories of cigarette smoking have been obtained. Unless otherwise specified, the data quoted in the following paragraphs are taken from the most recent report of the U.S.P.H.S. study (*41*).

6.4 In the U.S. Public Health Service study the data for white underground uranium miners who died from January 1950 through September 1967 show a statistically significant excess of deaths ascribed to lung cancer in each of the three categories of estimated cumulated exposures under 840 CWLM (ref. (*41*), also table 1 in app.). For all exposures less than 840 CWLM, 7.2 deaths were expected, on the basis of the death rates for the general white male population of the mining area, and 25 were observed. This excess is most unlikely to be due to chance ($p < 0.01$). In the exposure

category of 120 to 359 CWLM, 2.4 deaths were expected and 10 were observed ($p < 0.01$).

6.5 For the three exposure categories over 840 CWLM, the most recent data continue to show the consistent and marked increase in lung cancer risk with increasing exposure that was observed earlier. This provides strong evidence for the hypothesis that radiation is a major causal factor in lung cancer at these ex- [p. 19]
posure levels.

6.6 A trend toward increasing risk with increasing exposure is not seen in the three exposure categories under 840 CWLM; indeed, the relative excess of observed over expected is lowest in the 360 to 839 CWLM category. There are, however, several reasons why it is difficult to demonstrate the presence or absence of a trend at these levels:

(a) Numbers are small and random fluctuations may be important. Variations on only one or two deaths in any of these categories would produce changes in their relative positions on a scale of risk.

(b) Measurements of exposure levels in the mines and estimates of the cumulative individual exposures may not be sufficiently accurate to discriminate among the three categories.

(c) Prior experience in hard-rock mines also involving exposure to radon daughters (that included in the computation of CWLM) has naturally become of relatively greater significance when the exposure from uranium mining is small. Thus, seven of the eight lung cancer cases in the < 120 CWLM category had prior hard-rock mining experience of between 7 and 30 years. In the two other categories (120 to 359 CWLM and 360 to 839 CWLM), however, one half of the lung cancer patients had prior hard-rock mining experience of 2 years or less. If attention is restricted to miners without prior hard-rock experience, there were in the three exposure categories under 840 CWLM, 3.1 expected lung cancer deaths and six observed. Among miners with less than 10 years of prior hard-rock experience, there were, in the same exposure categories, 1.6 expected and eight observed lung cancer deaths. The impression is strong that prior hard-rock mining experience complicates the dose-response relationship in the lower exposure categories, but it is unlikely to explain the overall excess of lung cancer cases in these categories.

6.7 Uranium miners appear to be somewhat heavier smokers than the general male population of the United States, but not sufficiently so to introduce substantial changes in the expected number of lung cancer cases. Smoking habits of the men in the low-exposure categories are similar to those in the high-exposure categories, and the excess cases in the low-exposure categories cannot be explained by any peculiarity of smoking patterns.

6.8 The question of accuracy of statement of cause of death on death certificates has been carefully reviewed by the U.S. Public Health Service. The data quoted above refer to tables that include

only cases in which lung cancer is certified as the underlying cause of death. The restriction to cases in which the cancer was certified as the underlying cause was imposed because this is the basis for the cause-specific mortality rates in the general population from which expected numbers were derived. Not all the cases included in the latest mortality analysis have yet been reviewed histologically; however, in a review by the U.S. Public Health Service of 34 cases included in an earlier analysis based on the same criteria, 28 cases were confirmed as primary lung cancer, and only two were considered not to be primary lung cancer. Available material was inadequate for diagnosis in the other four cases (ref. (*2*), p. 1265). Several cases of lung cancer in addition to those used in the mortality analysis are known in the study population. The estimates of risk given in the U.S. Public Health Service data are minimal estimates, in this respect.

6.9 The biggest source of uncertainty in interpreting the data from the U.S. Public Health Service study, particularly in the low-exposure categories, is the accuracy of allocation to categories of exposure. This problem has been referred to earlier in the report. As time passes, more and more experience will be gained during periods when exposure levels have been more accurately recorded, and, correspondingly, interpretations will be more firmly based. Meanwhile, the possibility of errors in exposure estimates does not warrant the rejection of inferences from what, taken at face value, is a rather impressive accumulation of cases in the low exposure

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categories. The errors involved in omission of exposures attributable to prior hard-rock mining have been referred to in paragraph 6.5. With respect to errors in assignment of exposures during the uranium mining experience, it does not appear that there has been any differential bias in assignment to exposure categories of miners who subsequently developed lung cancer.

6.10 The question of whether the increased risk seen at approximately 100 to 400 CWLM is due to exposure to radon daughter products is complex. In favor of the hypothesis that radon daughters are a contributing factor is the evidence that these grants are primarily responsible for the lung cancer observed at high-exposure levels. On the principle of parsimony, in this instance by assuming that the same relationship holds for the lower exposure levels, it seems reasonable to attribute at least part of the observed increase at 100 to 400 CWLM to the radon daughters. However, the lack of demonstrated increase in risk with increasing exposure at the lower exposure levels calls for caution in accepting this hypothesis. The possibility that other factors associated with ura-

nium mining, or with mining in general, account for all or part of the increase cannot be excluded.

6.11 It should be noted that the data are compatible with a variety of dose-response curves, and theoretical dose-response relationships cannot be used to argue for or against causal association in the 100 to 400 CWLM exposure category. The observations do not support the hypothesis of a threshold in this range of exposure or higher.

6.12 In summary, it is concluded that there is a statistically significant increase in the lung cancer risk for miners with 100 to 400 CWLM exposure that cannot be explained by any known artifact of the data. The question of whether radiation exposures of this level induce cancer must still be considered open. In the opinion of the committee, the hypothesis is favored that radiation exposure at least contributed to the excess lung cancer observed in the miners in the approximately 100 to 400 CWLM category. This conclusion may require revision when more definitive data become available on such matters as:

(a) the measurement of CWLM from all mining experiences, not only that attributable to exposure in uranium mines;

(b) histologic confirmation of the types of lung cancer seen at the various levels of exposure;

(c) the identification of other, possibly relevant exposures experienced by uranium miners; and

(d) the use of various comparison groups, including miners with minimal radiation exposure.

B. Synergistic Effect of Cigarette Smoking and Uraninm Mining

6.13 Although available data are relatively sparse, there is a distinct suggestion in them that cigarette smokers among the uranium miners are particularly susceptible to lung cancer. Two pieces of evidence support this suggestion.

6.14 Among the white underground miners in the U.S. Public Health Service study group, 78 percent were smokers and 22 percent nonsmokers. Sixty of the 62 deaths from lung cancer to date have occurred in smokers. The number of lung cancer deaths expected on the basis of general population rates was 10.1. Given a relative risk of 10 for smokers vis-a-vis nonsmokers, these expected deaths would have broken down as 0.3 in nonsmokers and 9.8 in smokers. The deaths in excess of 10.1—that is, 51.9 deaths —are the deaths attributable to uranium mining. If these deaths occurred independently of smoking, we would expect to find them distributed by smoking habits in the same proportion as the mining population; that is, 22 percent of them, or 11.4 deaths, would have

been in nonsmokers. The occurrence of only two deaths in nonsmokers is not likely to be due to chance ($p < 0.01$).

6.15 Among 761 nonwhite, mostly American Indian, underground uranium miners in the U.S. Public Health Service study,

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1.3 deaths from lung cancer were expected and only two were observed, one in a smoker. Although there are alternative explanations, this observation is explicable in terms of a synergistic effect of cigarette smoking and uranium mining, inasmuch as 82 percent of the person-years at risk of the nonwhite group were referable to nonsmokers.

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SECTION VII. CONCLUSIONS

7.1 At this time, the empiric approach using epidemiologic data represents the best basis for establishment of guidance for exposure of uranium miners. This approach at present necessarily assumes that the cumulated exposure to radon and its daughter products, based on measurement or estimate of mine air and expressed in Working Level Months (WLM), bears a constant relationship to the radiation dose to the critical tissue.

7.2 Uncertainties in regard to estimations of Working Levels and of absorbed dose to tissue can be considered in two categories: (a) physical measurements of mine air, and (b) physical and physiologic processes in the lung.

7.3 In regard to the physical measurements, it is considered that exposure values assigned to the period before 1956 are highly unreliable, being based almost entirely on estimates, rather than measurements of concentrations. The sampling frequency thereafter increased with time, but even so some of the 1956–1960 values may be in error by an order of magnitude. Values for the period after 1960 are the most reliable, but nevertheless many of the Working Level values reported are only estimates, no measurements having been made. It is unfortunate that the early values are so unreliable, because the latent period for tumor induction makes these early values of exposure and dose particularly important.

7.4 Improvement in physical measurements may soon be expected. Assuming that other problems can be overcome, we may expect that measurements, in combination with information about the worker's activity, respiratory physiology, and associated environmental factors can be used to provide a reasonable estimate of exposure or body burden.

7.5 Although our present capabilities for estimating the actual dose-equivalent to lung tissue cannot be used for guidance purposes, studies of this problem should be continued and expanded to provide future understanding. The primary information needs concern: (a) the proportions of free ions, (b) more basic data with which to improve lung models, (c) the critical tissue, and (d) the quality factor for the radiation.

7.6 The presently available data on exposure to radon and its daughter products and the mortality rate from lung cancer do not permit reliable quantitative description of the exposure-effect relationship or identification of the general shape of the curve. The primary deficiencies in the data are: (a) uncertainties as to exposure and exposure rate, (b) limitations in number and followup time, and (c) unknown interrelationships of combined factors, such as cumulated exposure, exposure rate, age at exposure, minimal and exposure-related latent periods, relevant induction exposure, "wasted" exposure, and cancer-promoting effects of other agents and conditions. These deficiencies could be remedied at least in part by epidemiologic studies of properly chosen comparison groups.

7.7 The reported dominance of small-cell undifferentiated bronchogenic carcinomas among uranium miners exposed at the higher levels suggest the importance of the radiation factor, granted the strong possibility of the cocarcinogenic effect of cigarette smoking and perhaps also of fibrosing pulmonary disease.

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7.8 Recognizing the unreliability of present data on uranium miners, but accepting them at face value with a realization that decisions must be taken before completely adequate scientific evidence is available, the committee draws the following conclusions:

(a) There appears to be a causal association between lung cancer and exposures of approximately 1,000 CWLM and higher.

(b) There is a statistically significant increase in the lung cancer risk for miners with approximately 100 to 400 CWLM exposure that cannot be explained by any known artifact of the data.

(c) The hypothesis is favored, pending more definitive data, that radiation exposure at least contributed to the excess lung cancer observed in the miners in the 100 to 400 CWLM category.

7.9 Existing data strongly suggest that cigarette smokers among the uranium miners are particularly susceptible to lung cancer.

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4.2c IMPLICATION TO MAN OF IRRADIATION BY INTERNALLY DEPOSITED STRONTIUM-89, STRONTIUM-90, AND CESIUM-137, REPORT OF AN ADVISORY COMMITTEE FROM THE DIVISION OF MEDICAL SCIENCES: NATIONAL ACADEMY OF SCIENCES—NATIONAL RESEARCH COUNCIL, FEDERAL RADIATION COUNCIL, DECEMBER 1964.

FOREWORD

In its continuing assessment of the health implications of exposure of man to ionizing radiation, the Federal Radiation Council invited the National Academy of Sciences to aid it in reviewing various aspects of the field. An Advisory Committee to the Federal Radiation Council was duly appointed by the Academy within the Division of Medical Sciences of the National Research Council.

The first request of the Federal Radiation Council was for a summary statement concerning the effects to be expected in man from irradiation by internally deposited strontium-89, strontium-90, and cesium-137, with reference to effects that might occur at dose levels of the order of 25 rads or less. The report which follows was prepared by the Advisory Committee. It surveys the possible effects of these nuclides in man in light of their particular metabolic properties and in relation to the known effects of ir-

radiation from other internally deposited radioelements and from external sources.

The views of the committee are based on evidence documented in the scientific literature and reviewed extensively in cited reports by the National Academy of Sciences Committees on the Biological Effects of Atomic Radiation, by the United Nations Scientific Committee on the Effects of Atomic Radiation, and by the Medical Research Council Committee on the Hazards to Man of Nuclear and Allied Radiations. No attempt has been made to discuss the evidence fully again at this time. Consequently, the presented material is submitted as a working paper for the use of the Federal Radiation Council.

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SECTION I

INTRODUCTION

1.1 All ionizing radiations can cause the same types of biological effects, the probability of any given effect depending on the conditions of exposure. Consequently, the hazards of irradiation from radioactive strontium and cesium, as from any internally deposited radionuclide, depend on the distribution of the elements in the body, their retention, and their radioactive decay. These properties, in turn, depend on the chemical behavior of strontium and cesium in the forms in which they are encountered and on the physical characteristics of their several isotopes.

1.2 Cesium-137 is an alkali metal chemically similar to potassium, which it resembles metabolically. As such, it is distributed relatively uniformly throughout the body and is excreted largely within a period of months. Because of the distribution of cesium-137 in the body, the radiation from this isotope resembles whole body irradiation. It is a beta-emitter, decaying with a physical half-life of 29.7 years, to form barium-137m, which in turn decays almost at once with emission of gamma rays.

1.3 Strontium is an alkaline earth, similar to calcium and radium in its metabolism by the body. As such, it has a predilection for bone, into which it becomes tightly bound and from which it is excreted slowly over a period of years. Because the radiation from strontium-89 and strontium-90 is localized primarily in bone and to a lesser extent in bone marrow, the nuclides give rise to exposure principally of these tissues, although they may irradiate other parts of the body in the process of uptake and excretion. Both nuclides are beta-emitters, with physical half-lives of 50.5 days and 27.7 years, respectively. On decay strontium-90 gives rise to a beta-emitting daughter element, yttrium-90, which has a physical half-life of about 2.5 days.

1.4 Principles for evaluating the health implications of radionuclides, as summarized in earlier reports by the Federal Radiation Council (No. 3, 1962; No. 5, 1964), have laid stress on permanent somatic and genetic effects, which may be induced by low-level irradiation in the absence of immediate or obvious manifestations of radiation injury. In the report that follows, these principles will be applied primarily to a consideration of the health implications of the uptake of strontium-89, strontium-90, and cesium-137 by a small fraction of the population on a short-term basis (i.e., for a period of days to months).

1.5 The evaluation of the effects of these nuclides involves many uncertainties and depends heavily on extrapolation from studies

with experimental animals, since observations on the effects of radioactive strontium and cesium in man are fragmentary.

1.6 With whole body exposure, such as from radioactive cesium, the possible effects of chief concern are genetic damage, leukemia, and other neoplasms. Other effects to be considered, however, include injury to the developing fetus, life-shortening, and retardation of growth.

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1.7 With localized irradiation of the bone and bone marrow, as from radioactive strontium, the principal effects to be considered are induction of bone tumors and leukemia, as well as disturbances in the growth and development of skeletal parts and teeth.

1.8 Although radionuclides of cesium and strontium are considered separately in this report, it is recognized that they will be encountered together in most instances of contamination.

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SECTION II

CESIUM

Metabolism

2.1 Cesium exists as stable cesium-133 in mammals in a concentration of about 10^{-4} μgrams per gram of wet tissue. Cesium-137 is the only isotope of cesium that makes an appreciable contribution to the radiation dose to man. Cesium-134 has been detected in man but only in the presence of a much greater activity of the longer lived cesium-137.

2.2 Cesium-137 is a fission product which enters the human food chain primarily by deposition on foliage that is later consumed by domestic animals. The amount of cesium-137 that enters the human food chain appears to increase with the amount of rainfall in the area where dairy cattle graze (Rickard et al., 1962). The major portion of the cesium-137 burden in the United States population comes from the consumption of milk and milk products; meat products are the second most important source (Anderson, E. C. et al., 1957). A relatively high cesium-137 burden has been found in Swedish Lapps (Liden, 1962), resulting from the consumption of reindeer meat which, in turn, derived its cesium from a lichen having a high affinity for extracting this element from its environment. A similar food chain appears to account for the relatively high cesium-137 levels found in the Northern Alaskan Eskimos (Hanson et al., 1964). Elevated levels have been re-

ported in other populations living in the far north (United Nations Scientific Committee on the Effects of Atomic Radiation, 1964).

2.3 Cesium-137 has been detected in edible marine organisms, including fish, but the concentration factors are too small to make an important contribution to the total human intake.

2.4 Cesium-137 has also been observed in human milk (Aarkrog, 1962). The cesium-potassium ratios in human milk range up to about twice the corresponding ratios in the mother's diet, indicating that the mammary gland tends to concentrate cesium in the milk relative to potassium. The cesium-potassium ratios in human milk parallel but are slightly higher than the corresponding ratios in cow's milk from neighboring areas. The absolute cesium-137 content per unit volume is lower in human milk than in cow's milk, however, because the latter contains about three times as much potassium as the former.

2.5 Measurements in animals (Moore and Comar, 1963) show that a developing fetus comes rapidly into cesium-137 equilibrium with cesium ingested by the mother. In a small number of observed cases the concentration of cesium in children shortly after birth was essentially the same as that in the mother (Bengtason et al., 1964).

2.6 Most cesium salts are quite soluble and hence are rapidly and completely absorbed, with little dependence upon the route of administration. Tracer studies in the cow show that about 13 percent of a *single* cesium-137 dose appears in the milk over a 30-day period (Hood and Comar, 1953). In a woman essentially in cesium equilibrium, over 40 percent of the daily cesium-137 intake

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appeared in the milk at the beginning of lactation, this proportion decreasing to about 20 percent within a few months (Aarkrog, 1962).

2.7 Cesium, like potassium, tends to be found within cells, although small extracellular concentrations are observed. Assays of Japanese autopsy specimens (Yamagata, 1962) produced the values in Table 1.

TABLE 1. CESIUM-137 CONCENTRATION IN TISSUES OF JAPANESE PEOPLE*

Tissues	pCi of ^{137}Cs per gm of tissue	pCi of ^{137}Cs per gm of K
Muscle	29 5	13.2
Soft tissues	12.7	9.8
Bone and marrow	15.7	9.1
Average all tissues	20.0	10.0

*From Yamagata, 1962.

2.8 Although the distribution of cesium is somewhat different from that of potassium, over 55 percent of the cesium-137 burden can be expected to be in the total muscle mass.

2.9 The retention of ingested cesium as a function of time is a most important factor in any estimate of absorbed dose. Although some data have suggested that there is little choice between an exponential function and a power law function, retention studies which have been extended over several hundred days favor a two-component exponential function (Stewart et al., 1958; United Nations Scientific Committee on the Effects of Atomic Radiation, 1964). The short lived component with a biological half life of the order of one day contributes little to the total absorbed dose and can be neglected.

2.10 Biological half life values for the long lived component range from about 74 days (Liden, 1962) to 180 days (Stewart et al., 1958) in adults, with lower values for children (United Nations Scientific Committee on the Effects of Atomic Radiation, 1964). The range of observed values appears to represent differences among individuals rather than instrument or calibration errors. Values obtained by whole body counting agree well with those obtained by assays of excreta. A similar two-component exponential retention function was found in the dog (Nold et al., 1962), with biological half lives in a small series ranging from 18.8 to 40.9 days.

2.11 Data from adults are too meager as yet to permit a precise determination of a most probable biological half life, and indeed this value may be a function of the eating habits of a population. Retention data in children are even more meager, and few children have been studied for the lengths of time required to obtain good values of biological half life. During the first decade after birth, biological half lives for cesium-137 may be less than one-third of the adult value.

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2.12 In the light of these uncertainties, a value of 100 days has been taken as the biological half life of cesium-137 in normal adults of the general population (United Nations Scientific Committee on the Effects of Atomic Radiation, 1964). This value is almost certainly too large for children, perhaps by a factor of three to five. The use of too large a value of the biological half life will lead to an overestimate of the absorbed radiation dose.

2.13 Exposure to cesium-137 from weapons fallout is more apt to be long-continued, at an approximately constant level, than is exposure that might result from an industrial accident, which is apt to be limited to a single, brief period.

2.14 To illustrate the build-up of a cesium body burden, let us consider a steady-state situation in which there is a constant daily intake of k nanocuries of cesium-137. If a biological half life of 100 days is assumed, the effective decay constant $\lambda = 0.693/100 = 6.93 \times 10^{-3}$/day. At any time t days after the start of exposure, the body burden B in nanocuries will be given by

$$B = \frac{k}{\lambda}(1 - e^{-\lambda t}) \qquad \text{E–1}$$

$$= 144\,k(1 - e^{-0.00693t}) \qquad \text{E–2}$$

There will be a maximum body burden at equilibrium of

$$B_M = 144k \qquad \text{E–3}$$

but this value will be approached slowly. B will reach 90 percent of its maximum value in about 330 days.

Dosimetry

2.15 In calculating the absorbed dose, it seems reasonable to assume that the body burden is uniformly distributed throughout the body. The variations in concentration between one tissue and another are smaller than the uncertainties in the half-time of retention for a given individual. The tissue dose will come mainly from the beta particles emitted by cesium-137 itself and from the gamma rays emitted by its metastable daughter barium-137m (ICRP, 1960). The range of most of the beta particles will extend well beyond cellular boundaries, so that extracellular tissues will receive a radiation dose comparable to that delivered to the interior of the cell.

SECTION III

STRONTIUM-89 AND STRONTIUM-90

Metabolism

3.1 The behavior of strontium in mammals is inextricably linked with that of other elements, especially calcium. It is also affected by variations in nutrition, bone physiology, fetal development, and lactation. It is not feasible in this report to attempt a rigorous consideration of all such factors in estimating the hazard from radiostrontium to man; instead, attention is given primarily to

conditions that would result from short-term contamination, in which case it is assumed that fresh cow's milk would be the principal contributor to the body burden.

3.2 The metabolic properties described below are equally valid for strontium-89 and strontium-90. In this discussion, radioactive strontium is designated as Sr*.

3.3 After radiostrontium is ingested, part of it is absorbed from the gastrointestinal tract into the blood stream and part is excreted unabsorbed in the feces. That which is absorbed is (a) deposited in the skeleton, (b) distributed in the soft tissues and circulating fluids, or (c) removed from the body by urinary excretion and endogenous fecal excretion (United Nations Scientific Committee on the Effect of Atomic Radiation, 1962, 1964; Comar and Wasserman, 1964; Loutit, 1962; Caldecott and Snyder, 1960).

3.4 The pattern of skeletal distribution after short-term exposure can be pictured as follows: Radiostrontium from the blood rapidly enters the bone by ion exchange on the surfaces of bone crystal and by incorporation into new bone which is being formed in zones of growth and remodeling. This leads to focal areas of highly localized radioactivity and diffuse areas of generally lower concentration. In young, growing individuals and in cancellous bone formation rates are relatively high, resulting in comparatively high local deposition and intensity of radioactivity.

3.5 The removal of radiostrontium from bone, once it has been deposited, is relatively slow, depending mainly upon the extent of bone resorption and mineral exchange.

3.6 The behavior of strontium in the body can be considered either in terms of strontium itself or in terms of the relation between strontium and calcium (United Nations Scientific Committee on the Effects of Atomic Radiation, 1962; Comar and Wasserman, 1964; Caldecott and Snyder, 1960; Wasserman, 1963). Although the data on the retention of strontium in the body suffice for estimating body burdens for short-term ingestion, analysis of the strontium-calcium relationship facilitates estimating concentrations of radiostrontium in newly formed bone and in the entire skeleton under conditions of protracted intake. The reasons for this are (a) homeostatic control of calcium leads to a remarkable constancy of calcium concentrations in most tissues and fluids; (b) strontium metabolism is regulated more by calcium levels than by normal amounts of stable strontium; and (c) strontium and calcium movements are usually affected similarly by extraneous factors. Extensive experimental evidence in man and animals shows that the strontium-to-calcium ratio in tissues and secretions

is directly related to the ratio that exists in the diet, within normal dietary limits.

3.7 Organisms generally utilize and retain strontium less effectively than calcium; that is, they *discriminate* against strontium in favor of calcium. The term "Strontium-Calcium Observed Ratio" (OR) is used to denote the comparative strontium to calcium ratios that exist at equilibrium in a given component of the body and in its dietary precursor; for example,

$$OR_{bone/diet} = \frac{\text{Sr/Ca of bone}}{\text{Sr/Ca of diet}} \qquad \text{E–4}$$

3.8 The over-all discrimination, which is designated by the OR value, is brought about by one or more physiological processes, of which gastrointestinal absorption, renal excretion, placental transfer, and mammary secretion are most important (Comar and Wasserman, 1964).

3.9 The OR value is affected by age and dietary composition, although the effects of the latter are small unless the diet is highly exceptional. Under the usual dietary conditions the OR values for older children and adults fall within a reasonably narrow range, with few indications of variation by a factor as high as two (United Nations Scientific Committee on the Effects of Atomic Radiation, 1962; Comar and Wasserman, 1964).

3.10 In the movement of strontium and calcium between bone and the exchangeable pools there is little or no discrimination between the two elements. The terms $OR_{body/diet}$ and $OR_{bone/diet}$ are, therefore, used interchangeably. If the skeleton of an individual is formed entirely from a diet of a given Sr*/Ca ratio, then all the bone should have an essentially uniform concentration, equivalent to $(OR_{bone/diet}) \times$ (Sr*/Ca of diet); an example of this would be the case of a newborn child of a mother who had a constant dietary Sr*/Ca during gestation.

3.11 Under conditions of short-term exposure to radiostrontium or exposure to changing levels the situation is much more complex. The highest concentrations are localized in "hotspots" which represent sites of active bone formation and are estimated to contain about half of the deposited radiostrontium. The rest of the radioactivity is diffusely distributed in bone at a considerably lower concentration than in the "hotspots" (La Croix and Budy, 1962). The theoretical maximum concentration is equal to the value of $(OR_{bone/diet}) \times$ (Sr*/Ca of diet). In actuality, it is expected that the concentration in "hotspots" may be as low as half the theoretical maximum because of the contribution of calcium from the body stores.

3.12 Also significantly influencing the deposition and retention of radiostrontium is the rate of turnover of bone salts, or the rate of replacement of existing mineral in the skeleton. Some considerations suggest that the skeletal calcium of the newborn infant turns over so rapidly that appreciable equilibration of skeletal strontium to calcium ratio with the strontium to calcium ratio of the circulating fluids probably occurs within a matter of weeks (Comar et al., in preparation). This means that the strontium to calcium ratio of the skeleton of the newborn infant will be gov-

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erned primarily by the strontium to calcium ratio of the diet during the first few weeks, and perhaps months, after birth. In infants and young children it has been estimated that about 50 percent of bone mineral is replaced annually, with an almost complete replacement of skeletal mineral in the first two years of life (Bryant and Loutit, 1964). In older individuals, a gradation of replacement rates is thought to exist; for example, it is estimated that the replacement rate in adult long bones might be about 1 percent per year as compared to about 10 percent in adult cancellous bones (Loutit, 1962). Those parts of bone with the highest growth-rate are those in which are deposited the largest amounts of the radiostrontium ingested over a short time period.

3.13 Typical data for estimation of body concentrations of radiostrontium following short-term contamination of cow's milk are summarized in Table 2. The values have been appropriately rounded, since no single figure can be representative of an entire population, and since the values are intended only for illustrative comparisons and rough estimates.

3.14 The values for $OR_{body/diet}$ (column 1, Table 2) are as follows: for the fetus, a rounded value of 0.1 was used, although the data in the literature would suggest values up to 0.13 (United Nations Scientific Committee on the Effects of Atomic Radiation, 1962; Comar and Wasserman, 1964; Loutit, 1962); the OR value at birth is close to 1 (Lough et al., 1963), decreasing to about 0.5 at 1 year of age and probably reaching the adult value of 0.25 sometime shortly thereafter (United Nations Scientific Committee on the Effects of Atomic Radiation, 1962; Loutit, 1962; Benison et al., 1964); for pregnant and nursing women, the value accepted for adults (0.25) was used.

3.15 The fraction of the calcium intake that might be derived from fresh cow's milk was calculated from consideration of the amount of calcium consumed in fresh milk (column 3, Table 2) in relation to the total calcium intake (column 2, Table 2). The data on column 2, Table 2, were derived from recommended dietary in-

takes (Food and Nutrition Board, 1958 and 1963) and in column 3, Table 2, from estimates of milk consumption in home and school (Bureau of the Census and Division of Radiological Health, 1963). The diet of babies less than 4 months of age will contain no fresh cow's milk if they are breast-fed or receive formulas made with processed milk; however, for purposes of comparison, an entry has been made for such infants fed a diet based entirely on fresh cow's milk.

3.16 The values in column 5, Table 2, which represent the maximum Sr*/Ca in new bone per unit of Sr*/Ca in cow's milk, were calculated by multiplication of columns 1 and 4. The highest concentrations occur in the 4–6 month age group (except for the 0–4 month infant fed on fresh cow's milk) and are 2 to 5 times higher than those calcuated for ages 6 months to about 20 years.

3.17 The daily retention of Sr* per unit of Sr*/gram of calcium in fresh milk (column 6, Table 2) was calculated on the basis of a gastrointestinal absorption of 30 percent (Lough et al., 1963; Gran and Nicolaysen, 1964), neglecting endogenous losses, which are small. These values do not apply to long-term ingestion, since under chronic conditions the skeleton tends to approach a steady

TABLE 2.—ESTIMATION OF BODY CONCENTRATION OF RADIOSTRONTIUM RESULTING FROM SHORT-TERM INGESTION OF CONTAMINATED FRESH COW'S MILK

Age, Nutrition, and Physiological Status	(1) $OR_{body/diet}$	(2) Calcium intake g/day	(3) Calcium intake from fresh cow's milk [1] g/day	(4) Fraction of calcium intake from fresh cow's milk	(5) Maximum Sr*/Ca in new bone per unit of Sr*/Ca in cow's milk	(6) Daily Sr* retention per unit of Sr*/g of Ca in fresh milk [2]	(7) Calcium content of Body (g)	(8) Daily Sr* retention per gram of Ca in body per unit of Sr*/g of Ca in fresh milk
Fetus	0.1	—	—	—	0.07	—	—	—
0–4 mo. (breast-fed)	1.0	—	—	—	0.06	—	—	—
0–4 mo. (processed milk)	1 0	—	0	0	0	—	—	—
0–4 mo. (fresh cow's milk)	1.0	—	—	1.0	1 0	—	—	—
4–6 mo.	1.0	1.0	0.8	0.8	0.80	0.24	52–64	0.0041
6 mo–1 yr.	0.5	1.0	0.8	0.8	0.40	0 24	64–100	0.0029
1–4 yr.	0.25	1.0	0.6	0.6	0 15	0.18	100–201	0.0012
4–9	0.25	1.0	0 8	0.8	0.20	0 24	201–341	0.00089
9–14	0.25	1.2	0.8	0.7	0.18	0.24	341–715	0.00045
14–19	0.25	1.4	0.8	0 6	0.15	0.24	715–1073	0.00027
19–24	0.25	0.8	0.4	0.5	0.13	0.12	1073–1078	0 00011
24	0.25	0.8	0.3	0.4	0.10	0.09	1078	0 00008
Pregnant women	0.25	1.5	1 1	0.7	0.18	0.33	1078	0.00031
Nursing women	0.25	2.0	1 1	0.6	0.15	0.33	1078	0.00031

[1] These values also represent the Daily Sr* intake per unit of Sr*/gram of calcium in fresh cow's milk.

[2] Based on 30% gastrointestinal absorption.

state with regard to Sr* entry and removal, and the excretion from the body increases. From estimates of the total calcium of the body (Mitchell et al., 1945), the daily retention of Sr* per unit of Sr*/gram of calcium in fresh milk can be expressed in relation to the amount of calcium in the body (column 8, Table 2). For example, an adult man is estimated to consume daily 0.3 gm of calcium from fresh cow's milk; if this milk contained 1 picocurie of Sr*/gm Ca, it is assumed that he would consume 0.3 picocurie of Sr* of which 30 percent, or 0.09 picocurie, would be retained. If his body content of calcium were 1078 gm, then his daily retention of Sr* per gram of calcium in his body would be about 0.00008 picocurie.

3.18 The rate of elimination of radioactive strontium from the body, as influenced by age and other factors, is not well-known. Studies in several species of laboratory animals have indicated that the rate of excretion of strontium-85 varies markedly in relation to age during the first few months after a single injection of the isotope but later approximates the same power function in animals of all ages (see Finkel, Bergstrand, and Graubard, 1960; Speckman and Norris, 1964; Decker et al., 1964). Limited human data fitted with a power function and extrapolated to 40 years give a long-term retention half life of 110 years, or 4.0×10^4 days (Cohn et al., 1962), as compared with the half life of 1.3×10^4 days listed by the ICRP (1960). The difference between the two half lives is attributable in part to a relatively rapid rate of excretion during the first several months, which can be described by three successive exponential functions with half lives of 2.5, 13.7, and 843 days, respectively (Cohn et al., 1962). Clearly, more data are needed over longer intervals to enable confident prediction of the long-term retention of radioactive strontium by human populations of various ages following short-term intake.

3.19 Although the initial concentrations of radiostrontium are obviously highest in young infants fed fresh cow's milk, the turnover of the isotope and its removal from the body are also relatively high in infancy. Because these opposing effects cannot yet be balanced precisely, it is difficult to state unequivocally which age group of the population may receive the largest cumulative radiation dose from short-term ingestion of strontium-90. Strontium-89, however, which has a physical half life of only 50.5 days, will tend to be removed more slowly by excretion at all ages than by radioactive decay, so that the cumulative radiation dose from this isotope will depend primarily on its initial concentration in the body.

Dosimetry

3.20 It is not yet possible to interpret the radioactive strontium burden meaningfully in terms of the relevant resulting radiation dose to the target tissue of interest, especially under conditions of relatively short-term exposure to strontium-89 or strontium-90. At any given time, the maximum local concentration of radioactivity in the skeleton, and thus the maximum dose in "hotspots", depends on the Sr*/Ca in new bone (column 5, Table 2). On the other hand, the average concentration of radioactivity in the skel-

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eton, and thus the average dose to bone, is related to the ratio of Sr* in the body to the total calcium in the body. Use can be made of either of these values to estimate the corresponding doses in rads (see Loevinger, 1956; Mays et al., 1959; ICRP, 1960; United Nations Scientific Committee on the Effects of Atomic Radiation, 1964). The difference between the resulting two doses is large, and which of the two, if either, is appropriate in estimating health hazards is not clear. In general, however, values of the mean dose to bone are used, although it is recognized that they would be strictly appropriate only if the incidence of the effects in question varied as a linear function of the dose to bone over a wide range of doses. When the absorbed dose to the bone from these nuclides is used in this report, it will refer to the mean dose in rads.

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SECTION IV

GENETIC EFFECTS

4.1 Appraisal of genetic injury is hampered by our inability to measure the over-all damage resulting to the population from the total effects of deleterious mutations. Nevertheless, it is accepted that any increase in the mutation rate is undesirable, since mutations are preponderantly harmful and are transmitted to successive generations. Furthermore, since any increase in the radiation dose to germ cells is assumed to cause some increase in the mutation rate, the National Academy of Sciences-National Research Council Committee on Genetic Effects of Atomic Radiation recommended in 1956:

"That for the present it be accepted as a uniform national standard that X-ray installations (medical and nonmedical), power installations, disposal of radioactive wastes, experimental installations, testing of weapons, and all other humanly controllable sources of radiations be so restricted that members of our general population shall not receive from such sources an average of more than 10 roentgens, in addition to background, of ionizing radiation as a total accumulated dose to the reproductive cells from conception to age 30.

That individual persons not receive more than a total accumulated dose to the reproductive cells of 50 roentgens up to age 30 years (by which age, on the average, over half of their children will have been born), and not more than 50 roentgens additional up to age 40 (by which time about nine tenths of their children will have been born)."

4.2 The 1956 report was written before it was demonstrated in mice that, for those germ cell stages which, in man, are the ones of primary concern, an exposure to low-dose-rate radiation is less mutagenic than the same total dose given at a high dose rate. At about the same time, the susceptibility of human chromosomes in somatic cell cultures to breakage by radiation doses as low as 25 R was reported. After weighing the various aspects of these and other new developments, the Committee reiterated its position in 1960, reporting as follows:

"The Committee continues to recommend that for the general population the average gonadal dose accumulated during the first 30 years of life should not exceed 10 R of man-made radiation, and should be kept as far below this as is practicable. This is in essential agreement with the most recent suggestions of the International Commission on Radiological Protection."

4.3 The Committee did not comment further at this time with reference to the individual dose.

4.4 The last decade has been one of significant progress in genetics and molecular biology. Many of the details by which the DNA molecule replicates, mutates, carries information, and influences development are now known. The basic principles of protein synthesis under the control of DNA through the mediation of RNA are beginning to be understood. The identification of DNA with the gene has made possible a rational study of chemical muta-

tion, and a number of compounds known to affect DNA in one way or another have been shown to alter the mutation rate. There has also been considerable progress in understanding some of the chemical steps in the induction of mutation by ultraviolet radiation. The induction of mutation by ionizing radiation is less understood at the chemical level, but the biological knowledge of such mutation has been greatly increased. For example, the mutation process has been found to be dependent on a great many variables in a complex way. The stage of the cell in mitosis, the stage in the life cycle, the amount of oxygen in the cell, and a number of other factors have all been shown to be influential. There is also strong evidence for cell selection that can diminish, or perhaps in some circumstances increase, the impact of a mutation. When the 1956 report was written some of this was realized, but the problem of estimating the damage from radiation seemed simpler in some ways than it does now. In particular, at that time it was not realized that the dose rate was of importance. The roles of this and other factors, including complexities in the different mutational responses of male and female germ cells, have now been revealed through intensive studies in mice (Russell, 1963).

4.5 The science of human cytogenetics has been advanced considerably since the 1956 report. It is now realized that several types of human abnormality—severe syndromes with various physical defects and mental retardation—are caused by chromosomal aberrations. It is well established in experimental animals that nondisjunction, chromosome loss, and translocation are increased by radiation. Furthermore, it is now possible to study chromosome breakage and rearrangement in humans in the same manner as has been so productive of new information in plant genetics. Recent reports emphasize that irradiation in vitro with doses down to about 12 R causes about 1 percent of human somatic cells to have chromosome abnormalities, and radiation workers receiving approximately 10 times the background dose have been demonstrated to have a significant increase in abnormal chromosomes in circulating white blood cells (Norman et al., 1964).

4.6 There have been almost no reports on the mutagenic effects of radioactive strontium and radioactive cesium. Embryo mice from fathers that had received intravenous injections of 0.7 microcurie of strontium-90 per gram of body weight have been reported to have a higher frequency of cells with an abnormal number of chromosomes than the controls (Henricson and Nilsson, 1964). The authors stated that the results could be due to radiation-induced aneuploidy in the germ cells, but suggested that another type of damage not primarily connected with the chromosomes

may have been involved; namely, a radiation effect on the cell division mechanism that was transferred from spermatozoa to embryos. The same large amounts of strontium-90 injected intraperitoneally in mice have been reported to produce a significantly higher embryonic mortality in descendants than was found in the controls or after injection of the same number of microcuries of cesium-137 (Lüning et al., 1963a, 1963b). The effect was interpreted by the authors as resulting from incorporation of strontium-90 in the chromosomes. This interpretation raises the question of whether radioactive stontium should be given special consideration as a genetic factor. However, as the authors pointed out, there are apparently some puzzling inconsistencies in the re-

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sults which cannot be resolved without further experiments. Furthermore, even if the magnitude of the reported effect were confirmed, it would still seem unlikely that it would prove to be the limiting factor in setting up protective action guides for strontium-90. In the first place, the doses to the mice were large (about 18 microcuries per mouse). Second, the length of time the strontium stays in the germ cells, or even in their vicinity, is probably only of the order of days, and most of it that is not deposited in the bones is excreted.

4.7 A number of large-scale population studies on mammals have been completed or are under way (see Roderick, 1964). In general, doses delivered to mature germ cells at high dose rates have been observed to cause detectable effects on viability, size, and similar traits in the first generation progeny. Thus, large doses given to rats have been shown to have a significant effect on the maze-learning ability of their progeny (Newcombe and McGregor, 1964). Also, a significant increase in skeletal abnormalities has been found in the offspring of irradiated mice (Ehling and Randolph, 1962; Ehling, 1964). But experiments that have utilized radiation to premeiotic germ cells have, in general, been inconclusive, even when several generations have been examined. The inconclusive nature of the experiments should not be regarded as evidence against the existence of radiation-induced effects, but rather as an indication of the difficulty of precise study of such effects. Consistent with this thesis is the absence thus far of conclusive evidence of any substantial increase in overt genetic effects in the offspring of the Japanese A-bomb survivors (United Nations Scientific Committee on the Effects of Atomic Radiation, 1962).

4.8 Quantitative assessments of the genetic risk to human beings from radiation exposure are difficult because of the fact that almost all the information comes from experimental animals.

The problems of differential cell sensitivity, dose-rate effects, intercell selection, and the other complications all make it very difficult to assess the full impact of radiation even on a mouse population. In man the problem is compounded by the fact that the social impact of mutation depends on a number of uniquely human factors. The variety of effects that can occur as a result of mutation and chromosomal anomaly, and the incidence of these, have been discussed repeatedly (National Academy of Sciences-National Research Council, 1956, 1960; Medical Research Council, 1956, 1960; United Nations Scientific Committee on the Effects of Atomic Radiation, 1962; Federal Radiation Council, May, 1962).

4.9 In choosing the 10 R limit for population 30-year exposure, the Genetics Committee thought, for a variety of reasons, that doses below this level, although not desirable, would be acceptable if there were compensating benefits. It was also thought that the chance of genetic damage of such a nature as to affect the individual (by being expressed in his immediate family) would be acceptably small if the individual dose were kept below 50 R. The reasons for this conclusion still seem to be valid.

4.10 In reference to the dose of 25 rads of interest in this report, it may be noted that this is below the level that the Genetics Committee set for an individual dose, and would presumably be re-

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ceived at dose rates lower than those which had to be considered by that Committee. Furthermore, as long as the group exposed is small, the average dose to the population will not be greatly changed. Therefore, genetic considerations are not likely to be limiting if the exposed group constitutes a small fraction of the population.

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SECTION V

SOMATIC EFFECTS

Effects on Embryological Development

5.1 A single, brief exposure of the mammalian fetus to as little as 10 or 20 R of X-rays has been noted to cause abnormalities of brain development carrying over into adult life (Hicks and D'Amato, 1963). Developmental skeletal abnormalities have been

increased in mice genetically disposed to show them following a single, brief X-ray exposure at even the lowest dose level tested, namely 25 R (Russell, 1957).

5.2 Protracted exposure of mice, on the other hand, to a continuous dose of 12 R a day throughout the first 15 days of pregnancy has been observed to produce no gross anatomical abnormalities in the exposed offspring, although it shortened the reproductive life of the exposed female young (Russell et al., 1960). Exposure of pregnant rats to 1 R a day for 20 days has been reported to cause detectable changes in the development of behavior in the exposed offspring (Piontkovsky and Semagin, 1961; Piontkovsky, 1961); i.e., retarded development of conditioned reflexes and poorly retained reflexes. The brains of the affected offspring were said to be smaller than normal.

5.3 Effects of strontium-89 on development have been observed in one study with mice (Finkel, 1947). The doses injected were relatively high, 1 to 10 microcuries per gram weight in the pregnant animal. Strontium-89 was deposited in the bones of the offspring. The higher doses of strontium-89 resulted in stillbirth. At lower doses of strontium-89, retarded growth, malformation of the skeleton, anemia, and osteogenic sarcoma were noted.

5.4 Malformations have been increased in frequency in the human embryo and fetus by relatively large doses of radiation delivered at high dose rates. For example, an abnormally high incidence of microcephaly with mental retardation has been noted among Japanese children exposed in utero to the atomic bomb (see Burrow et al., 1964). From the meager data available, however, it is not possible to determine the relationship between the risk of severity of such effects and the radiation dose.

5.5 On the basis of a small study, it has been suggested that heterochromia of the iris may be related to prenatal diagnostic X-ray exposure (Lejeune et al., 1960), but in a subsequent, much larger study, the suggestion was not confirmed (Cheeseman et al., 1963). At the present time it seems unlikely that there is a causal association between prenatal X-ray exposure and heterochromia iridia, although the possibility of a much lower order of association than that originally reported cannot be unequivocally excluded.

Prenatal X-ray Exposure and Childhood Cancer

5.6 An association between prenatal X-ray exposure and the incidence of cancer in childhood has been reported, which is important in the present context because of the relatively small dose of radiation involved.

5.7 The original observation (Stewart et al., 1956; Stewart et al., 1958) was that about twice as many mothers of children who died of cancer reported diagnostic X-ray examination during the relevant pregnancy as did mothers of normal children. The significance of the finding was widely questioned because of the investigators' reliance on mothers' recall of X-ray exposures that may have occurred up to 10 years before. However, a number of subsequent studies, utilizing different methods, have confirmed the observation, although at a somewhat lower level of association than the original study (Ager et al., 1962; Ford et al., 1959; Kaplan, 1958; MacMahon, 1962; Polhemus and Koch, 1959). Some regative studies have been reported (Court-Brown et al., 1960; Kjeldsberg, 1957; Lewis, 1960; Murray et al., 1959; Wells and Steer, 1961), but all are based on small numbers of cases and no published study reports results significantly different (statistically speaking) from the mean value quoted below.

5.8 No factor which might increase both X-ray exposure and cancer rates and thus produce a spurious association has been definitely implicated, although most of the obvious possibilities have been explored.

5.9 If the association is assumed to be one of cause and effect, the maximum likelihood estimate of the cancer risk associated with prenatal X-ray exposure can be calculated. Such an estimate, based on pooled data from all published series (MacMahon and Hutchison, 1964), calculated the cancer risk of the exposed to be 40 percent higher than that of non-exposed children, the 5 percent confidence limits of this figure being 20 and 60 percent.

5.10 The X-ray dose involved in these exposures is not known precisely. For comparable procedures in Great Britain in 1957-58, the Adrian Committee reported a mean dose of 0.8 R to the maternal gonad, but with a range among hospitals from 0.03 to 10 R. It is likely that mean doses in the earlier periods included in the cancer studies were larger—perhaps between 2 and 5 R. The fetal exposure is essentially to the whole body.

5.11 An assumption of linearity in the dose-response relationship at a value of 2 leukemias per million exposed per year per rad, commonly quoted for the relationship in adults, would underestimate the frequency of leukemias associated with fetal irradiation by a factor of between 2 and 5. Associated with fetal irradiation, there are, in addition, other types of cancer (tumors of brain, kidney, and other sites) which have not so far been linked to radiation exposure in adults. In all, between 4 and 10 times as many cancer cases (leukemia and other cancers) are associated with this type of antenatal exposure as would be postulated by as-

suming an incidence of 2 cases (leukemia only) per million per year per estimated rad.

5.12 These data relate to what is essentially a single exposure—the effect of fractionation is unknown. Also equivocal is the effect of duration of gestation at exposure, the great majority of these procedures being conducted in the last trimester of pregnancy. One large study (Stewart et al., 1958) suggested higher risks for children exposed early in pregnancy, but the finding has not yet been confirmed by other work (MacMahon, 1962).

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Effects of Postnatal Exposure

Induction of Leukemia

5.13 An increased incidence of leukemia, a relatively rare disease in man, has been found in various population groups exposed to external radiation in childhood or adult life, as well as in utero. Data on animals given bone-seeking radionuclides indicate that malignancies of hemopoietic tissues may result from internal, as well as external, radiation exposure.

5.14 The incidence of leukemia in man has been observed to be increased after a single dose of external radiation to the whole body at a level of approximately 100 rads or more (Folley et al., 1952; United Nations Scientific Committee on the Effects of Atomic Radiation, 1964) and after irradiation of an appreciable portion of the bone marrow with approximately 500 rads or more (Court-Brown and Doll, 1959).

5.15 In the Hiroshima A-bomb survivors, the incidence of leukemia increased progressively to a maximum between the 4th and 7th years after exposure and declined thereafter, but it was still significantly above the control level in 1960. The incidence of leukemia integrated over the first 15 years after irradiation increased with dose at dose levels greater than approximately 100 rads. Although the exact relationship between dose and incidence has not been established, the increase above the natural incidence averaged over the 15-year period can be calculated to be about 1 to 2 cases per million persons per rad for each year at risk after exposure to 100-500 rads or more. It is not known how long the annual incidence will continue to exceed normal.

5.16 The risk estimate given above cannot be applied to the population at large without reservation. The survivors in Japan were heavily selected as a result of the early lethal effects of the exposure; thus the irradiated survivors may not represent the entire population with respect to susceptibility to leukemia induction. In

addition, the increase in incidence more nearly approximated a constant multiple of the natural age-dependent incidence than a constant number of excess cases. Hence, the estimate is probably too high in adolescent children and may be too low in adults; additional data will be needed for accurate estimation in limited age groups.

5.17 External radiation delivered at low dose rates to the entire body or to a large segment of the bone marrow has also appeared to be leukemogenic to human populations at high dose levels (United Nations Scientific Committee on the Effects of Atomic Radiation, 1964). Nevertheless, uncertainties about the influence of dose rate, fractionation, and total dose under these conditions make it impossible at present to estimate quantitatively the probability of leukemia under circumstances other than short-term exposure to high doses. Long-term exposure is less leukemogenic than short-term exposure for the same total dose if the dose-rate dependency observed in animals (Mole, 1962; Upton, 1964) also exists in man.

5.18 The types of leukemia showing a relationship to radiation exposure are the acute forms and the chronic granulocytic form (Moloney, 1959; United Nations Scientific Committee on the Ef-

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fects of Atomic Radiation, 1964). Related diseases also reported to occur more often than normal in irradiated populations include multiple myeloma (Lewis, 1964; Anderson and Ishida, 1964), aplastic anemia (Lewis, 1964), myelofibrosis with myeloid metaplasia (Anderson et al., 1964), Hodgkin's disease (Anderson and Ishida, 1964), and lymphosarcoma (Anderson and Ishida, 1964). The commonest form of chronic leukemia in the United States and the United Kingdom is the lymphocytic form, the incidence of which has increased during recent years; however, no correlation has been observed between previous radiation exposure and the frequency of this disease.

5.19 The induction of leukemia and lymphomas in animals by external radiation has been amply documented, but the dose-response relation is not precisely known, and there is no conclusive evidence that the frequency of these diseases is increased by less than 50 rads (United Nations Scientific Committee on the Effects of Atomic Radiation, 1962).

5.20 It is reasonably well established that iodine-131 administered in doses greater than 1 curie (e.g., for therapy of carcinoma of the thyroid) may be leukemogenic to man (Moloney, 1959; United Nations Scientific Committee on the Effects of Atomic Radiation, 1964). Hemopoietic tissue receives a considerable radia-

tion dose in the course of such therapy; i.e., of the order of 1.0 rad per millicurie (Sinclair, 1957; Halnan and Pochin, 1958).

5.21 It has not been established whether internal emitters selectively deposited in bone (bone-seekers) are leukemogenic in man. The apparent increase in leukemia among patients with polycythemia vera (Osgood, 1964) treated with phosphorus-32 is suggestive of this but not conclusive in the absence of an adequate control population. Leukemia has been reported in dial painters and other individuals who received radium internally some years previously. Hasterlik et al. (1964) have reported two cases (death certificates) of acute myelocytic leukemia in approximately 400 radium patients, one of which was confirmed by their study of the original blood smear made shortly before the patient's death in 1931. An additional case of myelocytic leukemia has been reported from a series of 150 radium patients studied in New Jersey; the body burden of radium-226 was less than 0.0042 microcurie. No leukemia has been found in a series of 237 individuals exposed to radium studied by Evans and colleagues in Boston.

5.22 Although the human data in themselves are not sufficient to establish that exposure to radium or other bone-seeking isotopes will lead to an increased leukemia incidence in man, large amounts of strontium-90 have been reported to cause leukemia in mice (Watanabe, 1957; United Nations Scientific Committee on the Effects of Atomic Radiation, 1962) and other animals. Furthermore, the onset of leukemias and lymphomas in mice has been found to be hastened with a dose of strontium-90 (8.9 microcuries per kilogram) which did not detectably induce bone tumors or shorten the life span (Finkel, 1959).

5.23 Preliminary results from experiments with dogs and swine (Andersen and Goldman, 1962; McClellan and Bustad, 1964; Andersen and McKelvie, 1964; Biskis et al., 1964) suggest that strontium-90 may induce leukemia and possibly other neoplasms of

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reticular tissues in these species also, but the data are too limited as yet to disclose dose-effect relationships. The lowest average dose at which such an effect has been observed thus far has been estimated to be 900 rads, delivered throughout life to the skeleton of a dog by strontium-90 administered daily in the diet. The animal in question died at 192 days of age, after being fed since birth a ration containing strontium-90 and after receiving strontium-90 in utero from its dam, which was fed the same ration (Andersen and Goldman, 1962).

5.24 The development of leukemia in 6 chronically strontium-90 treated dogs having cumulative mean skeletal doses of 900-4000

rads and in 3 chronically strontium-90 treated swine having cumulative mean skeletal doses of 16,000-18,500 rads contrasts with the absence thus far of bone tumors at these levels and the absence of leukemias at higher dose levels, where instead bone tumors were induced in high incidence (McClellan and Bustad, 1964; Andersen and Goldman, 1962; Andersen and McKelvie, 1964; Biskis et al., 1964). This dose and dose rate-dependent difference in the types of neoplasms cannot be explained. It may, however, be related to differences in (1) radiation dose rate, (2) radiation dose distribution, (3) age at exposure, (4) latent period of leukemias as opposed to bone tumors, or (5) other factors. Although the apparent differences may not be real, they imply that animals exposed chronically to strontium-90 from infancy may develop leukemia at dose levels lower than those causing a comparable increase in the incidence of bone neoplasms.

Induction of Bone Tumors

5.25 Therapeutic external irradiation has been followed in several dozen human patients by development of osteogenic sarcoma, the neoplasm in most cases arising at the site of a pre-existing benign tumor or chronic inflammation (Bloch, 1962). The latent period preceding the appearance of sarcomas has ranged from less than 3 to over 30 years (Bloch, 1962). In some instances, gross radiation damage to the bone was evident before the neoplasm appeared, but in other instances this was not detected. The relation between the incidence of sarcomas and the radiation dose cannot be inferred from the information at hand, but 3000 rads is the lowest dose thus far associated with the formation of such a tumor in the absence of factors known to predispose to neoplasia (Jones, 1953).

5.26 Doses of external radiation down to 250 R have been reported to induce osteogenic sarcomas in laboratory animals (Koletsky and Gustafson, 1955; Binhammer et al., 1957; Cater et al., 1959; Finkel et al., 1964a, 1964b); however, the natural frequency of such tumors is higher in these animals than in man, suggesting that their susceptibility to radiation neoplasia may also be higher. Precise information on dose-response relationships is not available for any species.

5.27 An increase incidence of benign bone tumors (i.e., osteochondromas) has been noted in children irradiated over the chest with doses ranging from 60-600 R (Pifer et al., 1963). The few tumors observed do not indicate the quantitative relationship between incidence and dose (Toyooka et al., 1963) but they suggest

that susceptibility to these effects may be higher in children than in adults.

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5.28 The induction of bone tumors in man by internally deposited radionuclides is documented by an increase in the incidence of osteosarcomas with increasing content of radium in the skeleton (Marinelli, 1958; Hasterlik et al., 1964). The available data imply that the tumor incidence more nearly approximates a sigmoid than a linear function of the terminal radium burden (Marinelli, 1958), in keeping with comparable data from experimental mice (Finkel, 1956), but the data are too scanty to define precisely the dose-response relation. There is no evidence that the induction of malignancy is associated with a terminal body burden of less than 0.4 microcurie of radium (United Nations Scientific Committee on the Effects of Atomic Radiation, 1964). Analysis of the human data is complicated by the fact that measurements of the terminal body burden have been made decades after incorporation of vastly larger amounts of radium and mesothorium into the skeleton, with the result that estimation of the original body burden, and hence of the total dose to the bone, involves assumptions about the fraction excreted (Norris et al., 1955). Assessment of the relevant tumorigenic dose is further complicated by large variations in the macroscopic and microscopic distribution of radium within the skeleton, the dose to different areas of bone varying by an order of magnitude or more (Lamerton, 1960; Rowland, 1963).

5.29 Oncogenic effects of bone-seeking radionuclides other than radium have been documented thus far only in laboratory animals, and results of such studies are as yet fragmentary for species other than the mouse (see Andersen and Goldman, 1962; Casarett et al., 1962; Dougherty, 1962). In CF_1 mice, the oncogenic potency of various radioelements, as compared with radium per microcurie injected, has been tentatively estimated as follows: radium-226, 1.0; strontium-90, 0.2; strontium-89, 0.1; calcium-45, 0.05; and plutonium-239, 20 (Finkel, 1956). These comparative potency values may not be valid at low levels of oncogenic effect, however, because the dose-effect curves for the various nuclides are complex in shape and not parallel. Furthermore, since the values were based on comparison of the effects of the several nuclides in relation to the respective amounts of radioactivity injected rather than in relation to the respective doses of radiation to bone, they may not be applicable to animals that differ from mice in the geometry, growth, and metabolism of their bones (Finkel, 1958). It has been calculated for example, that the mouse skeleton absorbs only 32 percent of the available energy from strontium-90 plus yttrium-90

contained therein, whereas the larger skeleton of the dog absorbs 79 percent and that of man 88 percent (Parmley et al., 1962). On the basis of the mean dose to bone, plutonium-239 and radium-226 appear significantly more effective than strontium-90 in inducing osteosarcomas in dogs (Dougherty, 1964), but the data are preliminary and the basis for the differences remains to be determined; i.e., it is not clear to what extent the differences are attributable to the higher effectiveness of the alpha particles from plutonium-239 and radium-226, as compared with the beta particles from strontium-90 plus yttrium-90, or to what extent the differences are attributable to other factors, such as distribution of the radiation in bone.

5:30 The influence of time-intensity factors in the induction of bone tumors is uncertain (Finkel et al., 1964b; Lamerton, 1960; Lamerton, 1959). The relative tumorigenic effectiveness of multiple injections of a radionuclide, as compared with a single injection of the same total dose, is difficult to evaluate because of

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differences in the distribution of the radioactivity within bone under the different conditions of administration. There is evidence, however, that irradiation at a low dose rate, through gradual incorporation of strontium-90 into the skeleton from the diet over a greatly protracted interval is substantially less oncogenic than irradiation at higher rates (Finkel et al., 1960).

5.31 The effects of physiological variables on susceptibility to induction of bone tumors are, likewise, poorly known. Strain and species variations in susceptibility among rodents are marked and unexplained (Lamerton, 1960; Law, 1960; Finkel et al., 1961). Age variations, similarly, have been noted in the carcinogenic response of animals to bone-seeking radionuclides, but it is not yet possible in such instances to determine the extent to which the observed variations may be ascribed to differences in uptake and retention of the nuclide and to what extent they reflect differences in radiosensitivity (Lamerton, 1960).

Tumors of the Thyroid

5.32 The relationship between irradiation and induction of thyroid tumors was evaluated in 1962 by a panel of the National Academy of Sciences-National Research Council (Federal Radiation Council Report *Pathological Effects of Thyroid Irradiation,* 1962). The conclusions reached at that time have been strengthened and extended by findings in the interim (Saenger et al., 1963; Lindsay and Chaikoff, 1964; Pifer and Hempelmann, 1964).

5.33 The situation at present may be summarized as follows: external radiation delivered to the thyroid at dose levels above 100 rads has been correlated with the appearance of thyroid nodules in human beings. In some studies, the incidence has appeared to be proportional to dose within the range of approximately 100 to 300 rads, from which the risk over this dose range has been estimated to be 1 per million person-years per rad during at least the first 16 years after exposure (United Nations Scientific Committee on the Effects of Atomic Radiation, 1964). It has been suggested that external radiation localized to the thyroid region alone (Pifer and Hempelmann, 1964) and radiation from radioactive iodine (Doniach, 1963) are less tumorigenic to the thyroid than is external radiation not so sharply localized. These studies imply that exposure of tissues other than the thyroid contributes indirectly to thyroid neoplasia or that the tumorigenic effect decreases with decreasing dose rate, or both; however, these questions remain open at present. The bulk of the thyroid tumors associated to date with radiation has occurred among people exposed to X-rays during childhood.

Other Neoplasms

5.34 Tumors of epithelial and fibro-vascular tissue adjoining cranial bone have been associated with irradiation from bone-seeking radionuclides in laboratory animals and human beings (e.g., Casarett et al., 1962; Hasterlik et al., 1964). Such tumors include squamous cell carcinomas of the paranasal sinuses, which are rare in the general population. Although the increased frequency of these neoplasms is attributable to radiation emanating from radioisotopes deposited in adjacent bone, quantitative dose-incidence data for such growths are lacking.

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5.35 Tumors of tissues other than those mentioned in the foregoing paragraphs have been induced by irradiation, but the relative increase in their incidence appears to have been small in man. Therefore, although quantitative estimates are not possible, it is unlikely that the over-all risk of malignancy from whole body irradiation, as in the case of internally deposited cesium-137, will exceed by any large factor the risk of leukemia, thyroid tumors, and skeletal neoplasms (United Nations Scientific Committee on the Effects of Atomic Radiation, 1964). By the same token, the over-all risk of malignancy from exposure to internally deposited radioactive strontium is unlikely to exceed greatly the risk of skeletal tumors, leukemia, and cancers of soft tissue adjoining cranial bone.

Other Somatic Effects in Children and Adults

5.36 Although a number of permanent effects other than malignancy have been observed following postnatal exposure to radiation, few are of concern at low dose levels. One of these is nonspecific deterioration and life shortening from causes other than neoplasia. Data on animals indicate a dose-dependent shortening of life-span. Data on human beings (Seltser and Sartwell, 1964) are, likewise, consistent with a life-shortening effect of irradiation, but the relation to dose cannot be estimated from the limited information available at this time. It is clear that the effect is so small, however, as to be detectable only in sizable populations and at dose levels exceeding 100 rads.

5.37 Effects on the growth and development of bone and teeth are well known (see Ellinger, 1957). Stunting effects are dose-dependent and vary inversely in relation to age and maturity. Effects of this sort have been reported in Japanese surviving exposure to A-bomb radiation in childhood (Greulich et al., 1953). Such effects have not been documented, however, at dose levels below 100 rads. Few data are available on their induction by administration of radionuclides, although impaired growth and deformation of bone have been noted in dogs with burdens of 300 microcuries of strontium-89 at birth and in mice under similar conditions (Finkel, 1947, and personal communication).

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SUMMARY AND CONCLUSIONS

The possible biological effects of irradiation from internally deposited strontium-89, strontium-90, and cesium-137 have been reviewed. Particular consideration has been given to effects that might result from uptake of any one of these isotopes by a small fraction of the population over a short period of time under conditions leading to a cumulative average absorbed dose of the order of 25 rads or less to any tissue of the body within about one year after contamination.

Because of differences in the behavior of radioactive strontium and radioactive cesium in the body and differences in the radioactive decay rate of their several isotopes, the implications of internally deposited radioactive strontium differ from those of

radioactive cesium. Cesium-137, a beta-emitter, is distributed relatively uniformly throughout soft tissues and gives rise to a gamma ray-emitting daughter element, resulting in irradiation of essentially the whole body. Strontium-89 and strontium-90, on the other hand, are localized chiefly in the skeleton and teeth and give rise to energetic beta-rays, which are considered to affect mainly the bone, bone marrow, and adjacent structures. Tissues remote from bone, such as the gonads, receive comparatively little irradiation from radioactive strontium, with the result that effects on these tissues are regarded as non-limiting under the conditions of interest in this report.

In the absence of direct observations of effects from internally deposited radioactive cesium and strontium in human beings, the evaluation has been based of necessity on extrapolation from the effects of these radionuclides in experimental animals and the effects of irradiation from other sources in man. The observed effects have resulted, however, from irradiation under conditions that do not precisely duplicate those associated with deposition of radioactive cesium and strontium in the human body under the hypothetical conditions of interest. Hence, the conclusions derived herein are considered tentative.

Risks of chief concern in the case of irradiation from internally deposited cesium-137 under the conditions in question are considered to be the following:

1. *Carcinogenic effects on the exposed embryo and fetus*

An association between cancer incidence in childhood and antenatal diagnostic X-ray examination has been reported, which implies that the frequency of cancer may be increased by a single exposure of the fetus to high dose-rate whole body radiation at dose levels of 5 rads or less (see paragraphs 5.6–5.12). If this interpretation is verified, similar carcinogenic effects on the fetus and embryo might result from 25 rads delivered over a period of weeks by cesium-137, but the degree to which the incidence of any such effect would be altered by the relatively low dose rates in question cannot be determined from the data now available. The reported association between prenatal exposure and cancer involves a dose of radiation smaller than that associated with any other comparable injury in man. It suggests that sensitivity to radiation carcinogenesis may be several times higher before birth than later in life. At present, therefore, the fetus is considered to represent the critical segment of the population for a given dose from cesium-137 under the conditions of interest in this report.

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2. *Effects on the development of the exposed embryo and fetus*

Disturbances of growth have been noted in developing embryos of experimental animals after a single X-ray dose as low as 10-20 rads. Effects on the development of the human embryo and fetus might result, therefore, from comparable doses delivered by cesium-137, although it cannot be predicted from the evidence at hand what effects, if any, would occur at the low dose rates in question, particularly since the total dose received at any given stage in development would be small. The frequency and severity of any such effects would be expected to depend on the age of the embryo at the time of exposure.

3. *Carcinogenic effects on the exposed child and adult*

A dose-dependent increase in the incidence of leukemia, thyroid tumors, and, to a lesser extent, other neoplasms has been observed in man at dose levels of about 100 rads and more. The precise way in which the incidence of these effects is related to the dose and dose rate is not known, and it is not clear whether smaller amounts of radiation can augment the risk of cancer. The excess incidence of cancer demonstrably associated with high doses, however, is of the order of one additional neoplasm per million person-years at risk per rad, which can reasonably be assumed to represent an upper limit of any effect that might occur at lower doses and dose rates.

4. *Genetic effects*

It is assumed that any increase in radiation exposure to the germ cells causes some increase in the mutation rate. Hence, heritable effects may be expected to result from 25 rads under the conditions in question. However, 25 rads is below the limit of 50 rads for an individual recommended by the National Academy of Sciences-National Research Council Committee on Genetic Effects of Atomic Radiation in 1956. Furthermore, the radiation would presumably be received at dose rates lower than those which had to be considered by that Committee and would therefore be less damaging. Also, as long as the group exposed is small, the average dose to the population will not be greatly changed. Therefore, genetic considerations are not likely to be limiting if the exposed group constitutes a small fraction of the population.

Risks of chief concern in the case of irradiation from strontium-89 and strontium-90 under the conditions in question are considered to be the following:

1. *Carcinogenic effects on the exposed embryo and fetus*

The embryo does not take up radioactive strontium in its bone until the second trimester, when its osseous tissues begin to mineralize, but thereafter it incorporates the element throughout its skeleton. Indications that susceptibility to leukemogenesis by X-rays may be 2–5 times higher during the fetal period than in later life, and that fetal irradiation induces other neoplasms not known to be associated with irradiation in the adult (see paragraphs 5.6–5.12), imply that the probability of effects from a given concentration of radioactive strontium in bone may be maximal during prenatal development. On the other hand, retention of strontium may be limited by metabolic factors to a greater degree during the fetal period than later in life. Also irradiation from radiostrontium differs from X-irradiation in being concentrated in bone and bone marrow and in being absorbed during an interval of months

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rather than seconds or minutes. The extent to which these differences may reduce the leukemogenic effectiveness of radioactive strontium, as compared with that of X-rays, is not known. Thus, whether exposure in utero to radiostrontium under the conditions of interest would increase the incidence of leukemia and other cancers in the exposed child cannot be decided conclusively from existing data. The inference that the fetus is the most critical member of the population must also be considered tentative.

2. *Disturbances of skeletal growth and development in the exposed embryo and fetus*

Since skeletal abnormalities have been noted in embryos of genetically susceptible laboratory animals after a single X-ray dose as low as 25 rads, it is conceivable that some human embryos might be affected by 25 rads delivered over a period of months from internally deposited strontium-89 or strontium-90. However, mouse embryos given approximately 12 rads daily for 15 days by continuous exposure to gamma rays showed no gross defects, presumably because the radiation was less effective at the lower dose rate. Thus, it is highly questionable that such effects would occur at a total dose of 25 rads under the low dose rates in question.

3. *Carcinogenic effects on the exposed child and adult*

Radioactive strontium has been observed to induce leukemia and bone tumors in dogs and swine, but few such animals have been studied to date, and the effects have not been demonstrated at average dose levels below about 900 rads. It is not clear whether

strontium-89 or strontium-90 under the conditions of interest (i.e., 25 rads delivered over a period of months) would increase the incidence of these forms of cancer in man. Any increment above the natural incidence that might result under these circumstances would, however, be small.

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4.2d AN ESTIMATE OF RADIATION DOSES RECEIVED BY INDIVIDUALS LIVING IN THE VICINITY OF A NUCLEAR FUEL REPROCESSING PLANT IN 1968, DEPARTMENT OF HEALTH, EDUCATION, AND WELFARE, MAY 1970

FOREWORD

The recent growth in the utilization of nuclear reactors for electrical generating plants has brought with it the need for nuclear reprocessing plants that extract usable uranium and plutonium from spent fuel elements. The Bureau of Radiological Health performs a technical review and evaluation of the public health factors of all nuclear facilities and provides technical assistance to State Health departments responsible for assessing population exposure and radiation levels in the environment. The Northeastern Radiological Health Laboratory, under the aegis of the Division of Environmental Radiation, has undertaken an environmental survey of the first commercial operating fuel reprocessing plant in the United States.

The technical reports series of the Bureau's regional laboratories and its Division of Environmental Radiation is used to publish the results of research projects and technical evaluations of nuclear facilities. These reports are distributed to State and local radiological health program personnel, Bureau technical staff, Bureau advisory committee members, radiation safety officers, libraries and information services, industry, the press, and other interested individuals. These reports are also included in the collection of the Library of Congress and the Clearinghouse for Federal Scientific and Technical Information.

I encourage the readers of these reports to inform the Bureau of any omissions or errors. Your additional comments or requests for further information are also solicited.

JOHN C. VILLFORTH,
Director,
Bureau of Radiological Health.

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PREFACE

The projected increase in the utilization of nuclear power for electrical generating plants has resulted in both State and Federal public health agencies placing increased program emphasis on the surveillance of nuclear power plants. The Bureau of Radiological Health provides recommended nuclear facility surveillance program information for the guidance of health agencies. In order to provide a better technical basis for environmental surveillance recommendations, a series of field studies have been conducted at operating nuclear facilities to obtain better data on radionuclides in plant effluents and their subsequent distribution in the environment.

This field study around the Nation's first commercial nuclear fuel reprocessing plant was for the purpose of identifying the movement of critical radionuclides through the atmospheric and aqueous environments in relationship to the fuel reprocessing procedures. Technical data obtained from this study will be used to: (1) develop minimum and optimum requirements for environmental surveillance around nuclear fuel reprocessing plants, (2) designate the radionuclides and environmental pathways of greatest dosimetric significance, and (3) provide estimates and measurements of the radiation dose to populations in the area of a facility.

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Northeastern Radiological Health Laboratory.

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ABSTRACT

The public health implications associated with a nuclear facility can be best evaluated in terms of the radiation dose delivered to persons in the vicinity of the facility. This report attempts, by use of the dose commitment concept and surveillance data previously collected, to estimate radiation doses in 1968 to persons in the vicinity of a fuel reprocessing plant from ingestion and inhalation.

The dose commitment accrued in 1968 to a hypothetical "typical individual" is not thought to differ significantly from that for the average adult population in the rest of New York State and is attributable essentially to fallout. This commitment was 77 millirem from strontium 90 to the bone and 1.7 millirem whole body from cesium 137 delivered over a 50-year period.

For the hypothetical "maximum individual" the dose commitment to the bone from strontium 90 is 532 millirem and the first-year dose following ingestion is 38 millirem. The whole-body dose from ingestion of cesium 137 and cesium 134 (mostly from deer meat) is 257 millirem. Preliminary data

indicate that the external gamma dose above natural background is approximately 1.2 millirem per year to the "maximum individual." Estimated doses from tritium and krypton 85 were negligible (~2 millirem/year).

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ACKNOWLEDGEMENT

Grateful appreciation is expressed by the Environmental Radiation Activities Staff, Northeastern Radiological Health Laboratory, to the New York State Health Department and the Atomic Energy Commission who provided the radioactivity data for this report. In addition, the encouragement of Mr. Charles L. Weaver and the cooperation of the Division of Environmental Radiation, Bureau of Radiological Health, insured the successful completion of this study.

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AN ESTIMATE OF RADIATION DOSES RECEIVED BY INDIVIDUALS LIVING IN THE VICINITY OF A NUCLEAR FUEL REPROCESSING PLANT IN 1968

INTRODUCTION

The public health implications associated with a nuclear facility can best be evaluated in terms of the radiation dose delivered to persons in the vicinity of the facility. The Bureau of Radiological Health, Environmental Health Service, is at present investigating radiation levels around nuclear reactors and around a nuclear fuel reprocessing plant. Nuclear Fuel Services, Inc., processes spent fuel from nuclear reactors on a 3,300 acre site 30 miles southeast of Buffalo, in the town of Ashford, Cattaraugus County, N.Y. The company began to dissolve fuel in April 1966, and, beginning in September 1966, began discharging waste materials. Environmental surveillance around NFS has been performed since 1965 by the New York State Health Department (*1*). The AEC carries out an independent surveillance program (*2*). By 1968, meth-

odology and reporting were routine (*3*), and dosimetric calculations were made with data from this year. In addition to routine sampling, special studies on tritium (^{3}H) and krypton (^{85}Kr) in air were performed in 1967 (*4, 5*) and 1969 (*6*), and also provide basic information for this paper.

The purpose of the project around Nuclear Fuel Services (NFS) is to characterize completely the atmospheric and aqueous environments in relationship to the fuel reprocessing procedure in order to designate which radionuclides are of greatest dosimetric significance. This is being done through a series of field trips to make specific radiological measurements and through a review of previous surveillance data in an effort to extract dosimetric information. This paper describes the assumptions and procedures for determining radiation doses to persons in the vicinity of Nuclear Fuel Services during 1968 and presents and discusses these doses. Further, it relates the concentration of radionuclides in milk, drinking water, deer meat, fish, and air around NFS and their intake by humans.

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External radiation measurements are also discussed. Doses are calculated in terms of "dose commitments"; i.e., the dose delivered (in millirem) to a critical organ during a 50-year period (or during life) from a particular intake. Use of the dose commitment concept provides a means of determining the relative significance of doses due to human intake.

The internal radiation dose commitment for an individual in a population group, due to a specific radionuclide, is the product of (1) the factor for converting activity intake to dose, (2) the weight or volume intake of the media per individual per unit time, and (3) the concentration of the radionuclide per unit weight or volume of media. The dose commitment concept applied to the population of the northeastern United States for the years 1961–1968 has been described in detail elsewhere (*7*). Other investigators have employed a similar method in the estimation of population doses in the environs of a nuclear facility (*8*).

DOSE COMMITMENT FACTORS

Selection of factors for converting activity intake to dose has been previously described in detail and is beyond the scope of this presentation (*7*). However, it is pertinent to briefly discuss dose variables which influence the selection of dose commitment factors. Dose commitment factors for airborne tritium and krypton 85, which were not included in the earlier work, are presented in more detail.

Selection of factors for converting activity intake to dose requires consideration of a variety of age dependent variables such as: effective energy and half-time of the radionuclide in the organ of reference, fraction of intake reaching the organ of reference, and organ mass. Furthermore, factors employed in the calculation of radiation dose also vary depending on the mode of intake and the solubility of the radionuclide.

Selection of radionuclide and population groups for which dose commitments are calculated is constrained due to limitations in the data available from environmental networks. For complete radiological evaluation one should be concerned with all population groups, since that group subject to the greatest radiation exposure is not always immediately discernible. However, due to limitations in the availability of data, doses have been calculated for only two population groups. The first designated as a "typical individual," is a *hypothetical* adult individual ingesting "average" concentration of specific radionuclides based on local environmental surveys. The second group, represented by a *hypothetical*

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"maximum individual" is assumed to ingest half the dietary intake qualities that the "typical individual" ingests. This intake is supplemented by deer meat from animals caught onsite or near NFS and personally caught fresh fish from the mouth of Cattaraugus Creek. This assumption was made because it is unlikely that the "maximum individual" would ingest the same quantities of food as a "typical individual," and in addition, deer and fish. A more likely case would be that half his diet would be from hunting and fishing. The radionuclide content of the diet, deer, and fish, the "maximum individual" ingests is assumed to contain the "maximum" concentration of specific radionuclides. Doses from tritium and krypton for the "typical individual" are based on exposure to average air concentrations of ^{3}H and ^{85}Kr over a 168-hour week. For the "maximum individual" these doses are based on exposure to the estimated maximum annual air concentrations of ^{3}H and ^{85}Kr which are assumed to be present 1.5 km from the plant at the property line. This point being the closest that there might be an inhabited dwelling. A 168-hour per week exposure is assumed.

Although all fission products and transuranic elements may be potential human hazards under specific environmental conditions, the radionuclides ^{90}Sr, ^{137}Cs, ^{134}Cs, ^{60}Co, ^{106}Ru-Rh, ^{3}H, and ^{85}Kr are those for which data on concentrations in milk, food, and air around NFS are available. Dosimetric evaluations in this paper will be limited to these radionuclides alone.

Since radionuclides incorporated into the food chain are likely to

be soluble, this physical state was assumed for all radionuclides present in milk, food, and drinking water.

For radionuclides having short effective half-times in the organs of interest, the majority of the total dose commitment is delivered during the first year after intake. Radionuclides with effective half-times in an organ of 100 days or less (i.e., ^{137}Cs, ^{134}Cs, ^{60}Co, ^{106}Ru-Rh, ^{3}H, and ^{85}Kr) deliver 90 percent of their total deliverable dose during the first year. Therefore, for the above radionuclides, the dose delivered in the first year after intake and the dose commitment (i.e., 50 years of lifetime dose) are equivalent. For ^{90}Sr approximately 7 percent of the dose commitment is delivered in the first year after intake (*11*).

Dose factors used in this paper have all previously appeared in the published literature. The dosimetric models for ^{90}Sr, ^{137}Cs, and ^{3}H (ingestion) and the modifications necessary for application of the models to environmental radioactivity have been previously discussed in great detail (*7*). Dose commitment factors for ^{134}Cs, ^{60}Co, and ^{106}Ru-Rh also appear in the literature (*12*). The values used in a model for organ mass, effective energy and half-life and radionuclide transfer from diet to the organ of interest are those recommended by the ICRP (*13*).

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Some further explanation is required concerning the dose commitment factors for ^{3}H and ^{85}Kr in air. The major route of exposure of these radionuclides by humans is by inhalation and skin absorption for ^{3}H and by submersion in air for ^{85}Kr. The dose commitment factors used, as stated in the reference (*14*), are: $3.6 \cdot 10^{4}X$ for ^{3}H and $4.0 \cdot 10^{4}X$ for ^{85}Kr for a 168-hour week, where X is the radionuclide concentration in $\mu Ci/cm^3$. The concentration in the reference is stated in terms of $\mu Ci/cm^3$ of air and the estimated dose is calculated in rem per week. These equations are then converted to dose per year instead of dose per week ($\cdot 52$); millirem instead of rem ($\cdot 10^{3}$); and μCi/liter instead of $\mu Ci/cm^3$. When the radionuclide concentration is in terms of μCi/liter, the term X_a is used in the equation. The above conversions yield dose commitment factors for ^{3}H and ^{85}Kr of $1.87 \cdot 10^{6}X_a$ and $2.08 \cdot 10^{6}X_a$ respectively. The short biological half-times of ^{3}H and ^{85}Kr in the body make the dose delivered in the first year after exposure comprise the entire dose commitment from these radionuclides. Of course, continuous plant operation would lead to continuous exposure to these radionuclides.

Factors for relating activity intake to dose commitment, in terms of millirem dose per 50 year (or life) are presented in table 1. These factors relate activity intake to dose for a single intake

situation. A continuous intake situation can, however, be viewed as a series of discrete intakes. This is valid if variation in activity intake during the period of intake is minimal, if metabolic and ingestion factors during the period of intake and dose commitment remain constant, and if the intake period is short relative to the period for which the dose commitment is being calculated.

ESTIMATES OF DIETARY INTAKE AND EXPOSURE TIME PERIOD

Direct measurement of dietary intake is not available for populations in the vicinity of Nuclear Fuel Services. Measurement of radionuclide milk concentrations, however, provides an indirect measure of total radionuclide intake. Extensive studies in New York City indicate that in 1968 the contribution of ^{90}Sr intake from milk was 37 percent of the total ^{90}Sr intake (*15*). This relationship can then be used to estimate total ^{90}Sr intake from milk data alone. Similarly, the intake of ^{137}Cs from milk in late 1967 (Chicago) was 30 percent of the total ^{137}Cs intake in the whole diet (*16*). The intake of ^{3}H from milk to the total diet is assumed to have the same ratio as the liquid intake from milk to the total liquid intake (*9*) (i.e., 40 percent). These data are used to estimate the total dietary intake of the above radionuclides from their reported levels in milk.

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TABLE 1. FACTORS FOR CALCULATING DOSE COMMITMENTS

Radionuclide[1]	Critical organ	Mode	Dose commitment factor[2] (millirem per 50 year per μCi intake)
^{90}Sr (*7*)	Bone	Ingestion	$8.4 \cdot 10^3$
^{137}Cs (*7*)	Whole body	Ingestion	$0.06 \cdot 10^3$
^{134}Cs (*12*)	Whole body	Ingestion	$0.08 \cdot 10^3$
^{60}Co (12)	G.I. tract	Ingestion	$0.04 \cdot 10^3$
^{106}Ru-Rh (*12*)	G.I. tract	Ingestion	$0.195 \cdot 10^3$
^{3}H (*7*)	Whole body	Ingestion	0.13
^{3}H (*14*)	Whole body	Inhalation and skin absorption	$<1.87 \cdot 10^6 X_a$
^{85}Kr (14)	Whole body	Submersion in air	$<2.08 \cdot 10^6 X_a$

[1] Reference from which dose model was obtained in parenthesis.

[2] Dose commitment refers to the dose delivered (in millirem) to a critical organ during a 50-year period (or during life) from a particular intake.

[3] X_a (concentration is in terms of μCi/liter) dose is in terms of millirem delivered for the first year after exposure which in this case is analogous to the dose commitment.

Estimates of maximum and average intakes of deer meat are based on several discussions with deer hunters and reflect personal opinion. Intakes of fish also reflect conversations with local sportsmen in earlier dosimetric studies at Richland, Wash. (*10*).

These figures are in agreement with the dietary intake studies conducted by the USDA of the fish and fish products intake of commercial fishermen (*17*).

As previously stated, the "typical individual" and the "maximum individual" are presumed to be exposed to ^{3}H and ^{85}Kr concentrations for the same period of time (168 hours per week) albeit at different concentration levels.

A summary of dietary intakes and exposure periods appear in table 2.

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TABLE 2. A SUMMARY OF YEARLY DIETARY INTAKES AND EXPOSURE TIMES

Media	Typical	Maximum
Milk	310 liter	380 liter
Deer	2 kg	50 kg
Fish	5.5 kg	40 kg
Drinking water	440 liter	730 liter
Air	8,736 hours	8,736 hours
River bank	0 hours	200 hours

TREATMENT OF DATA AND LIMITATIONS

Samples for analysis of ^{90}Sr, ^{137}Cs, and ^{3}H in milk were obtained from ten farms in Cattaraugus County, N.Y. For 1968, a total of 180 samples were analyzed by the State of New York Department of Health by radiochemical and/or gamma spectrometric analysis (*1*). About one-quarter that number of public drinking water samples were analyzed in the same year by the AEC (*2*).

Analytical errors in radiochemical analysis are usually between 5 and 10 percent. Sampling errors are difficult to evaluate. However, variations in results for ^{90}Sr and ^{137}Cs in milk, averaged over the northeastern United States, yield standard deviations which are, in most cases, less than 25 percent of the mean value; although in several instances standard deviations as high as 50 percent of the reported means have been encountered (*7*). Variations in data around NFS, representing a much smaller sample size, can be expected to reflect ranges in results at least as great.

Radionuclide levels in deer samples, 14 in number during 1968, represent concentrations in the meat only. Unfortunately, due to sample preparation techniques, this is not the case for fish samples (9 during 1968), and the level represents radionuclide concentrations in whole fish. The deer meat samples were obtained from animals throughout Ashford Township; the maximum value was, however, from an animal killed onsite. All fish samples were

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caught at the mouth of the Cattaraugus Creek. In addition to ^{90}Sr and ^{137}Cs, these samples were analyzed for ^{134}Cs, ^{60}Co, and ^{106}Ru-Rh. Because ^{90}Sr tends to concentrate in bone, the whole fish sample when used to estimate dose would tend to overestimate the dose from ^{90}Sr. Tritium was not analyzed in fish flesh, and it is assumed that a reasonable estimate of its concentration in fish is the same as its concentration in surrounding water (i.e., ^{3}H in the environment and fish assumed to be in equilibrium). Doses are calculated from the average and maximum concentrations of specific radionuclides in a media over a 1-year (1968) period of time.

Airborne levels of ^{3}H in the environs of NFS were not available for 1968 and were indirectly obtained from 1967 surveys. A study during that year determined the tritiated moisture content in 700 air samples around NFS (*4*). To convert these values to ^{3}H in air, calculations were made for the weight of water in air (based on 25° C and 50 percent relative humidity) and the density of air; so that the concentrations of ^{3}H per liter of air is $1.18 \cdot 10^{-5}$ times the concentration of ^{3}H per liter of moisture. The large quantity of data from this survey was further analyzed and weighted for variations in the yearly wind rose pattern yielding an estimate of average ^{3}H concentrations over a 1-year period. An estimation of the maximum annual ^{3}H air levels present near a point 1.5 km from the plant at the property line was obtained from the above study. This is the closest habitable dwellings might be established without land sale by the plant.

Similar treatment was accorded ^{85}Kr. Average ^{85}Kr levels had been directly determined in 1968 (5 measurements) (*5*). The recent evaluations performed by the Northeastern Radiological Health Laboratory provide estimates of the maximum annual concentration to which the "maximum individual" might be exposed. This measurement was obtained for a 3-hour period during reactor fuel dissolution. Based on wind rose data, ^{85}Kr concentrations could not be constant in any single direction (octant) for more than 20 percent of the time; and this factor is also considered in estimating the maximum concentrations over a year's period of time. A yearly stability profile assumed 33 percent of the time in each of the three following stability conditions: Moderately to Extremely Stable, Slightly Stable, and Slightly Unstable. The maximum annual ^{85}Kr concentration has been estimated for a point 1.5 km from the plant at the property line.

Results of environment sampling used to calculate dose commitments appear in table 3.

TABLE 3. CONCENTRATIONS OF RADIONUCLIDES IN ENVIRONMENTAL MEDIA COLLECTED AROUND NFS IN 1968 (μCi/LITER OR μCi/kg)

Radionuclide	Media	Average	Maximum
^{90}Sr	Milk	$11 \cdot 10^{-6}$	$21 \cdot 10^{-6}$
	Deer[1]	$11 \cdot 10^{-5}$	$54 \cdot 10^{-5}$
	Fish[2]	$34 \cdot 10^{-5}$	$64 \cdot 10^{-5}$
^{137}Cs	Milk	$27 \cdot 10^{-6}$	$12 \cdot 10^{-5}$
	Deer	$13 \cdot 10^{-3}$	$67 \cdot 10^{-3}$
	Fish	$63 \cdot 10^{-5}$	$36 \cdot 10^{-4}$
^{134}Cs	Deer	$26 \cdot 10^{-4}$	$12 \cdot 10^{-3}$
	Deer	—	$90 \cdot 10^{6}$
^{60}Co	Fish	$21 \cdot 10^{-5}$	$30 \cdot 10^{-5}$
^{106}Ru-Rh	Fish	$85 \cdot 10^{-5}$	$21 \cdot 10^{-4}$
^{3}H	Milk	$<12 \cdot 10^{-4}$	$23 \cdot 10^{-4}$
	Deer	$30 \cdot 10^{-3}$	$46 \cdot 10^{-3}$
	Fish	$12 \cdot 10^{-3}$	$50 \cdot 10^{-3}$
	Drinking water	$< 3 \cdot 10^{-3}$	$10 \cdot 10^{-3}$
	Air[3]	$3 \cdot 10^{-8}$	$8 \cdot 10^{-8}$
^{85}Kr	Air	$23 \cdot 10^{-9}$	$^{4}13 \cdot 10^{-8}$

[1] Deer—meat only.
[2] Fish—whole fish.
[3] Survey carried out in 1967.
[4] Survey carried out in 1969.

Studies by the AEC (*2*) show the mean results of TLD monitoring at five locations around NFS to be less than 4 millirem [1] (at the 99-percent confidence level) above background for two monthly periods during 1968 (October 6th through November 15th, and November 15th through December 15th). One location may have been as high as 5 millirem above background [2] for an approximate 1-month period. Data supplied by New York State reported an

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average reading of 4.8 milliroentgens per month above background as measured with a pressurized ion chamber along the Cattaraugus Creek on three occasions in 1969.[3]

RESULTS AND DISCUSSIONS

The dose commitments accrued in 1968 to a "typical" and "maximum individual" around Nuclear Fuel Services are presented in table 4. The major dosimetric intake for a "typical individual" was due to ^{90}Sr and ^{137}Cs ingestion in the diet. A dose commitment from dietary ^{90}Sr of 77 millirem and from dietary

[1] Dose measured in millirads, converted to millirem by use of an RBE of one. Dose measured with shielded dosimeters and thus represent gamma dose component only.
[2] Measured with open window dosimeter, and therefore represents beta and gamma components.
[3] 6.7 microroentgens/hour × 24 hour/day × 30 days/month equal 4.8 milliroentgens/month. This is in terms of exposure dose rather than absorbed dose since the tissue equivalency of the ion chamber is not known. The AEC data are in terms of absorbed dose (*19*).

^{137}Cs of 1.7 millirem can be compared to dose commitments of 72 millirem and 1.3 millirem, respectively from the intake of these radionuclides during 1968 based on milk samples collected in other parts of New York State (362 samples). Considering analytical and statistical variations in the data, the dose commitment from diet to the "typical individual" around NFS does not differ significantly from that of the average adult population of the rest of New York State and can be attributed largely to fallout. The dose commitment from other radionuclides to a "typical individual," including ^{3}H and ^{85}Kr in air, was less than 2 millirem. When one considers the addition of local fish and deer meat to the diet, it is observed (from table 4) that the ^{90}Sr dose commitment to the "typical individual" is increased by 20 percent and the ^{137}Cs dose commitment doubled.

As previously noted, except for the dose commitment from ^{90}Sr, all of the dose commitments from other radionuclides are essentially delivered in the first year after intake. The total dose delivered in the first year after intake to a "typical individual" is low compared to the Federal Radiation Council recommendation for a *suitable sample of the population* (500 millirem per year to bone and 170 millirem per year to the whole body) (*19*). The total dose for a "typical individual" is approximately 1 percent of the FRC's Radiation Protection Guide for bone and less than 3 percent of the Guide for the whole body.

The dose commitments in 1968 were in the same dosimetric range as doses from natural radioactivity (80 to 200 millirem per year), or approximately 2 percent of the dose commitment from natural radioactivity (5,000 millirem in 50 years) (*20*). This is consistent with data on studies of population in the northeastern United States which found the ^{90}Sr bone dose commitment from fallout over a 7-year period to be 10 percent of the 50-year natural radiation dose (*7*).

TABLE 4. DOSE COMMITMENT ACCRUED IN 1968 IN THE VICINITY OF NUCLEAR FUEL SERVICES

Radionuclide	Critical organ	Media	Dose commitment[1] (millirem) Typical individual	Maximum individual
^{90}Sr[2]	Bone	Diet[3]	77	90
		Deer	1.9	227
		Fish	16	[4]215
^{137}Cs	Whole body	Diet	1.7	4.5
		Deer	1.6	[5]200
		Fish	0.2	8.6
^{134}Cs	Whole body	Deer	0.4	48
^{60}Co	G.I. tract	Deer	<0.01	0.2
		Fish	0.05	0.5
^{106}Ru-Rh	G.I. tract	Fish	0.9	16.4
^{3}H	Whole body	Diet	<0.1	0.3
		Deer	0.1	0.3
		Fish	<0.01	0.3
		Drinking water	<0.17	1.0
		Air (inhalation and skin absorption)	<0.05	0.1
^{85}Kr	Whole body	Submersion in air	0.05	0.3

[1] Dose per 50 years or per lifetime.

[2] For ^{90}Sr $\sim$ 7 percent of the dose commitment to bone delivered is delivered during the first year after intake:

Diet: 5.4 millirem (typical) and 6.3 millirem (maximum).

Deer: 0.1 millirem (typical) and 16 millirem (maximum).

Fish: 1.1 millirem (typical) and 15 millirem (maximum).

For other radionuclides >90 percent of the dose delivered in the first year after intake.

[3] Diet intake indirectly determined through use of radionuclide value reported in milk.

[4] Represents whole fish. The majority of ^{90}Sr concentrates in bone which is usually considered inedible. Therefore the dose commitment may represent a high estimate.

[5] From sample caught onsite.

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From table 4 it can be seen that for the "maximum individual" the dietary ^{90}Sr and ^{137}Cs dose commitments in 1968 are higher than for the "typical individual," even though he was assumed to have half the dietary intake (in terms of quantity). This is due to an increase in the maximum concentrations of ^{90}Sr and ^{137}Cs in milk when compared to the average concentrations. More significantly, the ingestion of deer meat and fish increased the dose commitments to the "maximum individual" from ^{90}Sr and ^{137}Cs, and also from ^{134}Cs and ^{106}Ru-Rh.

The additional dose from ^{60}Co is minor. In the case of the "maximum individual" his total dose commitment accrued in 1968 to bone from ^{90}Sr is 532 millirem. However, this includes analysis of whole fish which would tend to overestimate ^{90}Sr intake. To the

whole body from ^{137}Cs and ^{134}Cs it is 257 millirem based on meat from a deer trapped onsite. In the first year following intake, the ^{90}Sr dose would be 38 millirem or less than 3 percent of the dose recommendations as they apply to the *maximum exposed individual.*[4] The whole-body dose from ingestion to the "maximum individual" is estimated to be 50 percent of the dose recommendations for the *maximum exposed individual.* In addition to the above doses the "maximum individual" might receive a 17 millirem dose to the gastrointestinal tract, the majority of it due to ingestion of ^{106}Ru-Rh in fish. Assuming the "maximum individual" ingested 50 kg of deer meat and 40 kg of fish per year, the data suggest that the maximum intake of deer meat be limited to about 100 kg of deer meat and 300 kg of fish per year. The suggested allowable consumption agrees with recommendation made by others for deer meat (*21*). It is highly unlikely, based on diet studies, that the allowable intake of fish would ever be consumed.

The contribution of ^{3}H to the whole-body dose commitment of a "maximum individual," both from ingestion and air exposure is minor compared to the above doses. It amounts to 2 millirem, the majority of which is accrued via drinking water. The ^{85}Kr dose due to air submersion is 0.3 millirem. This dose must be considered in light of the assumptions for wind direction, point of exposure, and period of exposure made above.

Data on external radiation exposure indicate a mean gamma dose around NFS of 4 millirem per month above background. This would amount to an additional whole-body exposure of approximately 1.2 millirem for the "maximum individual" who might spend 200 hours per year fishing. This dose is, because of its mode of measurement, mostly gamma and probably results from stream and silt contamination by gamma emitting radionuclides.

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The above discussion is limited to estimates of dose commitments accrued and avoids delineation of the size of the population at risk. Some preliminary data are available which provide a general idea of the size of the populations involved. Census data (1960) indicate populations of approximately 6,000, 16,000, and 170,000 persons living within a 5-mile, a 10-mile, and a 25-mile radius of the plant respectively (*24*). Perhaps more significant are data available on the number of hunters and fishermen in the area. It

[4] The FRC recommendation for the average of a suitable sample of exposed population group is interpreted to apply to the maximum permissible per capita annual dose received by the public. The FRC recommendation for individuals is interpreted to apply to the *maximum exposed individual.* For bone this is 500 millirem/year versus 1,500 millirem/year (*19*). The AEC regulation limit of 500 millirem/year whole body to any individual is interpreted to apply to the *maximum exposed individual* (22,23).

is estimated by the New York State Health Department that three to four dozen hunters are present near the site during hunting season and less than one dozen at other times (*25*). A survey performed by the Conservation Officers of Regions I and II, New York State Conservation Department (*25*) during three week days and three Saturdays and Sundays in July-August 1969 indicated heavy fishing pressure in the Springville area (approximately 6 miles from the site) and near the inlet to Lake Erie (approximately 25 miles from the site) when compared to other sites fed by the Cattaraugus Creek. Most fish caught were for personal consumption. At the first site noted above 44 persons were fishing during the survey period, averaging 4 to 10 fishing trips per year. This survey indicated one individual fishes 180 days per year and that maximum consumption might be as high as 160 kg per year. At the second site mentioned 62 persons were fishing during the survey period, averaging 10 trips per year although many individuals averaged 30 to 40 trips per year. It may be expected that more intense fishing pressures occur during the April and May trout fishing season. Furthermore, since the survey covered a short period of time, yearly figures might differ. In any case, the above data, while valuable does not definitively evaluate the size of the populations described in this report.

SUMMARY

The dose commitment concept when applied to a "typical individual" and "maximum individual" in the vicinity of Nuclear Fuel Services provides a simple means of determining significant environmental surveillance data. Based on surveys carried out by the New York State Department of Health, the Bureau of Radiological Health, U.S. Public Health Service, and the Atomic Energy Commission, the dietary dose to the "typical individual" around NFS in 1968 is not thought to differ significantly from that for the average adult population of the rest of New York State and was attributable essentially to fallout. This dose commitment (77 millirem) was approximately 2 percent (in one year) of the dose commitment from natural radioactivity over a 50-year period. When ingestion of typical amounts of deer and fish were added to the diet, the dose delivered in the first year after intake was approximately 1 percent of the FRC recommendations for bone dose (500 millirem per year) and 3 percent of their recommendations

for whole-body dose (170 millirem per year). The presence of Nuclear Fuel Services, based on data presently available, did not

significantly increase the radiation dose to the "typical individual" in 1968 above that due to fallout and natural radiation.

The "maximum individual" was assumed to obtain half his radionuclide intake from a diet containing maximum amounts of specific radionuclides as well as ingesting 50 kg of deer meat and 40 kg of fish per year. For the "maximum individual" the first year dose following ingestion is 38 millirem to the bone from ^{90}Sr or 3 percent of the AEC Regulations.[5] The whole-body dose from ingestion of ^{137}Cs and ^{134}Cs (mostly from deer meat) is 257 millirem or 50 percent of the AEC Regulations. These data suggest that in order not to exceed the AEC Regulations deer meat intake be limited to 100 kg per year. Preliminary data indicate that the external gamma dose above natural background is approximately 1.2 millirem per year to the "maximum individual."

The dose from ^{3}H to a "maximum individual" was 2 millirem while that to the "typical individual" around NFS was negligible. The whole-body dose from ^{85}Kr in air to a "maximum individual" was 0.3 millirem and that to the "typical individual" 0.05 millirem.

Comparisons of dose commitments to FRC recommendations and AEC Regulations raise questions concerning the existence of the *hypothetical* "typical" and "maximum" individuals, the size of the population at risk fitting these categories, and the suitability of using established guidelines for comparison purposes, especially when population groups are ill defined. These questions, together with knowledge about dietary and living habits of populations at risk, require a more definitive dose study than has already been attempted.

RECOMMENDATIONS

A. Population dose study

The purpose of this study would be to realistically define existent population groups on the bases of geographic location, occupation, age, and ethnic and/or cultural differences; and to determine the actual radiation dose to these populations:

1. Define in terms of size and location specific populations at risk.

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2. Determine the intake of radionuclides (^{90}Sr, ^{137}Cs and ^{134}Cs) to these populations by means of "market basket," "home sampling," and "institutional diet sampling."
3. Determine doses from ^{129}I by analysis of milk samples.
4. Based on the results of the dietary studies, carry out whole-body counting (particularly for ^{137}Cs and ^{134}Cs) of selected individuals.

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[5] As they relate to a maximum exposed individual.

5. Determine the feasibility of a bioassay program for determination of ^{3}H, ^{90}Sr, and ^{239}Pu in populations around NFS.

6. Determine the radionuclide content of selected human tissues in the above population groups (upon autopsy if and when samples become available).

7. Establish control groups in the Boston area (or other) and simultaneously perform the above enviromental sampling and bioassay procedures.

B. Continuous monitoring of the external environment around NFS by means of field samplers

The purpose of this study would be to establish mean and maximum levels of marker radionuclides (^{85}Kr in the air environment, ^{137}Cs, ^{90}Sr, and ^{3}H in the aqueous environment) by continuous field monitoring. Studies during FY 70 were done to establish that these specific radionuclides are of dosimetric importance. Investigations of the feasibility of field samplers now make it possible to continuously, automatically monitor the air environment and/or sample the aqueous environment.

1. Establish a suitable number of automatic continuously monitoring ^{85}Kr air stations in the area of NFS. In addition, in the predominate wind direction establish an automatic monitor for ^{3}H.

2. Obtain a suitable monthly particulate stack air sample for ^{3}H.

3. Establish a suitable number of automatic weir and ion exchange type stream samplers at pertinent locations. These to be collected monthly and the appropriate analysis performed.

4. Relate time release versus location versus concentration for the marker radionuclides in the two environmental media.

C. Radionuclide levels in wildlife

The purpose of this study is to investigate the maximum and average levels of dosimetrically important radionuclides in wildlife and fish commonly hunted and ingested around NFS and to establish their radionuclide levels in relation to their range from NFS.

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1. Establish which game is important around NFS, the range of this game, and the size of the human population at risk from ingestion of wildlife and fish.

2. Establish proper sampling at various distances from NFS in the forest and stream environments.

3. Perform radionuclide determination for ^{137}Cs, ^{134}Cs, ^{106}Ru-Rh, and ^{90}Sr on the edible portions of wildlife game and fish.

4. Establish the size of human population at risk to this type of exposure and the degree of exposure.

The duration of the above studies is estimated to be 2 years after initiation. Completion of an in-depth population dose study, a continuous field monitoring environmental program, and a radionuclide level in game evaluation should more properly define the

actual and potential human radiation doses due to operation of a nuclear fuel reprocessing plant.

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4.2e LIQUID WASTE EFFLUENTS FROM A NUCLEAR FUEL REPROCESSING PLANT, DEPARTMENT OF HEALTH, EDUCATION, AND WELFARE, NOVEMBER 1970

FOREWORD

The recent growth in the utilization of nuclear reactors for electrical generating plants has brought with it the need for nu-

clear reprocessing plants that extract usable uranium and plutonium from spent fuel elements. The Bureau of Radiological Health performs a technical review and evaluation of the public health factors of all nuclear facilities and provides technical assistance to State health departments responsible for assessing population exposure and radiation levels in the environment. The Northeastern Radiological Health Laboratory under the aegis of the Division of Environmental Radiation has undertaken an environmental survey of the first commercial operating fuel reprocessing plant in the United States.

The technical report series of the Bureau's regional laboratories and its Division of Environmental Radiation is used to publish the results of research projects and technical evaluations of nuclear facilities. These reports are distributed to State and local radiological health program personnel, Bureau technical staff, Bureau advisory committee members, radiation safety officers, libraries and information services, industry, the press, and other interested individuals. These reports are also included in the collections of the Library of Congress and the National Technical Information Service.

I encourage the readers of these reports to inform the Bureau of any omissions or errors. Your additional comments or requests for further information are also solicited.

JOHN C. VILLFORTH, *Director,*
Bureau of Radiological Health.

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PREFACE

The projected increase in the utilization of nuclear power for electrical generating plants has resulted in both State and Federal public health agencies placing increased program emphasis on the surveillance of nuclear power plants. The Bureau of Radiological Health provides recommended nuclear facility surveillance program information for the guidance of health agencies. In order to provide a better technical basis for environmental surveillance recommendations, a series of field studies have been conducted at operating nuclear facilities to obtain better data on radionuclides in plant effluents and their subsequent distribution in the environment.

This field study around the Nation's first commercial nuclear fuel reprocessing plant was for the purpose of identifying the movement of critical radionuclides through the atmospheric and aqueous environments in relationship to the fuel reprocessing procedures. Technical data obtained from this study will be used to: (1) develop minimum and optimum requirements for environmental surveillance around nuclear fuel reprocessing plants, (2) designate the radionuclides and environmental pathways of greatest dosimetric significance, and (3) provide estimates and measurements of the radiation dose to populations in the area of a facility.

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ABSTRACT

The liquid waste effluents from Nuclear Fuel Services were studied in detail during a six-month period May through October 1969. The concentrations and amounts of individual radionuclides discharged from the plant were measured and the amounts of sedimentation of individual radionuclides in the lagoon system were estimated.

Tritium, ruthenium-106, strontium-90, cesium-137 and cesium-134 were the principal radionuclides discharged to the environment during this period. No relationship could be established between the amount and burnup of fuel processed and the amount of activity discharged from the plant to the lagoon system during this study. For the Yankee fuel campaign of May-August 1969, the waste management practice and not the amount of fuel processed was the controlling factor in the amount of activity discharged from the plant to the lagoon system.

During June and November 1969 simultaneous sampling was carried out at the point of discharge of the waste and several locations on the Buttermilk and Cattaraugus Creeks. Tritium, ruthenium-106, and strontium-90 were the radionuclides present in the highest concentrations in these streams during these periods. Stream dilution and absorption factors were calculated for individual radionuclides at various locations along the stream system. A comparison of the concentrations of the radionuclides in Cattaraugus Creek with 10CFR20 discharge concentration limits showed that strontium-90 was about 20 percent of the concentration limit during both sampling periods. All other radionuclides were less than 10 percent of the concentration limits during these periods.

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LIQUID WASTE EFFLUENTS FROM A NUCLEAR FUEL REPROCESSING PLANT

INTRODUCTION

Increase in the use and number of nuclear reactors has brought with it the need for nuclear fuel reprocessing plants that extract usable uranium and plutonium from spent fuel elements. Presently, one commercial plant, Nuclear Fuel Services, Inc., is in operation in western New York, a second plant is under construction in Illinois, and others are being planned. The fact that such plants discharge radionuclides to the environment necessitates surveillance around the plant in order to determine the quantity and composition of waste-discharge, the effect of such discharge on the environment where it accumulates, and the level of radiation dose delivered to surrounding populations.

Nuclear Fuel Services, Inc., began processing fuel in April 1966. Since 1964, the New York State Department of Health has conducted an extensive environmental surveillance program around this plant (*1*). The Atomic Energy Commission (*2*) and Nuclear Fuel Services (*3*) also conduct environmental surveillance programs around the plant site.

The Bureau of Radiological Health has a responsibility to provide guidance to state and local health agencies in developing surveillance programs for nuclear facilities including fuel reprocessing plants. In order to meet this responsibility, the Bureau of Radiological Health, in cooperation with the New York State Department of Health, the Atomic Energy Commission, and Nuclear Fuel Services, began in 1969 a special study of the Nuclear Fuel Services plant and its environs for the purpose of determining the requirements of environmental surveillance programs for such plants.

The objectives of this study are:

(1) To develop minimum and optimum requirements for environmental surveillance programs around nuclear fuel reprocessing plants.
(2) To designate the radionuclides and environmental pathways of greatest dosimetric significance.
(3) To provide methods for estimating the radiation dose to the populations in the area of a facility.

This report presents the results of that part of the study concerned with the liquid waste effluents discharged from Nuclear Fuel Services and includes the following information:

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(1) Identification of radionuclides discharged from the plant.
(2) Measurements of radionuclide concentrations and total activities discharged in the dissolved (soluble) and suspended (insoluble) liquid effluent fractions.
(3) The influence of the type, age, and amount of fuel processed on the amount of activity discharged.
(4) Determination of the relationship between the concentrations of various radionuclides discharged from the plant and subsequent levels at various locations in the aqueous environment.
(5) Measurements of concentrations of radionuclides in bottom sediments from the aqueous environment.

PLANT LOCATION AND LIQUID WASTE DISCHARGE PRACTICES

Nuclear Fuel Services, Inc., operates the nation's first commercial nuclear fuel reprocessing plant on the 3,300 acre site of Western New York Nuclear Service Center located in the town of Ashford, Cattaraugus County, New York. This site is located 30 miles southeast of Buffalo and about 4 miles south of Springville. This plant operates under license CSF-1 issued by the U.S. Atomic Energy Commission. The process employed is a chop, leach, and Purex-solvent extraction procedure and the plant capacity is estimated to be one metric ton of uranium per day (4).

The high level liquid waste from plant operations is concentrated and stored in a multiple contained, underground, tank farm. Low level waste generated from evaporator condensates, plant floor drains, laundry and decontamination operations is discharged into interceptor tanks and then to a series of three holding ponds or lagoons prior to discharge into the aqueous environment. Figure 1 is a diagram showing the lagoon and stream systems into which the low level wastes are discharged. There are two interceptor tanks each with a 22,000 gallon capacity. Technical specification 4.2.1 of license CSF-1 states that in any calendar quarter no more than 48 curies of combined equivalent unidentified alpha and beta activity, other than tritium or iodine-131, shall be transferred to the lagoons and that the concentration of the waste discharged shall be less than 5×10^{-3} μCi/ml. When the combined gross alpha and beta activities in an interceptor tank are less than 5×10^{-3} μCi/ml, then the waste is neutralized using sodium hydroxide

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and bottom drained by gravity to lagoon-1. If the activity level exceeds the above concentration, then the waste is either diluted

to the desired concentration or returned to the plant for further processing. Photographs of the interceptor tanks, lagoons, and weir are presented in Appendix I.

The lagoons accept the transfers from the interceptor tanks and provide time for precipitation and sedimentation of insolubles. Lagoon-1 has a capacity of 300,000 gallons and a continuous high level overflow into lagoon-2. Lagoon-2 has a 2,300,000 gallon capacity and is drained into lagoon-3 through a valved line 18 inches from the bottom of the lagoon. Lagoon-3 has a 2,500,000 gallon capacity and the waste is discharged to the aqueous environment through a flow metering system. The valved drain line from lagoon-3 is 3 feet from the bottom. The waste management practice is to close off the drain line from lagoon-3 when lagoon-2 is drained into lagoon-3, and to shut off the drain line from lagoon-2 when waste is being discharged from lagoon-3.

The waste from lagoon-3 is discharged into Erdman's Brook which flows into Frank's Creek which flows into Buttermilk Creek. The Buttermilk Creek flows into Cattaraugus Creek which eventually empties into Lake Erie. As shown in figure 1, the entire route to Cattaraugus Creek including the confluence of the Buttermilk and Cattaraugus Creeks is on NFS leased property and is a posted restricted area. The rate of discharge from lagoon-3 is controlled in proportion to the Cattaraugus Creek flow to keep the concentrations in Cattaraugus Creek below the established limits. Technical specification 4.2.2 states that "Activity released to Cattaraugus Creek from all sources on the site shall not at any time result in a concentration, as measured at the monitoring station in Cattaraugus Creek, which exceeds twice the concentration specified in Title 10 Code of Federal Regulations Part 20; provided however, that in any 365 consecutive day period, the average concentration of radioactivity in Cattaraugus Creek shall not exceed that specified in Title 10 Code of Federal Regulations Part 20."

Sampling Locations

The sampling locations used in this study are identified by number in figure 1. A list of the sampling locations used, their identification numbers, and their distance from lagoon-3 measured along the streams is presented in table 1. Photographs of the collection sites nos. 5, 6, and 8 are presented in Appendix I.

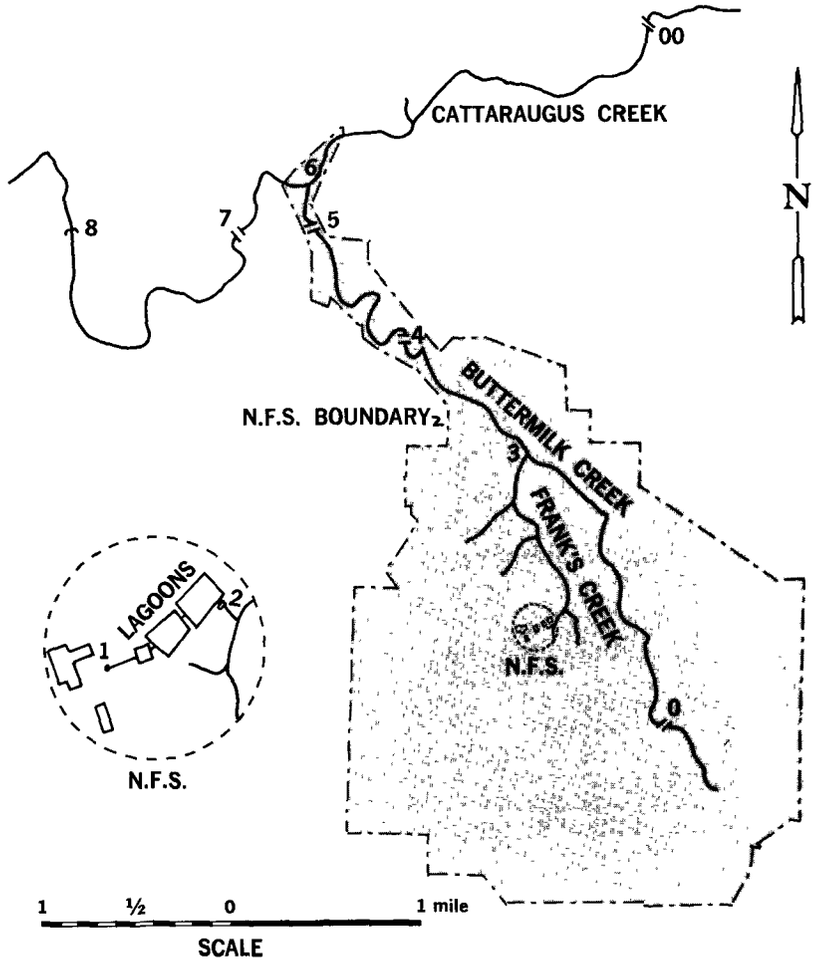

FIGURE 1.—Sample collection locations on lagoons and stream systems.

TABLE 1. SAMPLING SITES USED FOR CHARACTERIZATION OF LIQUID WASTE FROM NUCLEAR FUEL SERVICES

Location	Site identification number	Distance from lagoon-3 (miles)
Interceptor tank	1	—
Lagoon-3 weir	2	—
Confluence of Frank's and Buttermilk Creeks	3	1.1
Bridge at Bond Road	4	2.0
Bridge at Thomas Corners Road	5	3.3
Confluence of Buttermilk and Cattaraugus Creeks	6	3.5
Felton Bridge	7	4.1
Springville Dam	8	6.1
Buttermilk Road	0	1.8 (upstream of site #3)
Bigelow Bridge	00	2 3 (upstream of site #6)

LIQUID WASTE DISCHARGES

Samples Collected

For the purpose of defining liquid waste discharges from the plant, three composite interceptor and six composite lagoon samples were supplied by Nuclear Fuel Services during 1969. The interceptor composites represented waste discharged from the plant to the lagoon system. The lagoon composites represented waste discharged from the lagoon system to the aqueous environment. The interceptor samples represented time periods covering a fuel campaign,[1] while the lagoon samples were all monthly composites. From the volume of liquid waste represented by a composite, the total activity discharged either from the plant or from the lagoons for a given period could be calculated. Information on these composite samples is presented in table 2 and fuel processing information for the campaign periods covered by the interceptor composites is presented in table 3.

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TABLE 2. COMPOSITE LIQUID WASTE EFFLUENT SAMPLES FROM NUCLEAR FUEL SERVICES—1969

Sample site	Description	pH	Volume equivalent	Total volume represented (gallons)
1	Interceptor-A 4/1 to 5/21	>7	1 ml ≈ 30,000 gal	2.60×10^6
1	Interceptor-B 5/21 to 8/4	>7	1 ml ≈ 2000 gal	4.27×10^6
1	Interceptor C 8/18 to 9/14	1	1 ml ≈ 1000 gal	1.91×10^6
2	Lagoon-3 May	11	1 ml ≈ 1000 gal	1.73×10^6
2	Lagoon-3 June	11	1 ml ≈ 1000 gal	3.68×10^6
2	Lagoon-3 July	11	1 ml ≈ 1000 gal	3.62×10^6
2	Lagoon-3 August	11	1 ml ≈ 1000 gal	2.85×10^6
2	Lagoon-3 September	7	1 ml ≈ 1000 gal	3.99×10^6
2	Lagoon-3 October	8	1 ml ≈ 1000 gal	3.25×10^6

TABLE 3. FUEL PROCESSING INFORMATION FOR PERIODS COVERED BY INTERCEPTOR COMPOSITES—1969

	Process Dates			
	2/17–4/1	4/1–5/10	5/24–7/9	8/18–9/21
Campaign	NPR[2]	NPR	Yankee[3]	NPR
Reactor discharge date	April 1968	April 1968	March 1968	No irradiation
Fuel burnup MWD/MTU[1]	2500	2500	20,000	0
Enrichment ^{235}U	0.7%	0.7%	4.9%	0.7%
Amount of fuel processed MTU	28	21	20	30

[1] MWD/MTU = Megawatt days per metric tonne of uranium.
[2] New Production Reactor, a plutonium production reactor at Hanford, Wash.
[3] Yankee Nuclear Power Station, a 600 megawatt pressurized water reactor at Rowe, Mass.

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[1] A campaign is a processing run on a specific fuel including cleanout and turnaround of the plant in preparation for the next campaign.

Dates indicated in table 3 represent the periods during which the processing of the fuel was begun. Interceptor-A was collected as representative of waste originating from an NPR campaign, and interceptor-B was collected as representative of waste originating from a Yankee campaign. It should be noted, however, that as far as the low level liquid wastes are concerned, no line can be drawn indicating the end of one campaign and the beginning of another. Some overlapping is unavoidable due to the nature of the operation. Since the campaign of 8/18 to 9/14 involved unirradiated fuel, the waste represented by the composite for that period (interceptor-C) most likely originated from activities left over from the Yankee campaign.

Measurements and Results

These composite effluent samples were separated into dissolved and suspended solids fractions by filtration through an 0.45 μ membrane filter and each of these fractions analyzed separately.[2]

Gamma spectrometry using a Ge(Li) detector was used to identify the presence of gamma emitting radionuclides in these samples. The dissolved and suspended solids fractions from each sample were analyzed covering an energy range of 0–2000 KeV. Following the removal of the radionuclides of ruthenium and cesium (the principal gamma emitting radionuclides present), these samples, with the exception of interceptor-A and lagoon-3 May, were subjected to additional Ge(Li) qualitative analyses.

Table 4 lists the gamma emitting radionuclides identified in each of the fractions of these samples. The radionuclides are listed in order of decreasing estimated concentrations.

The gamma emitting radionuclides identified in the interceptor composites were essentially the same for the Yankee and NPR campaigns. Interceptor composites B and C showed small but detectable quantities of europium-154, europium-155 and manganese-54. These radionuclides were not identified in interceptor-A, but this was probably due to a difference in the sensitivity of the measurements resulting from a smaller size sample (see table 2). The lagoon-3 composites for the 6-month period May through October 1969 all contained essentially the same identifiable gamma

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emitting radionuclides. Radionuclides were identified in the dissolved solids fractions of interceptor-C which were not present in the dissolved solids fractions of the other composite effluent sam-

[2] This separation took place several months after collection of the sample. It was determined that this storage period did not significantly alter the distribution of activity between the dissolved and suspended solids fractions.

ples. This resulted from the sample being acid (pH = 1.0). The aliquots used to make up the composite were collected from the interceptor tanks prior to the neutralization of the waste. All other composite effluent samples were basic (pH = > 7), having been collected after neutralization of the waste.

Quantitative analyses on these composite samples were carried out for gross alpha, gross beta, tritium, ruthenium-106, cesium-137, cesium-134, cerium-144, zirconium-95, cobalt-60, manganese-54, strontium-90, promethium-147, plutonium-238, plutonium-239, plutonium-241, uranium-232, uranium-234, and uranium-238. In addition, americium-241, curium-242, and curium-244 were measured in the interceptor composites only. The results of these measurements for the interceptor samples are presented in tables 5–7 and for the lagoon-3 samples in tables 11–16. The total activity in curies, represented by the composite, for each of the radionuclides, is also presented in these tables. All activities were corrected for decay to the midpoint of the collection period except for the gross alpha and beta activities [3] for which no decay correction was applied. It should also be noted that the gross beta measurements do not include tritium and because of self-absorption effects soft beta activities will not contribute substantially to the gross beta measurement.

Examples of the alpha and gamma spectra obtained during the analyses of these samples are presented in Appendix II. A brief description of the procedures used in the analyses of these samples is presented in Appendix III.

Activity Discharged from Plant to Interceptor Tanks

Tritium was the principal radionuclide being discharged from the plant to the interceptor tanks. During the period covered by interceptor composites B and C,[4] 820 curies of tritium were discharged from the plant and this was 13 times more than any other radionuclide.

[3] The gross alpha and beta measurements were made about 2 months after collection of the samples.

[4] Due to analytical difficulties ^3H was not measured in Interceptor-A.

TABLE 4. NUCLEAR FUEL SERVICES LIQUID EFFLUENT SAMPLES—1969. RESULTS OF QUALITATIVE GAMMA ANALYSES

Radionuclides identified																			
Interceptor						Lagoon-3													
A		B		C		May		June		July		Aug.		Sept.		Oct.			
Diss.	Sus.	Diss.	Sus.	Diss.	Sus.	Diss.	Sus.	Diss.	Sus.	Diss.	Sus.	Diss.	Sus.	Diss.	Sus.	Diss.	Sus.		
^{106}Ru	^{106}Ru	^{106}Ru	^{106}Ru	^{137}Cs	^{106}Ru	^{106}Ru	^{106}Ru	^{106}Ru	^{106}Ru	^{106}Ru	^{106}Ru	^{106}Ru	^{106}Ru	^{106}Ru	^{137}Cs	^{106}Ru	^{137}Cs		
^{137}Cs	^{144}Ce	^{137}Cs	^{144}Ce	^{106}Ru	^{95}Zr	^{137}Cs	^{137}Cs	^{137}Cs	^{137}Cs	^{137}Cs	^{137}Cs	^{137}Cs	^{137}Cs	^{137}Cs	^{106}Ru	^{137}Cs	^{106}Ru		
^{134}Cs	^{95}Nb	^{134}Cs	^{95}Nb	^{134}Cs	^{95}Nb	^{134}Cs	^{134}Cs	^{134}Cs	^{134}Cs	^{134}Cs	^{134}Cs	^{134}Cs	^{144}Ce	^{134}Cs	^{134}Cs	^{134}Cs	^{134}Cs		
^{125}Sb	^{95}Zr	^{125}Sb	^{95}Zr	^{144}Ce	^{137}Cs	^{125}Sb	^{144}Ce	^{125}Sb	^{144}Ce	^{125}Sb	^{144}Ce	^{125}Sb	^{60}Co	^{125}Sb	^{54}Mn	^{125}Sb	^{144}Ce		
^{60}Co	^{137}Cs	^{60}Co	^{137}Cs	^{60}Co	^{60}Co	^{60}Co	^{95}Nb	^{60}Co	^{60}Co	^{60}Co	^{60}Co	^{60}Co	^{54}Mn	^{144}Ce	^{60}Co	^{60}Co	^{60}Co		
	^{134}Cs		^{134}Cs	^{125}Sb	^{134}Cs		^{95}Zr		^{60}Co		^{125}Sb						^{125}Sb		
	^{60}Co		^{60}Co	^{95}Nb	^{54}Mn		^{60}Co		^{125}Sb		^{95}Nb						^{95}Nb		
			^{125}Sb	^{95}Zr	^{125}Sb						^{95}Zr						^{95}Zr		
			^{154}Eu	^{54}Mn	^{144}Ce						^{54}Mn						^{54}Mn		
			^{155}Eu	^{154}Eu															
			^{54}Mn	^{155}Eu															

TABLE 5. NUCLEAR FUEL SERVICES LIQUID EFFLUENT SAMPLE—INTERCEPTOR COMPOSITE 4/1–5/21/69

Radionuclide	Microcuries per milliliter			Curies discharged
	Total	Dissolved	Suspended	
Gross α	2.4×10^{-6}	0.3×10^{-6}	2.1×10^{-6}	2.4×10^{-2}
Gross β	2.4×10^{-3}	0.6×10^{-3}	1.8×10^{-3}	2.4×10^{1}
^{3}H	N.A.	N.A.	N.A.	N.A.
^{106}Ru	1.5×10^{-3}	0.2×10^{-3}	1.3×10^{-3}	1.5×10^{1}
^{137}Cs	3.6×10^{-4}	3.1×10^{-4}	0.5×10^{-4}	3.5
^{134}Cs	8.4×10^{-5}	7.2×10^{-5}	1.2×10^{-5}	8.3×10^{-1}
^{90}Sr	1.9×10^{-4}	1.0×10^{-4}	0.9×10^{-4}	1.9
^{144}Ce	1.3×10^{-4}	$<1\times10^{-5}$	1.3×10^{-4}	1.3
^{147}Pm	9.0×10^{-5}	$<1\times10^{-5}$	9.0×10^{-5}	8.9×10^{-1}
^{95}Zr	7.3×10^{-5}	$<5\times10^{-6}$	7.3×10^{-5}	7.2×10^{-1}
^{60}Co	5.8×10^{-6}	2.3×10^{-6}	3.5×10^{-6}	5.7×10^{-2}
^{125}Sb	2.0×10^{-5}	1.2×10^{-5}	0.8×10^{-5}	2.0×10^{-1}
^{54}Mn	$<3\times10^{-6}$	$<1\times10^{-6}$	$<2\times10^{-6}$	$<3\times10^{-2}$
^{238}Pu	6.8×10^{-7}	$<2\times10^{-9}$	6.8×10^{-7}	6.7×10^{-3}
^{239}Pu	1.2×10^{-6}	$<2\times10^{-9}$	1.2×10^{-6}	1.2×10^{-2}
^{241}Pu	6.0×10^{-5}	$<2\times10^{-6}$	6.0×10^{-5}	5.9×10^{-1}
^{232}U	9.4×10^{-8}	6.5×10^{-8}	2.9×10^{-8}	9.2×10^{-4}
^{234}U	1.3×10^{-7}	8.8×10^{-8}	4.0×10^{-8}	1.3×10^{-3}
^{238}U	7.6×10^{-8}	5.1×10^{-8}	2.5×10^{-8}	7.5×10^{-4}
^{241}Am	3.2×10^{-7}	$<1\times10^{-8}$	3.2×10^{-7}	3.1×10^{-3}
^{242}Cm	1.5×10^{-7}	$<2\times10^{-8}$	1.5×10^{-7}	1.5×10^{-3}
^{244}Cm	3.0×10^{-8}	$<1\times10^{-8}$	3.0×10^{-8}	3.0×10^{-4}
Solids (mg/1)		7.3×10^{3}	1.3×10^{2}	

N.A.= No Analysis

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TABLE 6. NUCLEAR FUEL SERVICES LIQUID EFFLUENT SAMPLE—INTERCEPTOR COMPOSITE 5/21–8/4/69

Radionuclide	Microcuries per milliliter			Curies discharged
	Total	Dissolved	Suspended	
Gross α	6.2×10^{-6}	0.1×10^{-6}	6.1×10^{-6}	1.0×10^{-1}
Gross β	5.9×10^{-3}	2.1×10^{-3}	3.8×10^{-3}	9.6×10^{1}
^{3}H	4.8×10^{-2}	4.8×10^{-2}	N.A.	7.8×10^{2}
^{106}Ru	3.7×10^{-3}	1.1×10^{-3}	2.6×10^{-3}	6.0×10^{1}
^{137}Cs	4.4×10^{-4}	4.0×10^{-4}	0.4×10^{-4}	7.1
^{134}Cs	1.9×10^{-4}	1.7×10^{-4}	0.2×10^{-4}	3.1
^{90}Sr	2.3×10^{-4}	2.0×10^{-4}	0.3×10^{-4}	3,7
^{144}Ce	4.8×10^{-4}	$<3\times10^{-6}$	4.8×10^{-4}	7.8
^{147}Pm	2.5×10^{-4}	$<1\times10^{-6}$	2.5×10^{-4}	4.1
^{95}Zr	3.3×10^{-5}	$<1\times10^{-6}$	3.3×10^{-5}	5.3×10^{-1}
^{60}Co	1.4×10^{-5}	0.4×10^{-5}	1.0×10^{-5}	2.3×10^{-1}
^{125}Sb	1.2×10^{-5}	7.3×10^{-6}	4.5×10^{-6}	1.9×10^{-1}
^{54}Mn	3.7×10^{-7}	$<3\times10^{-7}$	3.7×10^{-7}	6.0×10^{-3}
^{238}Pu	1.1×10^{-6}	1.1×10^{-9}	1.1×10^{-6}	1.8×10^{-2}
^{239}Pu	3.1×10^{-6}	3.0×10^{-9}	3.1×10^{-6}	5.0×10^{-2}
^{241}Pu	1.3×10^{-4}	$<3\times10^{-7}$	1.3×10^{-4}	2.1
^{232}U	6.6×10^{-8}	4.4×10^{-8}	2.2×10^{-8}	1.1×10^{-3}
^{234}U	3.2×10^{-8}	2.1×10^{-8}	1.1×10^{-8}	5.2×10^{-4}
^{238}U	4.8×10^{-9}	2.9×10^{-9}	1.9×10^{-9}	7.8×10^{-5}
^{241}Am	9.1×10^{-7}	$<1\times10^{-8}$	9.1×10^{-7}	1.5×10^{-2}
^{242}Cm	2.8×10^{-6}	$<2\times10^{-8}$	2.8×10^{-6}	4.5×10^{-2}
^{244}Cm	5.5×10^{-7}	$<1\times10^{-8}$	5.5×10^{-7}	8.9×10^{-3}
Solids (mg/1)		4.5×10^{3}	3.7×10^{1}	

N.A.=No Analysis

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TABLE 7. NUCLEAR FUEL SERVICES LIQUID EFFLUENT SAMPLE—INTERCEPTOR COMPOSITE 8/18–9/14/69

Radionuclide	Microcuries per milliliter			Curies discharged
	Total	Dissolved	Suspended	
Gross α	1.5×10^{-6}	1.1×10^{-6}	0.4×10^{-6}	1.1×10^{-2}
Gross β	1.3×10^{-3}	1.2×10^{-3}	0.09×10^{-3}	9.4
^{3}H	5.0×10^{-3}	5.0×10^{-3}	N.A.	3.6×10^{1}
^{106}Ru	4.1×10^{-4}	3.3×10^{-4}	0.8×10^{-4}	3.0
^{137}Cs	5.6×10^{-4}	5.6×10^{-4}	0.03×10^{-4}	4.1
^{134}Cs	1.3×10^{-4}	1.3×10^{-4}	0.07×10^{-5}	9.4×10^{-1}
^{90}Sr	7.3×10^{-5}	7.3×10^{-5}	0.02×10^{-5}	5.3×10^{-1}
^{144}Ce	2.9×10^{-5}	2.9×10^{-5}	$< 3\times10^{-7}$	2.1×10^{-1}
^{147}Pm	2.4×10^{-5}	2.4×10^{-5}	$< 3\times10^{-7}$	1.2×10^{-1}
^{95}Zr	9.4×10^{-6}	4.4×10^{-6}	5.0×10^{-6}	6.8×10^{-2}
^{60}Co	3.8×10^{-6}	1.1×10^{-6}	2.7×10^{-6}	2.8×10^{-2}
^{125}Sb	3.2×10^{-6}	2.6×10^{-6}	0.6×10^{-6}	2.3×10^{-2}
^{54}Mn	9.3×10^{-3}	5.0×10^{-7}	4.3×10^{-7}	6.7×10^{-3}
^{238}Pu	4.0×10^{-7}	2.9×10^{-7}	1.1×10^{-7}	2.9×10^{-3}
^{239}Pu	3.8×10^{-7}	2.7×10^{-7}	1.1×10^{-7}	2.8×10^{-3}
^{241}Pu	2.9×10^{-5}	2.1×10^{-5}	0.8×10^{-5}	2.1×10^{-1}
^{232}U	2.0×10^{-8}	1.9×10^{-8}	0.09×10^{-8}	1.4×10^{-4}
^{234}U	1.7×10^{-8}	1.7×10^{-8}	0.04×10^{-8}	1.2×10^{-4}
^{238}U	7.5×10^{-9}	7.5×10^{-9}	$<0.1\times10^{-9}$	5.4×10^{-5}
^{241}Am	7.4×10^{-8}	5.4×10^{-8}	2.0×10^{-8}	5.4×10^{-4}
^{242}Cm	2.4×10^{-7}	1.7×10^{-7}	6.6×10^{-8}	1.7×10^{-3}
^{244}Cm	3.2×10^{-8}	3.2×10^{-8}	$< 2\times10^{-8}$	2.3×10^{-4}
Solids (mg/l)		2.4×10^{3}	1.6	

N.A.=No Analysis

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Sixty-five percent of the beta activity (exclusive of ^{3}H) measured in the interceptor composites was due to ruthenium-106. Cesium-137, cesium-134, strontium-90, cerium-144, and promethium-147 were the other major contributors to the beta activity. The relative contributions of the various radionuclides to the total beta activity of the three interceptor composites are presented in table 8.

TABLE 8. RELATIVE CONTRIBUTIONS OF INDIVIDUAL RADIONUCLIDES TO THE BETA ACTIVITY OF THE INTERCEPTOR COMPOSITES

Radionuclide	Percent of beta activity[1]
^{106}Ru	65
^{137}Cs	12
^{134}Cs	4
^{90}Sr	5
^{144}Ce	8
^{147}Pm	4
^{95}Zr	1
^{60}Co	0.3
^{125}Sb	0.3
^{54}Mn	<0.1

[1] Relative contribution of the individual radionuclide to the sum total of the activities of those radionuclides listed.

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Fifty-three percent of the alpha activity discharged from the plant during the period covered by the interceptor composites was due to radionuclides of plutonium. Curium-242, curium-244, and americium-241 were the other major contributors to the alpha activity. Radionuclides of uranium contributed only about 2.5 percent of the alpha activity. The relative contributions of the various radionuclides to the total alpha activity of the three interceptor composites are presented in table 9.

TABLE 9. RELATIVE CONTRIBUTIONS OF INDIVIDUAL RADIONUCLIDES TO THE ALPHA ACTIVITY OF THE INTERCEPTOR COMPOSITES

Radionuclide	Percent of alpha activity[1]
^{238}Pu	16
^{239}Pu	37
^{241}Am	11
^{242}Cm	28
^{244}Cm	5
^{232}U	1
^{234}U	1
^{238}U	0.5

[1] Relative contribution of the individual radionuclide to the sum total of the activities of those radionuclides listed.

The amount of activity discharged from the plant to the lagoon system during a fuel campaign is influenced by many interrelated factors pertaining to plant operations and waste management practice (*4*). For the three campaign periods studied, the concentrations and amounts of activity discharged from the plant to the lagoon system (Tables 5, 6, and 7) were compared with the amount and burnup of fuel processed during these campaigns (Table 3). It was observed that for short-time intervals, such as a campaign, no direct relationship existed between the amount of activity discharged from the plant to the lagoon system and the amount and burnup of fuel processed. Even during the processing of unirradiated fuel (NPR fuel campaign 8/18–9/14), significant quantities of activity were discharged from the plant. The data

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obtained on waste discharged from the plant during the Yankee fuel campaign of 5/21–8/4 showed that the technical specification relative to discharge of waste from the interceptor tanks to the lagoons, as discussed on page 2, appeared to be the controlling factor in the concentration and amount of activity discharged from the plant to the lagoon system.

Activity Discharged from Lagoon-3 to Aqueous Environment

Tritium was the principal radionuclide being discharged to the aqueous environment from lagoon-3 during the period May-October 1969. Thirty-three times more tritium was discharged during the period than any other radionuclide. Seventy-three percent of the beta activity (exclusive of ^{3}H) discharged during this period was due to ruthenium-106. Strontium-90, cesium-137, and cesium-134 were the other major contributors to the beta activity. The activities due to cerium-144, promethium-147, zirconium-95, cobalt-60, antimony-125, and manganese-54 were less than two percent of the beta activity discharged. Listed in table 10 are the relative contributions of the various radionuclides to the beta activity (exclusive of ^{3}H) of the lagoon-3 composites for May-October 1969.

TABLE 10. RELATIVE CONTRIBUTIONS OF INDIVIDUAL RADIONUCLIDES TO THE BETA ACTIVITY OF LAGOON-3 COMPOSITES—MAY-OCTOBER 1969

Radionuclide	Percent of beta activity[1]
^{106}Ru	73
^{90}Sr	12
^{137}Cs	11
^{134}Cs	3
^{144}Ce	0.2
^{147}Pm	0.1
^{95}Zr	<0.1
^{60}Co	0.3
^{125}Sb	0.8
^{54}Mn	<0.1

[1] Relative contribution of the individual radionuclide to the sum total of the activities of those radionuclides listed.

TABLE 11. NUCLEAR FUEL SERVICES LIQUID EFFLUENT SAMPLE—LAGOON-3 COMPOSITE MAY 1969

Radionuclide	Microcuries per milliliter			Curies discharged
	Total	Dissolved	Suspended	
Gross α	2.2×10^{-6}	1.7×10^{-6}	0.5×10^{-6}	1.4×10^{-2}
Gross β	6.3×10^{-4}	4.3×10^{-4}	2.0×10^{-4}	4.1
^{3}H	4.3×10^{-2}	4.3×10^{-2}	N.A.	2.8×10^{2}
^{106}Ru	3.0×10^{-4}	2.6×10^{-4}	0.4×10^{-4}	2.0
^{137}Cs	9.6×10^{-5}	4.6×10^{-5}	5.0×10^{-5}	6.3×10^{-1}
^{134}Cs	2.3×10^{-5}	1.1×10^{-5}	1.2×10^{-5}	1.5×10^{-1}
^{90}Sr	7.3×10^{-5}	1.7×10^{-5}	5.6×10^{-5}	4.8×10^{-1}
^{144}Ce	6.6×10^{-6}	$< 5\times10^{-7}$	6.6×10^{-6}	4.3×10^{-2}
^{147}Pm	4.4×10^{-6}	$< 3\times10^{-7}$	4.4×10^{-6}	2.9×10^{-2}
^{95}Zr	3.0×10^{-7}	$<2\times10^{-7}$	3.0×10^{-7}	2.0×10^{-3}
^{60}Co	1.3×10^{-6}	1.1×10^{-6}	0.2×10^{-6}	8.5×10^{-3}
^{125}Sb	1.1×10^{-5}	1.0×10^{-5}	0.1×10^{-5}	7.2×10^{-2}
^{54}Mn	6.0×10^{-8}	$< 5\times10^{-8}$	6.0×10^{-8}	3.9×10^{-4}
^{238}Pu	2.0×10^{-8}	0.06×10^{-8}	1.9×10^{-8}	1.3×10^{-4}
^{239}Pu	3.2×10^{-8}	0.1×10^{-8}	3.1×10^{-8}	2.1×10^{-4}
^{241}Pu	2.2×10^{-6}	$< 3\times10^{-7}$	2.2×10^{-6}	1.4×10^{-2}
^{232}U	8.4×10^{-7}	7.8×10^{-7}	0.6×10^{-7}	5.5×10^{-3}
^{234}U	3.3×10^{-7}	3.1×10^{-7}	0.2×10^{-7}	2.2×10^{-3}
^{238}U	4.4×10^{-8}	4.1×10^{-8}	0.3×10^{-8}	2.9×10^{-4}
Solids (mg/1)		5.4×10^{3}	1.2×10^{2}	

N.A.=No Analysis.

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TABLE 12. NUCLEAR FUEL SERVICES LIQUID EFFLUENT SAMPLE—LAGOON-3 COMPOSITE JUNE 1969

Radionuclide	Microcuries per milliliter			Curies discharged
	Total	Dissolved	Suspended	
Gross α	8.2×10^{-7}	6.4×10^{-7}	1.8×10^{-7}	1.1×10^{-2}
Gross β	1.4×10^{-3}	1.3×10^{-3}	0.1×10^{-3}	1.9×10^{1}
^{3}H	4.3×10^{-2}	4.3×10^{-2}	N.A.	6.0×10^{2}
^{106}Ru	1.1×10^{-3}	1.0×10^{-3}	0.1×10^{-3}	1.5×10^{1}
^{137}Cs	7.3×10^{-5}	5.2×10^{-5}	2.1×10^{-5}	1.0
^{134}Cs	2.3×10^{-5}	1.6×10^{-5}	0.7×10^{-5}	3.2×10^{-1}
^{90}Sr	1.2×10^{-4}	1.1×10^{-4}	0.1×10^{-4}	1.7
^{144}Ce	1.6×10^{-6}	$< 5\times10^{-7}$	1.6×10^{-6}	2.2×10^{-2}
^{147}Pm	9.0×10^{-7}	$< 3\times10^{-7}$	9.0×10^{-7}	1.3×10^{-2}
^{95}Zr	4.1×10^{-8}	$< 1\times10^{-7}$	4.1×10^{-8}	5.7×10^{-4}
^{60}Co	1.3×10^{-6}	1.2×10^{-6}	0.1×10^{-6}	1.8×10^{-2}
^{125}Sb	6.8×10^{-6}	6.7×10^{-6}	0.1×10^{-6}	9.5×10^{-2}
^{54}Mn	$< 8\times10^{-8}$	$< 5\times10^{-8}$	$< 3\times10^{-8}$	$< 1.1\times10^{-3}$
^{238}Pu	9.7×10^{-9}	1.7×10^{-9}	8.0×10^{-9}	1.3×10^{-4}
^{239}Pu	1.7×10^{-8}	0.3×10^{-8}	1.4×10^{-8}	2.4×10^{-4}
^{241}Pu	7.0×10^{-7}	$< 3\times10^{-7}$	7.0×10^{-7}	9.7×10^{-3}
^{232}U	3.9×10^{-7}	3.8×10^{-7}	0.1×10^{-7}	5.4×10^{-3}
^{234}U	1.5×10^{-7}	1.4×10^{-7}	0.05×10^{-7}	2.1×10^{-3}
^{238}U	1.5×10^{-8}	1.4×10^{-8}	0.05×10^{-8}	2.1×10^{-4}
Solids (mg/1)		3.8×10^{3}	3.9×10^{1}	

N.A.=No Analysis.

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TABLE 13. NUCLEAR FUEL SERVICES LIQUID EFFLUENT SAMPLE—LAGOON-3 COMPOSITE JULY 1969

Radionuclide	Microcuries per milliliter			Curies discharged
	Total	Dissolved	Suspended	
Gross α	4.5×10^{-7}	2.9×10^{-7}	1.6×10^{-7}	6.2×10^{-3}
Gross β	1.5×10^{-3}	1.3×10^{-3}	0.2×10^{-3}	2.1×10^{1}
^{3}H	4.9×10^{-2}	4.9×10^{-2}	N.A.	6.7×10^{2}
^{106}Ru	1.2×10^{-3}	1.1×10^{-3}	0.1×10^{-3}	1.6×10^{1}
^{137}Cs	4.9×10^{-5}	0.4×10^{-5}	4.5×10^{-5}	6.7×10^{-1}
^{134}Cs	1.2×10^{-5}	0.1×10^{-5}	1.1×10^{-5}	1.6×10^{-1}
^{90}Sr	5.1×10^{-5}	2.0×10^{-5}	3.1×10^{-5}	7.0×10^{-1}
^{144}Ce	3.8×10^{-6}	$< 5\times10^{-7}$	3.8×10^{-6}	5.2×10^{-2}
^{147}Pm	2.0×10^{-6}	$< 3\times10^{-7}$	2.0×10^{-6}	2.7×10^{-2}
^{95}Zr	7.0×10^{-8}	$< 1\times10^{-7}$	7.0×10^{-8}	9.6×10^{-4}
^{60}Co	7.2×10^{-7}	4.5×10^{-7}	2.7×10^{-7}	9.9×10^{-3}
^{125}Sb	5.4×10^{-6}	5.1×10^{-6}	0.3×10^{-6}	7.4×10^{-2}
^{54}Mn	3.1×10^{-8}	$< 5\times10^{-8}$	3.1×10^{-8}	4.2×10^{-4}
^{238}Pu	1.4×10^{-8}	0.03×10^{-8}	1.4×10^{-8}	1.9×10^{-4}
^{239}Pu	3.7×10^{-8}	0.07×10^{-8}	3.6×10^{-8}	5.1×10^{-4}
^{241}Pu	2.6×10^{-6}	$< 3\times10^{-7}$	2.6×10^{-6}	3.6×10^{-2}
^{232}U	2.1×10^{-7}	1.5×10^{-7}	0.6×10^{-7}	2.9×10^{-3}
^{234}U	8.0×10^{-8}	5.7×10^{-8}	2.3×10^{-8}	1.1×10^{-3}
^{238}U	8.0×10^{-9}	5.2×10^{-9}	2.8×10^{-9}	1.1×10^{-4}
Solids (mg/1)		3×10^{3}	0.4×10^{3}	

N.A.=No Analysis.

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TABLE 14. NUCLEAR FUEL SERVICES LIQUID EFFLUENT SAMPLE—LAGOON-3 COMPOSITE AUGUST 1969

Radionuclide	Microcuries per milliliter			Curies discharged
	Total	Dissolved	Suspended	
Gross α	6.4×10^{-7}	4.5×10^{-7}	1.9×10^{-7}	6.9×10^{-3}
Gross β	1.3×10^{-3}	1.2×10^{-3}	0.1×10^{-3}	1.4×10^{1}
^{3}H	2.9×10^{-3}	2.9×10^{-3}	N.A.	3.1×10^{1}
^{106}Ru	8.3×10^{-4}	7.7×10^{-4}	0.6×10^{-4}	9.0
^{137}Cs	6.3×10^{-5}	4.0×10^{-5}	2.3×10^{-5}	6.8×10^{-1}
^{134}Cs	2.4×10^{-5}	1.5×10^{-5}	0.9×10^{-5}	2.6×10^{-1}
^{90}Sr	1.9×10^{-4}	1.9×10^{-4}	0.04×10^{-4}	2.1
^{144}Ce	1.6×10^{-6}	$< 5\times10^{-7}$	1.6×10^{-6}	1.7×10^{-2}
^{147}Pm	8.0×10^{-7}	$< 3\times10^{-7}$	8.0×10^{-7}	8.6×10^{-3}
^{95}Zr	4.0×10^{-8}	$< 1\times10^{-7}$	4.0×10^{-8}	4.3×10^{-4}
^{60}Co	7.3×10^{-6}	7.2×10^{-6}	0.1×10^{-6}	7.9×10^{-2}
^{125}Sb	7.6×10^{-6}	7.6×10^{-6}	0.04×10^{-6}	8.2×10^{-2}
^{54}Mn	$< 8\times10^{-8}$	$< 5\times10^{-8}$	$< 3\times10^{-8}$	$< 8.6\times10^{-4}$
^{238}Pu	6.9×10^{-9}	0.7×10^{-9}	6.2×10^{-9}	7.5×10^{-5}
^{239}Pu	6.7×10^{-9}	0.7×10^{-9}	6.0×10^{-9}	7.2×10^{-5}
^{241}Pu	4.4×10^{-7}	$< 3\times10^{-7}$	4.4×10^{-7}	4.8×10^{-3}
^{232}U	2.9×10^{-7}	2.9×10^{-7}	0.08×10^{-8}	3.1×10^{-3}
^{234}U	1.1×10^{-7}	1.1×10^{-7}	0.04×10^{-8}	1.2×10^{-3}
^{238}U	1.1×10^{-8}	1.1×10^{-8}	$< 0.1\times10^{-9}$	1.2×10^{-4}
Solids (mg/1)		2.4×10^{3}	2.1×10^{1}	

N.A.=No Analysis.

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TABLE 15. NUCLEAR FUEL SERVICES LIQUID EFFLUENT SAMPLE—LAGOON-3 COMPOSITE SEPTEMBER 1969

Radionuclide	Microcuries per milliliter			Curies discharged
	Total	Dissolved	Suspended	
Gross α	4.4×10^{-7}	3.9×10^{-7}	0.5×10^{-7}	6.6×10^{-3}
Gross β	8.7×10^{-4}	8.4×10^{-4}	0.3×10^{-4}	1.3×10^{1}
^{3}H	5.1×10^{-3}	5.1×10^{-3}	N.A.	7.7×10^{1}
^{106}Ru	3.8×10^{-4}	3.7×10^{-4}	0.09×10^{-4}	5.7
^{137}Cs	1.5×10^{-4}	1.4×10^{-4}	0.1×10^{-4}	2.3
^{134}Cs	3.7×10^{-5}	3.4×10^{-5}	0.3×10^{-5}	5.6×10^{-1}
^{90}Sr	1.2×10^{-4}	1.2×10^{-4}	0.06×10^{-4}	1.8
^{144}Ce	$<8\times10^{-7}$	$<5\times10^{-7}$	$<3\times10^{-7}$	$<1.2\times10^{-2}$
^{147}Pm	$<6\times10^{-7}$	$<3\times10^{-7}$	$<3\times10^{-7}$	$<9\times10^{-3}$
^{95}Zr	$<1.5\times10^{-7}$	$<1\times10^{-7}$	$<5\times10^{-8}$	$<2.3\times10^{-3}$
^{60}Co	4.0×10^{-6}	4.0×10^{-6}	0.04×10^{-6}	6.0×10^{-2}
^{125}Sb	4.5×10^{-6}	4.5×10^{-6}	$<4\times10^{-8}$	6.8×10^{-2}
^{54}Mn	1.0×10^{-7}	$<5\times10^{-8}$	1.0×10^{-7}	1.5×10^{-3}
^{238}Pu	3.2×10^{-9}	2.1×10^{-9}	1.1×10^{-9}	4.8×10^{-5}
^{239}Pu	3.6×10^{-9}	2.5×10^{-9}	1.1×10^{-9}	5.4×10^{-5}
^{241}Pu	$<4\times10^{-7}$	$<3\times10^{-7}$	$<1\times10^{-7}$	$<6\times10^{-3}$
^{232}U	1.3×10^{-7}	1.3×10^{-7}	0.07×10^{-8}	2.0×10^{-3}
^{234}U	6.5×10^{-8}	6.5×10^{-8}	0.04×10^{-8}	9.8×10^{-4}
^{238}U	1.4×10^{-8}	1.4×10^{-8}	$<0.01\times10^{-8}$	2.1×10^{-4}
Solids (mg/1)		2.6×10^{3}	2.2×10^{1}	

N.A.=No Analysis.

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TABLE 16. NUCLEAR FUEL SERVICES LIQUID EFFLUENT SAMPLE—LAGOON-3 COMPOSITE OCTOBER 1969

Radionuclide	Microcuries per milliliter			Curies discharged
	Total	Dissolved	Suspended	
Gross α	3.2×10^{-7}	3.1×10^{-7}	0.1×10^{-7}	3.9×10^{-3}
Gross β	8.8×10^{-4}	7.3×10^{-4}	1.5×10^{-4}	1.1×10^{1}
^{3}H	3.3×10^{-3}	3.3×10^{-3}	N.A.	4.1×10^{1}
^{106}Ru	3.1×10^{-4}	2.7×10^{-4}	0.4×10^{-4}	3.8
^{137}Cs	2.2×10^{-4}	1.6×10^{-4}	0.6×10^{-4}	2.7
^{134}Cs	4.6×10^{-5}	3.3×10^{-5}	1.3×10^{-5}	5.7×10^{-1}
^{90}Sr	1.2×10^{-4}	1.1×10^{-4}	0.1×10^{-4}	1.5
^{144}Ce	1.8×10^{-6}	$<5\times10^{-7}$	1.8×10^{-6}	2.2×10^{-2}
^{147}Pm	9.0×10^{-7}	$<3\times10^{-7}$	9.0×10^{-7}	1.1×10^{-2}
^{95}Zr	5.6×10^{-8}	$<1\times10^{-7}$	5.6×10^{-8}	6.9×10^{-4}
^{60}Co	2.2×10^{-6}	2.1×10^{-6}	0.1×10^{-6}	2.7×10^{-2}
^{125}Sb	1.6×10^{-5}	1.60×10^{-5}	0.08×10^{-6}	2.0×10^{-1}
^{54}Mn	4.6×10^{-8}	$<5\times10^{-8}$	4.6×10^{-8}	5.7×10^{-4}
^{238}Pu	4.7×10^{-9}	0.2×10^{-9}	4.5×10^{-9}	5.8×10^{-5}
^{239}Pu	6.3×10^{-9}	0.3×10^{-9}	6.0×10^{-9}	7.7×10^{-5}
^{241}Pu	4.0×10^{-7}	$<3\times10^{-7}$	4.0×10^{-7}	4.9×10^{-3}
^{232}U	2.4×10^{-7}	2.2×10^{-7}	0.2×10^{-7}	3.0×10^{-3}
^{234}U	9.0×10^{-8}	8.3×10^{-8}	0.7×10^{-8}	1.1×10^{-3}
^{238}U	9.0×10^{-9}	8.4×10^{-9}	0.6×10^{-9}	1.1×10^{-4}
Solids (mg/1)		1.7×10^{3}	3.2×10^{1}	

N.A.= No analysis

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Since the only alpha emitters measured in the lagoon-3 composites were radionuclides of uranium and plutonium, it is not possible to present data on the relative contributions of individual radionuclides to the total alpha activity of these composites. From the data on the uranium and plutonium, it may be observed that 18 times more uranium alpha activity than plutonium alpha activity was discharged from lagoon-3 during the period May-October 1969. Uranium-232 accounted for about 70 percent of this uranium activity. This relationship is just the reverse of what was the case for the interceptor composites. Twenty times more plutonium alpha activity than uranium alpha activity was discharged from the plant to the interceptor tanks during the period covered by the interceptor composites. This would indicate that the radionuclides of plutonium become insoluble to a greater extent than those of uranium in passing through the lagoon system.

Activity Deposited in Lagoon System

An estimate of the amount of activity deposited in the lagoon system can be made from a comparison of the activity discharged from the plant to the interceptor tanks and the activity discharged from lagoon-3 to the aqueous environment for a given period of time. The lagoon system hold-up period is estimated to be about 1 month. Therefore, all the waste represented by the interceptor composites for the periods of 4/1–5/21/69 and 5/21–8/4/69 would have passed through the lagoon system during the period of 5/1–9/4/69. A comparison of the amounts of activity of the various radionuclides discharged from the plant with the amounts discharged from lagoon-3 to the aqueous environment during this period is presented in table 17.

From the data in table 17, it can be estimated that the following relative amounts of activity leaving the plant were retained in the lagoon system through sedimentation:

(a) 50 percent of the gross beta and 67 percent of the gross alpha.

(b) Greater than 90 percent of the cerium-144, promethium-147, zirconium-95 and plutonium radionuclides.

(c) 70–75 percent of the cesium radionuclides, 59 percent of the cobalt-60, 39 percent of the ruthenium-106, 13 percent of the antimony-125, and only 7 percent of the strontium-90.

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(d) 8.5 times more uranium-232 and 3.8 times more uranium-234 were discharged from lagoon-3 than were discharged from the plant during this period. It would appear that uranium previously deposited in the lagoon sediments from a previous campaign was being redissolved and discharged from lagoon-3 during this period.

Distribution of Radionuclides Between Dissolved and Suspended Solids

The behavior of the various radionuclides in the aqueous environment will be dependent, to a great extent, upon whether the radionuclide remains soluable or becomes associated with the suspended material (insoluble) in the water. Information on the solubility of the radionuclides leaving lagoon-3 is useful in evaluating their behavior in the stream environment. Radionuclides associated with the suspended solids when leaving lagoon-3 can be expected to settle out in the stream shortly after discharge. Their transport in the aqueous environment would then be controlled by the movement of the bottom sediments rather than by the water itself. Table 18 shows the relative amounts of the various radionuclides associated with the dissolved and suspended solids in the water leaving lagoon-3 for the period May-October 1969. Most of the ruthenium-106, strontium-90, antimony-125, cobalt-60, and uranium discharged from lagoon-3 are present in a soluble form. The cesium radionuclides are partially present in both a soluble and insoluble form. Almost all of the cerium-144, promethium-147, zirconium-95, manganese-54, and plutonium are present in an insoluble form. A study of the relationship between these discharged activities and the concentrations present in the aqueous environment is reported in the following section.

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TABLE 17. COMPARISON OF ACTIVITIES DISCHARGED FROM PLANT WITH THOSE DISCHARGED TO AQUEOUS ENVIRONMENT

Radionuclide	Curies discharged		Lagoon-3
	Interceptor [1]	Lagoon-3 [2]	Interceptor
Gross α	1.2×10^{-1}	3.9×10^{-2}	0.33
Gross β	1.2×10^{2}	6.0×10^{1}	0.50
^{106}Ru	7.1×10^{1}	4.3×10^{1}	0.61
^{137}Cs	1.1×10^{1}	3.3	0.30
^{134}Cs	3.8	9.6×10^{-1}	0.25
^{90}Sr	5.6	5.2	0.93
^{144}Ce	8.5	1.4×10^{-1}	0.02
^{147}Pm	4.9	7.8×10^{-2}	0.02
^{95}Zr	9.4×10^{-1}	3.9×10^{-3}	<0.01
^{60}Co	2.9×10^{-1}	1.2×10^{-1}	0.41
^{125}Sb	3.8×10^{-1}	3.3×10^{-1}	0.87
^{54}Mn	5.6×10^{-3}	8.0×10^{-4}	0.14
^{238}Pu	2.5×10^{-2}	5.3×10^{-4}	0.02
^{239}Pu	6.2×10^{-2}	1.0×10^{-3}	0.02
^{241}Pu	2.7	6.5×10^{-2}	0.02
^{232}U	2.0×10^{-3}	1.7×10^{-2}	8.5
^{234}U	1.8×10^{-3}	6.9×10^{-3}	3.8
^{238}U	8.3×10^{-4}	7.6×10^{-4}	0.92

[1] Activities discharged from plant to interceptor tanks from 4/1 to 8/4 1969 with decay correction for 30-day hold-up period.

[2] Activities discharged from lagoon-3 to aqueous environment from 5/1 to 9/4 1969.

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TABLE 18. DISTRIBUTION OF RADIONUCLIDES BETWEEN DISSOLVED AND SUSPENDED SOLIDS IN WATER DISCHARGED FROM LAGOON-3 MAY-OCTOBER 1969

Radionuclide	Total curies discharged	Percent of total activity discharged	
		Dissolved	Suspended
Gross α	4.8×10^{-2}	79	21
Gross β	8.2×10^{1}	89	11
^{106}Ru	5.2×10^{1}	91	9
^{137}Cs	8.0	70	30
^{134}Cs	2.0	69	31
^{90}Sr	8.3	88	12
^{144}Ce	1.6×10^{-1}	0	100
^{147}Pm	9.2×10^{-2}	0	100
^{95}Zr	4.6×10^{-3}	0	100
^{60}Co	2.0×10^{-1}	95	5
^{125}Sb	5.9×10^{-1}	98	2
^{54}Mn	2.7×10^{-3}	0	100
Pu (α)	1.8×10^{-3}	6	94
U (α)	3.2×10^{-2}	92	8

[p. 25]

RELATIONSHIP OF STREAM CONCENTRATIONS TO LAGOON-3 DISCHARGES

Samples Collected

To define the relationship between the concentrations of radio-

nuclides discharged from lagoon-3 and the concentrations present in the Buttermilk and Cattaraugus Creeks, water samples were collected at the point of discharge (lagoon-3) and various locations along the creeks on June 17 and 18 and November 4 and 5, 1969. The locations from which samples were collected on these days are listed below:

Date	*Sampling Location*
June 17	2, 3, 4, 5, 6, 7, 8
June 18	2, 4, 5, 6, 7, 8
June 19	0, 00
November 4	2, 5, 7
November 5	2, 5 (samples were collected at station 5 every 2 hrs from 0830–1430)

These samples were immediately separated in the field into dissolved and suspended solids fractions by filtration through an 0.45 μ membrane filter, and the dissolved solids fractions acidified to 1 percent nitric acid.

Measurements and Results

Both the dissolved and suspended solids fractions of these samples were analyzed for gross alpha, gross beta, ruthenium-106, cesium-134, cesium-137, strontium-90, cerium-144, zirconium-95, cobalt-60, antimony-125, and manganese-54. Tritium was measured in the dissolved solids fractions only. The analytical procedures used in the analysis of these samples are described in Appendix III. Table 19 presents the results of these measurements for the June 1969 samples and table 20 for the November 1969 samples. Cerium-144, zirconium-95, and manganese-54 were not detected in either the dissolved or suspended solids fractions of these samples. Antimony-125, cobalt-60, and gross alpha were not detected in the suspended solids fractions of these samples. The minimum detectable concentrations in μCi/ml for these radionuclides in the samples from the Buttermilk Creek for the volumes analyzed and the counting times used were as follows: cerium-144 = 3×10^{-7}; zirconium-95 = 5×10^{-8}; manganese-54 = 3×10^{-8}; antimony-125 = 4×10^{-8}; cobalt-60 = 3×10^{-10}; gross alpha = 1×10^{-9}.

Plutonium and uranium analyses were carried out on the samples collected from locations 2 and 5 only. The results of these analyses are presented in table 21.

TABLE 19. *RADIONUCLIDE CONCENTRATIONS IN BUTTERMILK AND CATTARAUGUS CREEKS, JUNE 17–18, 1969*

Date	Location	Dissolved solids μCi/ml									Suspended solids μCi/ml				
		^{3}H	Gross α	Gross β	^{106}Ru	^{137}Cs	^{134}Cs	^{90}Sr	^{125}Sb	^{60}Co	Gross β	^{106}Ru	^{137}Cs	^{134}Cs	^{90}Sr
6–17	2	4.3×10^{-2}	5.1×10^{-7}	1.7×10^{-3}	7.8×10^{-4}	2.1×10^{-4}	6.9×10^{-5}	2.2×10^{-4}	7.5×10^{-6}	1.4×10^{-6}	1.7×10^{-5}	2.6×10^{-6}	9.2×10^{-6}	3.1×10^{-6}	2.5×10^{-7}
6–17	3	2.8×10^{-4}	3×10^{-9}	5.9×10^{-6}	4.0×10^{-6}	5.4×10^{-8}	1.8×10^{-8}	4.2×10^{-7}	3.5×10^{-8}	4.3×10^{-9}	1.1×10^{-7}	3.9×10^{-8}	3.7×10^{-8}	1.0×10^{-8}	2×10^{-9}
6–17	4	3.3×10^{-4}	4×10^{-9}	6.5×10^{-6}	4.4×10^{-6}	4.6×10^{-8}	1.5×10^{-8}	5.0×10^{-7}	3.6×10^{-8}	3.8×10^{-9}	1.2×10^{-7}	3.6×10^{-8}	3.8×10^{-8}	1.1×10^{-8}	3×10^{-9}
6–17	5	3.5×10^{-4}	5×10^{-9}	6.6×10^{-6}	4.6×10^{-6}	1.8×10^{-8}	6.0×10^{-9}	5.1×10^{-7}	4.3×10^{-8}	4.5×10^{-9}	8.1×10^{-8}	2.4×10^{-8}	3.3×10^{-8}	8.7×10^{-9}	$<1\times10^{-9}$
6–17	6	3.3×10^{-4}	4×10^{-9}	6.2×10^{-6}	4.3×10^{-6}	1.8×10^{-8}	5.0×10^{-9}	4.8×10^{-7}	4.0×10^{-8}	4.4×10^{-9}	2.0×10^{-7}	1.2×10^{-7}	2.3×10^{-8}	7.9×10^{-9}	$<1\times10^{-9}$
6–17	7	3.3×10^{-5}	$<1\times10^{-9}$	6.7×10^{-7}	5.2×10^{-7}	1.6×10^{-9}	6×10^{-10}	5.0×10^{-8}	4.0×10^{-9}	5×10^{-10}	6.7×10^{-8}	4.5×10^{-8}	1×10^{-9}	$<5\times10^{-10}$	$<1\times10^{-9}$
6–17	8	3.3×10^{-5}	$<1\times10^{-9}$	6.1×10^{-7}	4.7×10^{-7}	1.5×10^{-9}	$<5\times10^{-10}$	4.5×10^{-8}	3.8×10^{-9}	4×10^{-10}	1.2×10^{-8}	7×10^{-9}	1×10^{-9}	$<5\times10^{-10}$	$<1\times10^{-9}$
6–18	2	4.4×10^{-2}	5.8×10^{-7}	1.7×10^{-3}	8.0×10^{-4}	2.1×10^{-4}	6.8×10^{-5}	2.1×10^{-4}	7.4×10^{-6}	1.5×10^{-6}	1.7×10^{-5}	2.9×10^{-6}	1.1×10^{-5}	3.5×10^{-6}	2.1×10^{-9}
6–18	4	4.7×10^{-4}	4×10^{-9}	8.4×10^{-6}	6.5×10^{-6}	3.4×10^{-8}	1.1×10^{-8}	4.7×10^{-7}	4.6×10^{-8}	6.9×10^{-9}	6.5×10^{-8}	2.2×10^{-8}	1.4×10^{-8}	4.4×10^{-9}	NA
6–18	5	3.9×10^{-4}	4×10^{-9}	7.0×10^{-6}	4.9×10^{-6}	1.4×10^{-8}	4.5×10^{-9}	4.5×10^{-7}	4.0×10^{-8}	5.3×10^{-9}	4.9×10^{-8}	1.3×10^{-8}	1.5×10^{-8}	4.5×10^{-9}	NA
6–18	6	3.5×10^{-4}	5×10^{-9}	6.3×10^{-6}	4.3×10^{-6}	1.4×10^{-8}	4.5×10^{-9}	4.0×10^{-7}	4.0×10^{-8}	4.4×10^{-9}	4.3×10^{-8}	1.1×10^{-8}	9.5×10^{-9}	2.2×10^{-9}	NA
6–18	7	2.7×10^{-5}	$<1\times10^{-9}$	4.5×10^{-7}	3.4×10^{-7}	1×10^{-9}	$<5\times10^{-10}$	3.2×10^{-8}	3.2×10^{-9}	3×10^{-10}	3.5×10^{-8}	2.9×10^{-8}	$<1\times10^{-9}$	$<5\times10^{-10}$	NA
6–18	8	2.7×10^{-5}	$<1\times10^{-9}$	4.6×10^{-7}	3.6×10^{-7}	1×10^{-9}	$<5\times10^{-10}$	3.2×10^{-8}	3.0×10^{-9}	3×10^{-10}	1.5×10^{-8}	1.1×10^{-8}	$<1\times10^{-9}$	$<5\times10^{-10}$	NA
6–19	0	1.0×10^{-6}	$<1\times10^{-9}$	1.1×10^{-8}	1.1×10^{-8}	$<1\times10^{-9}$	$<5\times10^{-10}$	$<1\times10^{-9}$	$<2\times10^{-9}$	$<3\times10^{-10}$	1.3×10^{-8}	1.0×10^{-8}	$<1\times10^{-9}$	$<5\times10^{-10}$	NA
6–19	00	1.0×10^{-6}	$<1\times10^{-9}$	2.0×10^{-8}	1.6×10^{-8}	$<1\times10^{-9}$	$<5\times10^{-10}$	$<1\times10^{-9}$	$<2\times10^{-9}$	$<3\times10^{-10}$	1.4×10^{-8}	1.1×10^{-8}	$<1\times10^{-9}$	$<5\times10^{-10}$	NA

NA—No Analysis

TABLE 20. RADIONUCLIDE CONCENTRATIONS IN BUTTERMILK AND CATTARAUGUS CREEKS, NOVEMBER 4 AND 5, 1969

Date	Location	Dissolved solids μCi/ml									Suspended solids μCi/ml				
		^{3}H	Gross α	Gross β	^{106}Ru	^{137}Cs	^{134}Cs	^{90}Sr	^{125}Sb	^{60}Co	Gross β	^{106}Ru	^{137}Cs	^{134}Cs	^{90}Sr
11/4	2	1.2×10^{-2}	4.9×10^{-7}	1.1×10^{-3}	3.7×10^{-4}	1.5×10^{-4}	2.9×10^{-5}	2.7×10^{-4}	3.1×10^{-5}	5.9×10^{-6}	2.6×10^{-4}	2.8×10^{-5}	1.9×10^{-4}	3.6×10^{-5}	5.1×10^{-6}
11/4	5	1.4×10^{-5}	1.4×10^{-9}	1.5×10^{-6}	4.3×10^{-7}	1.5×10^{-8}	$<1\times10^{-8}$	3.0×10^{-7}	4.5×10^{-8}	$<1\times10^{-8}$	6.5×10^{-7}	7.0×10^{-8}	3.1×10^{-7}	7.0×10^{-8}	4.0×10^{-9}
11/4	7	3.4×10^{-6}	$<1\times10^{-9}$	2.7×10^{-7}	7.5×10^{-8}	$<1\times10^{-8}$	$<1\times10^{-8}$	6.9×10^{-8}	$<4\times10^{-8}$	$<1\times10^{-8}$	1.2×10^{-7}	2.0×10^{-8}	6.2×10^{-8}	2.0×10^{-8}	$<1\times10^{-9}$
11/5	2	9.6×10^{-2}	2.0×10^{-7}	1.5×10^{-3}	4.8×10^{-4}	3.3×10^{-4}	7.0×10^{-5}	2.7×10^{-4}	3.0×10^{-5}	8.7×10^{-6}	1.6×10^{-4}	6.6×10^{-5}	1.2×10^{-5}	2.5×10^{-6}	2.4×10^{-6}
11/5	5-1[1]	5.0×10^{-6}	1.3×10^{-9}	9.0×10^{-7}	1.7×10^{-7}	1.4×10^{-8}	$<1\times10^{-8}$	2.7×10^{-7}	$<4\times10^{-8}$	$<1\times10^{-8}$	1.5×10^{-7}	4.0×10^{-8}	7.2×10^{-8}	2.0×10^{-8}	$<2\times10^{-9}$
11/5	5-2	6.6×10^{-6}	1.2×10^{-9}	1.1×10^{-6}	2.2×10^{-7}	1.4×10^{-8}	$<1\times10^{-8}$	3.7×10^{-7}	$<4\times10^{-8}$	$<1\times10^{-8}$	1.8×10^{-7}	6.0×10^{-8}	6.7×10^{-8}	1.5×10^{-8}	N.A.
11/5	5-3	7.6×10^{-6}	1.6×10^{-9}	1.2×10^{-6}	2.6×10^{-7}	1.6×10^{-8}	$<1\times10^{-8}$	3.8×10^{-7}	$<4\times10^{-8}$	$<1\times10^{-8}$	1.7×10^{-7}	4.0×10^{-8}	9.3×10^{-8}	2.0×10^{-8}	N.A.
11/5	5-4	1.8×10^{-4}	1.7×10^{-9}	2.2×10^{-6}	8.1×10^{-7}	2.8×10^{-8}	$<1\times10^{-8}$	4.7×10^{-7}	8.0×10^{-8}	$<1\times10^{-8}$	4.5×10^{-7}	1.1×10^{-7}	1.7×10^{-7}	4.0×10^{-8}	$<2\times10^{-9}$

[1] Sample 5-1 was collected at 0:830, 5-2 at 10:30, 5-3 at 12:30 and 5-4 at 14:30

N.A.—No Analysis

TABLE 21. URANIUM AND PLUTONIUM CONCENTRATIONS IN BUTTERMILK CREEK JUNE 17 AND NOVEMBER 4, 1969

Location	Date	Dissolved solids μCi/ml					Suspended solids μCi/ml				
		^{232}U	^{234}U	^{238}U	^{238}Pu	^{239}Pu	^{232}U	^{234}U	^{238}U	^{238}Pu	^{239}Pu
2	6/17	3.4×10^{-7}	1.3×10^{-7}	1.3×10^{-8}	6.0×10^{-10}	1.1×10^{-9}	N.A.	N.A.	N.A.	5.0×10^{-9}	8.0×10^{-9}
5	6/17	3.4×10^{-9}	1.4×10^{-9}	2.2×10^{-10}	$<2\times10^{-11}$	$<2\times10^{-11}$	$<1\times10^{-11}$	2×10^{-11}	2×10^{-11}	$<1\times10^{-11}$	$<1\times10^{-11}$
2	11/4	2.9×10^{-7}	1.1×10^{-7}	9.7×10^{-9}	3.7×10^{-9}	4.5×10^{-9}	4.0×10^{-9}	1.7×10^{-9}	3.5×10^{-10}	1.2×10^{-8}	1.5×10^{-8}
5	11/4	6.0×10^{-10}	3.0×10^{-10}	1.2×10^{-10}	$<1\times10^{-11}$	$<1\times10^{-11}$	N.A.	N.A.	N.A.	1.5×10^{-11}	1.8×10^{-11}

N.A.—No Analysis

Stream and Discharge Variables

June - 1969

Prior to the sampling, waste had been discharged from lagoon-3 continuously since June 10. The discharge rate had been adjusted periodically according to the flow in Cattaraugus Creek. On June 17 the discharge rate from lagoon-3 was 95 gal/min and on June 18 it was 75 gal/min. The pH of the discharge was 11.5.

The flow-rate of the Buttermilk Creek was calculated to be 1.2×10^4 gal/min on June 17 and 8.5×10^3 gal/min on June 18. The flow-rate of the Cattaraugus Creek was calculated to be 1.2×10^5 gal/min on both 6/17 and 6/18.[5] Nuclear Fuel Services (*5*) reported the Cattaraugus Creek flow-rate to be 1.3 and 1.1×10^5 gal/min on these days.

The suspended solids concentration in the water leaving lagoon-3 was 7 mg/1 on 6/17 and 6 mg/1 on 6/18. The concentration in the Buttermilk Creek on these days ranged from 8–10 mg/1. The suspended solids concentration in Cattaraugus Creek on these days was not measured.

November - 1969

Prior to the sampling on November 4, waste had been discharged from lagoon-3 continuously since October 31 at a rate of 60 gal/min and a pH of 9.5. The discharge was terminated at 11:00 a.m. on November 4 and resumed at 9:00 a.m. November 5 at a flow-rate of 75 gal/min and a pH of 7. The samples collected on November 4 are representative of stream conditions during continuous discharge (prior to shutdown). The samples collected on November 5 are representative of stream conditions during a non-discharge period and during the initial stages following the resumption of discharge prior to establishment of equilibrium between the discharge and the streams.

The flow-rate of the Buttermilk Creek was calculated to be 5.2×10^4 gal/min on 11/4 and 4.0×10^4 gal/min on 11/5. The flow-rate in the Cattaraugus Creek was calculated to be 2.1×10^5 gal/min on 11/4. The suspended solids concentrations in mg/1 on these days were as follows:

	NOVEMBER 4	*NOVEMBER 5*
Lagoon-3	78	11
Buttermilk Creek	160	70
Cattaraugus Creek	190	42

[5] The flow-rates were calculated from the tritium concentrations as follows:

$$\text{Flow-rate gal/min} = \frac{{}^3\text{H conc in lagoon-3}}{{}^3\text{H conc in creek}} \times \text{gal/min leaving lagoon-3}$$

Data Evaluation

Tritium, ruthenium-106, and strontium-90 were the principal radionuclides present in the Buttermilk and Cattaraugus Creeks during both the sampling periods. Other radionuclides measured in the creeks, but in lower concentrations, were cesium-137, cesium-134, antimony-125, cobalt-60, uranium-232, uranium-234 and uranium-238. Almost all of the activity of those radionuclides detected in the creeks were associated with the dissolved solids with the exception of the radionuclides of cesium. For the cesium radionuclides, 40–95 percent of their activity was associated with the suspended solids. The cesium radionuclide concentration in a water sample increased with the suspended solids concentration and the percentage associated with the suspended solids fractions also increased. Listed in table 22 are the relative contributions of the various radionuclides to the beta activity (exclusive of ^{3}H) in Buttermilk and Cattaraugus Creeks for the June and November 1969 sampling periods.

TABLE 22. RADIONUCLIDES CONTRIBUTING TO BETA ACTIVITY OF BUTTERMILK AND CATTARAUGUS CREEKS

Radionuclide	Percent of beta activity[1]			
	Buttermilk Creek-Site 5		Cattaraugus Creek-Site 7	
	6/17/69	11/4/69	6/17/69	11/4/69
^{106}Ru	88	40	91	39
^{90}Sr	10	24	8	28
^{137}Cs	0.8	26	0.4	25
^{134}Cs	0 3	6	0.1	8
^{125}Sb	0.8	4	0.6	—
^{60}Co	<0.1	<0.1	<0.1	—

[1] Relative contribution of the individual radionuclide to the sum total of the activities of the radionuclides listed.

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The strontium-90, cesium-134, and cesium-137 contributions to the beta activity in November 1969 were greater than in June 1969. These differences in relative distribution of beta activity were due to a number of factors, such as: a) the waste discharged during the two periods had different distributions of beta activity, b) the November creek samples had high suspended solids concentrations resulting in higher cesium-134 and -137 concentrations, c) the pH of the November discharge was considerably lower than that of June resulting in lower absorption of strontium-90 by the stream system (see section below).

Absorption of Radionuclides by Stream

The ratio of the concentration of a radionuclide in the dissolved solids fractions of water leaving lagoon-3 to the concentration in the dissolved solids fractions of water at a location on a stream can be used to describe the behavior of that radionuclide in the stream environment and this ratio will be defined as the Effective Dilution Factor. The Effective Dilution Factor can be further defined as follows:

EDF = (DF) (AF)
EDF = Effective Dilution Factor
DF = Water Dilution Factor
AF = Stream Absorption Factor

The ratio of the tritium concentration in the water leaving lagoon-3 to the concentration in the water at a location is a measure of the Water Dilution Factor (DF). All other processes which remove a radionuclide from the water are included in the Stream Absorption Factor (AF).

Table 23 presents the Effective Dilution Factors and table 24 presents the Stream Absorption Factors for the radionuclides present in Buttermilk and Cattaraugus Creeks during June 17, 18 and November 4, 1969.

As stated above the Effective Dilution Factor for tritium is equal to the Water Dilution Factor for the streams. The Water Dilution Factor is a function of the flow-rates of the water leaving lagoon-3 and the water in Buttermilk and Cattaraugus Creeks and will vary according to these flows.

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TABLE 23. EFFECTIVE DILUTION FACTORS FOR RADIONUCLIDES IN BUTTERMILK AND CATTARAUGUS CREEKS JUNE 17, 18, AND NOVEMBER 4, 1969

Location	Date	Effective dilution factor (EDF)					
		^{3}H	^{106}Ru	^{137}Cs	^{90}Sr	^{125}Sb	^{60}Co
3	6/17	1.5×10^{2}	2.0×10^{2}	3.8×10^{3}	5.2×10^{2}	2.1×10^{2}	3.3×10^{2}
5	6/17	1.2×10^{2}	1.8×10^{2}	1.2×10^{4}	4.3×10^{2}	1.7×10^{3}	3.1×10^{3}
7	6/17	1.3×10^{3}	1.5×10^{3}	1.3×10^{5}	4.4×10^{3}	1.9×10^{3}	2.8×10^{3}
5	6/18	1.1×10^{2}	1.6×10^{2}	1.5×10^{4}	4.7×10^{2}	1.9×10^{2}	2.8×10^{2}
7	6/18	1.6×10^{3}	2.4×10^{3}	2.1×10^{5}	6.6×10^{3}	2.3×10^{3}	5.0×10^{3}
5	11/4	8.5×10^{2}	8.6×10^{2}	1.0×10^{4}	9.0×10^{2}	6.9×10^{3}	—
7	11/4	3.5×10^{3}	4.9×10^{3}	—	3.9×10^{3}	—	—

TABLE 24. STREAM ABSORPTION FACTORS FOR RADIONUCLIDES IN BUTTERMILK AND CATTARAUGUS CREEKS JUNE 17, 18, AND NOVEMBER 4, 1969

Location	Date	Stream absorption factors-AF				
		^{106}Ru	^{137}Cs	^{90}Sr	^{125}Sb	^{60}Co
3	6/17	1.3	2.5×10^{1}	3.5	1.4	2.2
5	6/17	1.5	1.0×10^{2}	3.6	1.4	2.6
7	6/17	1.2	1.0×10^{2}	3.4	1.5	2.2
5	6/18	1.5	1.4×10^{2}	4.3	1.7	2.5
7	6/18	1.5	1.3×10^{2}	4.1	1.4	3.1
5	11/4	1.0	1.2×10^{1}	1.1	0.8	—
7	11/4	1.4	—	1.1	—	—

The Stream Absorption Factors for June 17 indicate that most of the removal of activity by absorption takes place during passage of the water between sites 2 and 3. This may be due to the pH of the water which was 11.5 upon discharge from lagoon-3. The absorption of the radionuclides takes place while the waste is still basic, prior to dilution by the streams. The Stream Absorption Factor for strontium-90 on November 4 was 1.1, a factor of about 3 less than on June 17. The pH of the waste discharge had been reduced to 7 and this appears to have resulted in a lower removal of strontium-90 by the stream system. The amounts of activity removed from the water in its passage between lagoon-3 and the Cattaraugus Creek may be estimated from the Stream Absorption Factors for site 7. These values for the 2 sampling periods are presented below in table 25.

TABLE 25. RELATIVE AMOUNTS OF ACTIVITY REMOVED FROM WATER IN PASSAGE FROM LAGOON-3 TO CATTARAUGUS CREEK

Radionuclide	Percent of activity removed in stream	
	June 17, 18, 1969	November 4, 1969
^{106}Ru	26	29
^{137}Cs	>99	>99
^{90}Sr	72	9
^{125}Sb	31	—
^{60}Co	66	—

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COMPARISON OF THE CONCENTRATIONS OF RADIONUCLIDES IN CATTARAUGUS CREEK WITH THE 10CFR20 DISCHARGE CONCENTRATION LIMITS

A comparison of the concentrations of the radionuclides in Cattaraugus Creek with the 10CFR20 discharge concentration

limits (*6*) was made to provide information of the relative dosimetric importance of these radionuclides. Presented below in table 26 are the fractions of the 10CFR20 discharge concentration limits for each of the radionuclides measured in Cattaraugus Creek on June 17 and November 4, 1969.

TABLE 26. FRACTIONS OF 10CFR20 DISCHARGE CONCENTRATION LIMITS IN CATTARAUGUS CREEK[1] FOR INDIVIDUAL RADIONUCLIDES

Radionuclide	Fraction of concentration limit	
	June 17, 1969	November 4, 1969
^{90}Sr	1.7×10^{-1}	2.3×10^{-1}
^{106}Ru	5.2×10^{-2}	7.5×10^{-3}
^{3}H	1.1×10^{-2}	1.0×10^{-3}
^{137}Cs	8.0×10^{-5}	1.5×10^{-3}
^{125}Sb	4.0×10^{-5}	$<4\times10^{-4}$
^{60}Co	1×10^{-5}	$<2\times10^{-4}$

[1] Sample collected at site 7 (Felton Bridge)

These data show that strontium-90 at about 20 percent of the concentration limit is the radionuclide of most dosimetric significance in the Cattaraugus Creek. Ruthenium-106 and tritium concentrations also exceeded 1 percent of the concentration limits on June 17.

The cesium-137 concentration in Cattaraugus Creek is only a very small fraction of the concentration limit. However, the data on cesium-137 in fish (*7*) indicate concentrations which are dosimetrically significant when the fish is ingested. This shows that a comparison of concentration of a radionuclide with the concentration limit is only one of the factors which must be considered in evaluating the dosimetric significance of that radionuclide since the concentration limit does not take into consideration concentration which may occur in the pathways to man; such as, fish, deer, or other wildlife which are influenced by the stream system.

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Shleien (*8*) has calculated the dose commitments accrued in 1968 for ^{90}Sr, ^{137}Cs, ^{131}Cs, ^{106}Ru, and ^{3}H ingested in fish from the Cattaraugus Creek for typical and maximum individuals.

RADIONUCLIDES IN BOTTOM SEDIMENTS FROM BUTTERMILK AND CATTARAUGUS CREEKS

Samples Collected

Bottom sediments were collected from sites 5 and 8 on May 28, 1968, June 19 and November 6, 1969. The samples were collected

using a scoop near the edge of the stream where sediments were likely to collect. The sample was then passed through a coarse screen to remove leaves, sticks, etc.

Measurements and Results

The sediment samples were analyzed for ruthenium-106, cesium-134, cesium-137, strontium-90, cobalt-60, plutonium-238, and plutonium-239. Table 27 presents the results of these measurements in microcuries per gram of dried sediment. The analytical techniques used are described in Appendix III.

Data Evaluation

The concentrations of radionuclides in the sediments from site 8 increased with each collection. This increase in concentration may have been due to: a) an increase in the plant discharge, b) a stream variable influencing the bottom sediments, and c) a variable in the sample collection.

The evaluation of sediment sample data is very difficult due to the variable nature of the stream bottom from one collection period to another and to the variability in sample collection from one period to another (*9*). It was not within the scope of this phase of the study to investigate these variables. A much more detailed study of bottom sediments will be required in order to define the usefulness of sediment sampling in environmental surveillance programs.

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TABLE 27. RADIONUCLIDE CONCENTRATIONS IN BOTTOM SEDIMENTS FROM BUTTERMILK AND CATTARAUGUS CREEKS

Date	Location	Concentration microcuries/gram						
		^{106}Ru	^{137}Cs	^{134}Cs	^{90}Sr	^{60}Co	^{238}Pu	^{239}Pu
5/28/68	5	8.0×10^{-5}	7.0×10^{-5}	1.2×10^{-5}	2.6×10^{-6}	4.9×10^{-7}	5.0×10^{-8}	9.1×10^{-8}
5/28/68	8	8.0×10^{-6}	1.2×10^{-5}	1.7×10^{-6}	8.0×10^{-7}	1.7×10^{-7}	1.2×10^{-8}	2.3×10^{-8}
6/19/69	5	1.3×10^{-4}	1.1×10^{-4}	2.1×10^{-5}	1.3×10^{-5}	1.5×10^{-6}	3.0×10^{-8}	5.0×10^{-8}
6/19/69	8	3.4×10^{-5}	3.5×10^{-5}	7.7×10^{-6}	9.9×10^{-6}	2.1×10^{-7}	N.A.	N.A.
11/6/69	5	1.1×10^{-4}	1.1×10^{-4}	2.2×10^{-5}	1.3×10^{-5}	1.3×10^{-6}	N.A.	N.A.
11/6/69	8	1.9×10^{-4}	9.4×10^{-5}	2.9×10^{-5}	2.2×10^{-5}	2.3×10^{-6}	6.3×10^{-8}	5.3×10^{-8}

SUMMARY

The liquid waste affluents from Nuclear Fuel Services were studied during a 6-month period from May through October 1969. Composite samples of the liquid discharge were collected at the interceptor tanks, the point of discharge from the plant, during each of 3 fuel processing campaigns. At the same time, monthly composites were collected from lagoon-3, the point of discharge to the aqueous environment. These samples were analyzed for their specific radionuclide content and from the volume of water represented by the composite, the total activity of each radionuclide for a given discharge period was calculated.

The same radionuclides were discharged from the plant during each of the three campaign periods studied. No relationship could be established between the amount and burnup of fuel processed and the amount of activity discharged from the plant to the lagoon system during these periods. For the Yankee fuel campaign of May-August 1969, the waste management practice and not the amount of fuel processed was the controlling factor in the amount of activity discharged from the plant to the lagoon system.

It was estimated that greater than 90 percent of the cerium-144, promethium-147, zirconium-95, plutonium-238, plutonium-239, and plutonium-241, and 75 percent of the cesium-134 and cesium-137 discharged from the plant were deposited by sedimentation in the lagoon system, and therefore, not discharged to the aqueous environment. About 70 percent of the ruthenium-106 and 90 percent of the strontium-90 and antimony-125, discharged from the plant passed through the lagoon system and were discharged to the stream system.

The amounts of specific radionuclides discharged from the lagoon system to the aqueous environment during the period May-October 1969 were as follows:

Radionuclide	Curies discharged	Radionuclide	Curies discharged
^{3}H	1.7×10^{3}	^{95}Zr	4.6×10^{-3}
^{106}Ru	5.2×10^{1}	^{60}Co	2.0×10^{-1}
^{137}Cs	8.0	^{125}Sb	5.9×10^{-1}
^{134}Cs	2.0	^{54}Mn	2.7×10^{-3}
^{90}Sr	8.3	$Pu(\alpha)$	1.8×10^{-3}
^{144}Ce	1.6×10^{-1}	$U(\alpha)$	3.2×10^{-2}
^{147}Pm	9.2×10^{-2}	Gross α	4.8×10^{-2}
		Gross β	8.2×10^{1}

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During June and November 1969 simultaneous sampling was

carried out at lagoon-3, the point of discharge, and several locations on the stream system influenced by the discharge. Tritium, ruthenium-106, and strontium-90 were the radionuclides present in the highest concentrations in the Buttermilk and Cattaraugus Creeks during these periods. Dilution factors were calculated at various locations for each of the radionuclides measured in the stream samples. From these data, an estimate was made of the relative amount of a radionuclide removed from the water in passage from lagoon-3 to the Cattaraugus Creek. These data for strontium-90 showed that 75 percent of the strontium-90 discharged was removed from the water during June when the plant discharge was pH = 11 and only 10 percent of the strontium-90 discharged was removed from the water during November when the plant discharge was pH = 7.

A comparison of the concentrations of radionuclides in the Cattaraugus Creek (the unrestricted aqueous environment) with the 10CFR20 discharge concentration limits showed that strontium-90 was about 20 percent of the concentration limit during both sampling periods. Ruthenium-106 was 5 percent of the concentration limit during June and about 1 percent in November. Tritium was 1 percent of the concentration limit in June, and 0.1 percent in November. All other radionuclide concentrations were less than 1 percent of the concentration limits during both the sampling periods.

CONCLUSIONS AND RECOMMENDATIONS

The results of this report pertain primarily to the design of surveillance programs around nuclear fuel reprocessing plants and the designation of significant radionuclides and environmental pathways. In order to maintain an evaluation of the radionuclides released to the aquatic environment and to continually estimate the population exposure from this pathway, a program of periodic checks would have to be made relative to the following factors:

1. The waste discharged should be monitored for significant individual radionuclides. Specific analyses should be carried out for tritium, ruthenium-106, strontium-90, cesium-134, and cesium-137 in composite samples from lagoon-3: The frequency of analysis should be determined by the concentrations of the radionuclides released but at a minimum should be carried out monthly.

2. Specific analysis should be performed for tritium, ruthenium-106, strontium-90, cesium-134, and cesium-137 in composite samples of water from Cat-

taraugus Creek. Frequency of analysis should be determined by the concentrations of radionuclides present but at a minimum should be carried out monthly.

3. Determination should be made of the concentrations of tritium, ruthenium-106, strontium-90, cesium-134, and cesium-137 in the edible portions of fish, deer, and other wildlife which would be influenced by the radionuclides present in the stream environment.

4. Radiation dose estimates should be made by establishing the size of the human population at risk for ingestion of fish and wildlife and the intakes of the significant radionuclides via these pathways.

Work in these areas is currently being pursued by the facility, the New York Department of Environmental Conservation, and the U.S. Public Health Service. Activities of this nature would be applicable for similar facilities in similar environments.

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(3) JOINT COMMITTEE ON ATOMIC ENERGY, Congress of the United States. Part II. Hearing on the environmental effects of producing electric power. Statement by T. C. Runion, President of Nuclear Fuel Services, Inc., U.S. Government Printing Office, Washington, D.C. (1970).

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4.3 URANIUM MINERS EXPOSURE GUIDELINES

4.3a RADIATION PROTECTION GUIDELINES, FEDERAL RADIATION COUNCIL

January 15, 1969, 34 Fed. Reg. 576 (1969)

MEMORANDUM FOR THE PRESIDENT

DECEMBER 27, 1968.

Pursuant to Executive Order 10831 and Public Law 86–373, the Federal Radiation Council transmits to you additional information and recommendations for the guidance of Federal agencies in their conduct of radiation protection activities as they apply to the underground mining of uranium ore.

As noted in its July 21, 1967, memorandum for the President, the Council stated that in approximately 1 year it would review its guidance for radiation protection in uranium mining, and if indicated the recommendations would be changed accordingly. The three recommendations were:

1. Occupational exposure to radon daughters in underground uranium mines be controlled so that no individual miner will receive an exposure of more than 6 WLM in any consecutive 3-month period and no more than 12 WLM in any consecutive 12-month period. Actual exposures should be kept as far below these values as practicable.

2. Areas in underground uranium mines, whether normally or occasionally occupied, be monitored for the concentration of radon daughters in mine air. The location and frequency of taking samples should be determined in relation to compliance with recommendation number 1.

3. Appropriate records of the exposure from radon daughters in the mine air received by individuals working in uranium mines be established and maintained.

As used in this memorandum, the "Working Level" (WL) is defined as any combination of the short-lived radon daughters in one liter of air that will result in the ultimate emission of 1.3×10^5 MeV of potential alpha energy. Exposure to these radon daughters over a period of time may be expressed in terms of Working Level Months (WLM). Inhalation of air containing a radon daughter concentration of 1 WL for 170 hours results in an exposure of 1 WLM.

For its review the Council had the following information, which was developed over the past 18 months.

(a) Three reports from a special task group established to review progress made in radiation protection practices in uranium mines. The task group consisted of representatives of Federal and State agencies, industry, labor, medical, and standard-setting organizations.

(b) A report by the Resource Management Corporation on a short-term study of the impact of uranium mining safety standards on the uranium producing and nuclear power industries.

(c) A report by the advisory committee to the FRC from the Division of Medical Sciences of the National Academy of Sciences-National Research Council (NAS-NRC). This report, "Radiation Exposure of Uranium Miners," included a review of the testimony presented in the 1967 hearings of the Joint Committee on Atomic Energy, as well as the updated epidemiology study conducted by the U.S. Public Health Service.

(d) U.S. Department of Labor hearings on Radiation Standards for Mining under the Walsh-Healey Public Contracts Act, November 20 and 21, 1968.

On the basis of its review of the information, the Council has reached the following conclusions:

1. That available data are still insufficient, though somewhat more complete than they were when the Council made its recommendations to the President on July 21, 1967, to determine an exposure level at or below which underground uranium miners may be exposed without significantly increased risk of lung cancer.

2. That available data indicate a higher than expected mortality rate in the lower exposure categories (i.e., less than 840 WLM) as well as in the higher categories (i.e., larger than 840 WLM).

The Council therefore recommends that:

1. Occupational exposure to radon daughters in underground uranium mines be controlled

so that no individual miner will receive an exposure of more than 6 WLM in any consecutive 3-month period and no more than 12 WLM in any consecutive 12-month period. Actual exposures should be kept as far below these values as practicable.

2. Areas in underground uranium mines, whether normally or occasionally occupied, be monitored for the concentration of radon daughters in mine air. The location and frequency of taking samples should be determined in relation to compliance with recommendation number 1.

3. Appropriate records of the exposure from radon daughters in the mine air received by individuals working in uranium mines be established and maintained.

4. As a policy measure of prudence the agencies having responsibility for regulating the uranium mining industry be advised that the Federal Radiation Council recommends an annual exposure level of 4 WLM as of January 1, 1971.

5. Prior to this date, the Council will consider all pertinent information including epidemiological data, miner exposure records, health considerations, mining practices and costs thereof, and applicable research and development results, to determine whether or not to modify this recommendation.

6. The uranium mining industry is urged to continue efforts to progressively lower exposure levels in the mines so that the anticipated 4 WLM standard can be attained by January 1, 1971.

7. To assist the Council in its periodic review of radiation protection in uranium mines an interagency group will be established with representation from agencies of the Council. This group will keep all relevant information and developments under continuing surveillance and make reports to the Council in advance of its periodic review.

8. Agencies having responsibility for the protection of underground uranium miners should establish levels of radon daughter concentrations in underground uranium mines above which (a) occupancy would be restricted or prohibited, and (b) action would be required to reduce concentrations. Such limits on concentrations are intended to assist in ensuring that exposures of individual miners are held within the approved guidance. In general, adequate control of the environment is recommended over achieving compliance with the exposure guide by distributing exposures over a larger number of miners.

Cigarette smoking in uranium mines. As noted in the task group reports and the report of the NAS-NRC advisory committee to the FRC, existing data strongly suggest that cigarette smokers among the underground uranium miners are particularly susceptible to lung cancer. This may be a synergistic effect between the inhalation of cigarette smoke and radon daughter products or other materials associated with uranium mining. Therefore, the Council urges that concerted effort be made by all concerned to discourage cigarette smoking by underground uranium miners.

If the foregoing recommendations are approved by you for the guidance of Federal agencies in the conduct of their radiation protection activities, it is further recommended that this memorandum be published in the FEDERAL REGISTER.

WILBUR J. COHEN,
Chairman.

The recommendations in the preceding memorandum are approved for the guidance of Federal agencies, and the memorandum shall be published in the FEDERAL REGISTER.

LYNDON B. JOHNSON.

4.3b RADIATION PROTECTION GUIDELINES, FEDERAL RADIATION COUNCIL

December 18, 1970, 35 Fed. Reg. 19218 (1970)

MEMORANDUM FOR THE PRESIDENT

DECEMBER 1, 1970.

In accordance with Executive Order 10831 and Public Law 86–373, the Federal Radiation Council transmits to you a recom-

mendation for the modification of guidance applicable to Federal agencies in their conduct of radiation protection activities as it applies to underground mining of uranium ore.

The latest recommendations of the Federal Radiation Council on this subject were submitted to the President in a memorandum, December 27, 1968. The recommendations were approved by the President on January 11, 1969, and the memorandum was published in the FEDERAL REGISTER, January 15, 1969 (34F.R. 576). The memorandum contained four recommendations bearing directly on the modification recommended now. These were:

1. Occupational exposure to radon daughters in underground uranium mines be controlled so that no individual miner will receive an exposure of more than 6 WLM in any consecutive 3-month period and no more than 12 WLM in any consecutive 12-month period. Actual exposures should be kept as far below these values as practicable.

4. As a policy measure of prudence the agencies having responsibility for regulating the uranium mining industry be advised that the Federal Radiation Council recommends an annual exposure level of 4 WLM as of January 1, 1971.

5. Prior to this date, the Council will consider all pertinent information including epidemiological data, miner exposure records, health considerations, mining practices and costs thereof, and applicable research and development results, to determine whether or not to modify this recommendation.

7. To assist the Council in its periodic review of radiation protection in uranium mines an interagency group will be established with representation from agencies of the Council. This group will keep all relevant information and developments under continuing surveillance and make reports to the Council in advance of its periodic review.

Pursuant to recommendation 7, the Interagency Uranium Mining Radiation Review Group was established under the chairmanship of the Surgeon General, U.S. Public Health Service. At its last meeting the Interagency Group concluded that the information that would permit the Council to fulfill adequately the requirement of recommendation 5 would not be available in time to permit the Council to reconsider the guidance before the date in recommendation 4. Accordingly, the Group recommended to the Council that the date in recommendation 4 be changed to July 1, 1971.

The Federal Radiation Council concurs in the judgment of the Interagency Group that more time is needed to take the action provided for in recommendation 5, and agrees that a postponement for the period of time required to complete the review is desirable.

The Council, therefore, recommends that the date in recommendation 4 of the Council's memorandum of December 27, 1968, to the President, be changed to July 1, 1971.

If the foregoing recommendation is approved by you for the guidance of Federal agencies in the conduct of their radiation pro-

tection activities, it is further recommended that this memorandum be published in the FEDERAL REGISTER.

ELLIOT L. RICHARDSON,
Chairman.

The recommendation in the preceding memorandum is approved for the guidance of Federal agencies and the memorandum shall be published in the FEDERAL REGISTER.

RICHARD NIXON.

4.3c RADIATION PROTECTION GUIDANCE, UNDERGROUND MINING OF URANIUM ORE, ENVIRONMENTAL PROTECTION AGENCY

May 25, 1971, 36 Fed. Reg. 9480 (1971)

UNDERGROUND MINING OF URANIUM ORE

RADIATION PROTECTION GUIDANCE FOR FEDERAL AGENCIES

The President's Reorganization Plan No. 3 of 1970 transferred to the Environmental Protection Agency (EPA) the functions of the former Federal Radiation Council (FRC) which was established under Executive Order 10831 and Public Law 86–373. These functions include recommending radiation protection guidance for Federal agencies.

In a memorandum to the President published in the FEDERAL REGISTER on December 18, 1970, the FRC recommended that annual exposure levels of miners to radon daughters in underground uranium mines should be no more than 4 WLM,[1] effective as of July 1, 1971. This memorandum also recommended that the FRC consider additional information to determine whether or not to modify this recommendation. The additional information has been considered and the Administrator of EPA has concluded that this recommendation should not be modified.

Public comment on this matter is invited.

BACKGROUND

The FRC, noting an increase in the 1960s in lung cancer among underground uranium miners in the United States associated with

[1] "WLM" is Working Level Months, a term commonly used to express a miner's calculated exposure to radon daughter products found in the mine air. This is derived from the Working Level (WL), a unit which is defined as any combination of short-lived radon daughters in one liter of air that will result in the ultimate emission of 1.3×10^5 MeV of potential alpha energy.

the inhalation of radioactive materials, undertook a study of the problem, resulting in issuance of Report No. 8, "Guidance for the Control of Radiation Hazards in Uranium Mining," in September 1967.

The FRC submitted three memorandums to the President on this subject, and the recommendations contained in the memorandums were approved by the President. In the first memorandum, approved by the President and published in the FEDERAL REGISTER on August 1, 1967, 32 F.R. 1183, the FRC initially considered exposure guidance of 36, 12 and 4 WLM per year. It concluded that the best balance between risks to the miners and control capability was a limit of 12 WLM per year based on the information available at that time on epidemiological studies, animal experiments, miner exposure records, health considerations, mining practices and costs thereof, and applicable research and development results.

The second memorandum, approved by the President and published in the FEDERAL REGISTER on January 15, 1969, 34 F.R. 576, includes, among others, the following five recommendations:

1. Occupational exposure to radon daughters in underground uranium mines be controlled so that no individual miner will receive an exposure of more than 6 WLM in any consecutive 3-month period and no more than 12 WLM in any consecutive 12-month period. Actual exposures should be kept as far below these values as practicable.

4. As a policy measure of prudence the agencies having responsibility for regulating the uranium mining industry be advised that the Federal Radiation Council recommends an annual exposure level of 4 WLM as of January 1, 1971.

5. Prior to this date, the Council will consider all pertinent information including epidemiological data, miner exposure records, health considerations, mining practices and costs thereof, and applicable research and development results, to determine whether or not to modify this recommendation.

6. The uranium mining industry is urged to continue efforts to progressively lower exposure levels in the mines so that the anticipated 4 WLM standard can be attained by January 1, 1971.

7. To assist the Council in its periodic review of radiation protection in uranium mines an interagency group will be established with representation from agencies of the Council. This group will keep all relevant information and developments under continuing surveillance and make reports to the Council in advance of its periodic review.

Pursuant to recommendation No. 7, an interagency group was established. This group was known as the Interagency Uranium Mining Radiation Review Group (IUMRRG) and consisted of representatives from the Department of Health, Education, and Welfare, the Department of Agriculture, the Department of the Interior, the Department of Labor, the Department of Commerce, the Department of Defense, and the Atomic Energy Commission.

The Surgeon General, U.S. Public Health Service, was appointed Chairman.

The third memorandum, approved by the President and published on December 18, 1970, 35 F.R. 9218, stated that IUMRRG required additional time to complete its review and recommended that the effective date be postponed from January 1, 1971 to July 1, 1971.

CONCLUSIONS

Following a review and analysis of the information referenced below, the Administrator has reached the following conclusions:

a. The major areas of consideration in connection with determining radiation protection guidance for uraninum miners are:

(1) Protection of the health of uranium miners.

(2) Technical feasibility of achieving various levels of exposure.

(3) Economic impact of achieving various levels of exposure.

b. The primary objective of EPA guidance for underground uranium mining standards is to protect miners from radiation induced lung cancer. Although the magnitude of risk attributable to radiation exposures incident to uranium mining is still in dispute among the participants in the IUMRRG review, it is concluded that radiation exposure is the major identified factor causally related to an increased lung cancer risk. Thus, the major principle on which EPA guidance is based is the reduction of the radiation exposure to uranium miners to the lowest practicable level.

c. A standard of 4 WLM per year is technically feasible.

d. A standard of 4 WLM per year would not have a severe impact on the underground uranium mining community, provided additional time is allowed for compliance in certain instances.

e. A standard greater than 4 WLM per year probably would result in dosages exceeding those permitted for other occupational radiation exposure situations.

f. The risk of lung cancer appears to be enhanced by cigarette smoking in combination with the inhalation of radioactive materials; therefore, smoking by underground uranium miners should continue to be discouraged.

DECISIONS

In light of the conclusions noted above, the Administrator does not find a basis for modifying the guidance approved by the President that an annual exposure level of 4 WLM be effective as of July 1, 1971.

The authority which EPA derived from the former FRC is limited to recommending guidance for Federal agencies. Other agencies are responsible for setting and enforcing standards. It is for these agencies to consider what provision it is appropriate to make, in enforcement of standards, for those cases where immediate enforcement of a 4 WLM per year standard would cause excessive financial loss which would compel the closing of mines resulting in substantial loss of employment for miners. It is the

Administrator's concern that, if variances are granted for specific mines by the appropriate regulatory agencies, such mines be brought into compliance with the 4 WLM per year guidance at the earliest possible time.

In this connection it should be noted that the recommendation of 4 WLM per year was approved by the President and published in the FEDERAL REGISTER on January 15, 1969, to be effective January 1, 1971. (The effective date was later extended to July 1, 1971.) Thus, industry has been aware of the impending 4 WLM per year limit for 2½ years.

The Administrator strongly urges that epidemiological and related experimental studies and research on better radiation control procedures and methods continue to be actively and vigorously pursued by both the industry and Federal agencies.

AVAILABILITY OF REPORTS TO PUBLIC

The foregoing conclusions and decisions were based on information and reports prepared by the IUMRRG, subgroups of the IUMRRG, and a report of the National Academy of Sciences-National Research Council (NAS–NRC). These reports are available to the public at EPA Headquarters and the 10 EPA Regional Offices at the addresses noted at the end of this notice.

For the convenience of the public, the following reports and summaries are set forth below:

(1) The IUMRRG report by the Chairman of the IUMRRG.
(2) Summaries of the subgroup reports.
(3) The conclusions of the NAS–NRC report.

IUMRRG REPORT

The final report of the IUMRRG was in the form of a letter dated April 26, 1971, from the Chairman of the IUMRRG, the Surgeon General, U.S. Public Health Service. This letter is set forth below:

DEPARTMENT OF HEALTH, EDUCATION, AND WELFARE
WASHINGTON, D.C. 20201
SURGEON GENERAL OF THE PUBLIC HEALTH SERVICE

HON. WILLIAM D. RUCKELSHAUS,
Administrator,
Environmental Protection Agency,
Washington, D.C. 20460.

April 26, 1971.

DEAR MR. RUCKELSHAUS: In accordance with the recent exchange of correspondence between you and Secretary Richardson concerning the efforts of the Interagency Uranium Mining Radiation Review Group which I chair, I am enclosing final reports summarizing the conclusions reached by the subgroups of our committee. I believe that these reports, as well as the full

reports of the subgroups sent to you earlier, represent a workmanlike review of the assigned problems.

The methodology and content of the reports were discussed at length at a meeting of the Interagency Review Group held on April 1, 1971. While there were a number of differences of opinion on other matters, the Group did reach a consensus that there is an increased risk of lung cancer associated with all ranges of radiation exposure examined, including the 120–359 cumulative working level month category. It seems clear to me then that the guidance concerning the allowable radiation level in uranium mines must [sic] be as low as possible.

The courses of action available to you concern principally the schedule for achievement of the lower levels. The arguments for early adoption of low levels center around human health considerations—lower levels established soon will achieve lower total lifetime exposure to hazard. The arguments for more time to achieve the lower guidance center around economic considerations—possible damage to the domestic uranium mining industry may result from more stringent requirements. Comments from each Review Group member on both the appropriate level to be established and the schedule for reaching that goal are attached for your use in reaching a decision.

A discussion of the alternatives I outlined in an enclosure to my February 26 memorandum to the members of the Review Group follows:

1. That the guidance of 4 WLM per year go into effect on or before July 1, 1971.

Pro: Exposure of miners to radiation in the uranium mines would be decreased; total exposure in cumulative working level months would increase at a lower rate than at present.

Con: Total exposure of miners to radiation in the uranium mines would sible adverse affect on the domestic uranium mining industry. Some miners might be thrown out of work.

2. That the guidance of 8 WLM per year go into effect in 1 year and that the guidance of 4 WLM per year go into effect in 2 years.

Pro: Industry would have time to comply with lower standards gradually thus diminishing possible economic damage and layoffs; total exposure in cumulative working level months would increase at a lower rate than at present.

Con: Total exposure of miners to radiation in the uranium mines would increase at a higher rate than under a 4 WLM per year guidance.

3. That the guidance remain at 12 WLM.

Pro: Industry is, by and large, already complying with this exposure guidance; no increased cost would be necessary; there would be no adverse economic impact.

Con: Exposure of miners to radiation in the uranium mines would remain at the current level as would their cumulative total exposure.

The member from the Atomic Energy Commission urges the continuation of the Review Group. With the submission of this letter to you, however, I believe that the work of the present Interagency Uranium Mining Radiation Review Group is concluded, and I shall convene no further sessions. I would, however, be happy to arrange for the participation of this Department in any interagency committee constituted to consider this subject.

Sincerely yours,

JESSE L. STEINFELD, M.D.
Surgeon General, Chairman,
Interagency Uranium Mining Radiation Review Group.

Enclosures:

NOTE: Enclosures are located at EPA Headquarters and the 10 EPA Regional offices at the addresses noted at the end of this notice.

NAS–NRC REPORT

The NAS–NRC prepared a report for the IUMRRG dated January 27, 1971, titled "Epidemiologic Studies of Uranium Miners." This report referenced an earlier NAS–NRC report dated August 1968 titled "Radiation Exposure of Uranium Miners." The conclusions of the January 1971 report are set forth below:

In its report of August, 1968, the NAS–NRC Advisory Committee to the Federal Radiation Council concluded as follows:[1]

"(a) There appears to be a casual association between lung cancer and exposures of approximately 1,000 CWLM and higher.

"(b) There is a statistically significant increase in the lung cancer risk for miners with approximately 100 to 400 CWLM exposure that cannot be explained by any known artifact of the data.

"(c) The hypothesis is favored, pending more definitive data, that radiation exposure at least contributed to the excess lung cancer observed in miners in the 100 to 400 CWLM category."

The Analyses in the present PHS report strengthen the conclusions of the previous NAS–NRC Committee. Of particular significance are the following:

1. With further accumulation of data, an increased lung cancer risk continues to be seen for miners in the 120–359 CWLM category.

2. This increase is seen using a variety of analytic methods, based on different assumptions. In spite of intensive study, no likely source of error or bias that could account for the increase has been identified. In particular, cigarette smoking does not account for the excess. Certain biases that have been identified are in the direction to suggest that radiation exposure may have been overestimated and that therefore the effect observed may in fact be attributable to doses lower than those of the 120–359 CWLM category. There is no evidence that these bases affect differentially miners who have or have not developed lung cancer.

3. Up dating and improvement in the quality of the data on exposure levels has eliminated apparent irregularities in the dose-response relationship in the lower dose categories seen in previous analyses.

4. An independent review of the histologic characteristics of the lung tumors in miners and appropriate controls using a careful statistical design and conducted on behalf of the PHS interagency review group has confirmed the earlier finding of Saccomano and others that the particular form of lung cancer that occurs in excess in miners exposed to high doses is also in excess among cases occurring in miners exposed to the lowest categories of dose.

5. The Ad Hoc Committee reaffirms the statement of the 1968 National Academy of Sciences–National Research Council Committee quoted above. This conclusion is unanimous.

[1] "Radiation Exposure of Uranium Miners." A report of an Advisory Committee from the Division of Medical Sciences: National Academy of Sciences–National Research Council–National Academy of Engineering, Federal Radiation Council, Washington, D.C., August 1968, p. 24, paragraphs 7, 8.

IUMRRG SUBGROUPS

The IUMRRG established subgroups to carry out various tasks. These tasks and a brief summary of the conclusions of the subgroups were:

I. *Health effects.* Subgroup IA: Task—Review and update the U.S. Public Health Service epidemiologic study of underground uranium miners in accordance with the advice and recommendations of an ad hoc committee of the National Academy of Sciences–National Research Council (NAS–NRC), set up at the request of the FRC.

Conclusions: Unanimously agreed with the conclusions of the NAS–NRC report (set forth above).

Subgroup IB: Task—Review all appropriate experimental and epidemiological studies, including published and unpublished information on the induction of lung cancer by radiation, and review theoretical considerations related to the epidemiological exposure units of WLM to the radiation protection units of rads and rems to critical tissues.

Conclusions: The bronchial epithelium is a relatively sensitive tissue with respect to radiation induced cancer; radiation is the major identified carcinogenic agent associated with lung cancer in uranium miners and that a standard greater than 4 WLM per year probably would result in dosages to the critical tissues of lung exceeding dosages permitted for other occupational radiation exposure situations.

II. *Monitoring, exposure and mining practice.* Task—Analyze data on industry performance in controlling radon daughter concentrations in mine air using Department of Labor Inspection data, U.S. Bureau of Mines inspection data and State records.

Conclusions: Most of the industry is now meeting a 12 WLM per year standard and data indicate that it is feasible to reduce exposures to 4 WLM per year with current technology. However, it recommended that a sufficient time to achieve compliance be allowed, if an exposure standard of less than 12 WLM is adopted.

III. *Economics.* Task—Examine the economic impact of proposed annual exposure standards set at 12 WLM, 8 WLM, and 4 WLM. In carrying out this particular phase the FRC contracted with Arthur D. Little, Inc., for an evaluative report.

Conclusions: Technology is available by which the industry can achieve a 4 WLM per year standard and such a standard would not have a severe economic impact on the underground uranium mining industry provided adequate time was allowed for compliance. It concluded that a period of 1 year to achieve an 8-WLM-per-year standard and 2 years to achieve a 4-WLM-per-year stand-

ard may be reasonable. The report also stated that the effect of a 4-WLM-per-year standard on available uranium reserves would be a relatively minor reduction, i.e., less than 10 percent.

IV–A. *Diagnosis and therapy of lung cancer.* Task—Review information related to diagnosis and treatment of lung cancer, including pathological review for cancer cell-type and sputum cytology.

Conclusions: Present methods of treatment of lung cancer are unsatisfactory; sputum cytology and analysis can be useful in the early diagnosis of lung cancer. Earlier diagnoses might improve the prospect for cure. It also concluded that there is a demonstrable relationship between the cumulative exposure level and the frequency of small cell, anaplastic carcinomas that could not be attributed to age or cigarette smoking.

IV–B. *Radiation concentration and exposure techniques and equipment.* Task—Collect, analyze, and interpret measurement technology for determining radon and radon daughter concentrations in mine air and potential use of various types of radiation exposure monitoring devices.

Conclusions: Satisfactory instruments are available for radon and radon daughter concentration measurement but no personal monitoring devices are available at the present time.

PUBLIC COMMENT

All reports referred to above are to be found in EPA Headquarters located at 1626 K Street NW., Washington, D.C., telephone (202) 632–7792 and the 10 Regional Offices located at:

REGION	ADDRESS	TELEPHONE NO.
I	John F. Kennedy Federal Bldg., Boston, MA 02203.	617—223–6884
II	26 Federal Plaza, New York, NY 10007.	212—264–2525
III	401 North Broad St., Philadelphia, PA 19108.	215—597–9151
IV	50 7th St. NE., Atlanta, GA 30323.	404—526–5215
V	433 West Van Buren St., Chicago, IL 60607.	312—353–5264
VI	1114 Commerce St., Dallas, TX 75202.	214—749–2827
VII	610 East 12th St., Kansas City, MO 64106.	816—374–3038
VIII	Federal Office Bldg., 19th and Stout St., Denver, CO 80202.	303—297–4457
IX	760 Market St., San Francisco, CA 94102.	415—556–4303
X	1319 2d Ave., Seattle, WA 98101.	206—442–0530

All interested persons who desire to submit written comments for consideration in connection with this matter should send them to the Administrator, EPA, Washington, D.C., 20460, within 30 days after publication of this notice in the FEDERAL REGISTER. Comments received after that period will be considered if it is practicable to do so, but assurance of consideration cannot be given except as to comments filed within the period specified.

Dated: May 19, 1971.

WILLIAM D. RUCKELSHAUS,
Administrator.

4.3d RADIATION PROTECTION GUIDANCE, UNDERGROUND MINING OF URANIUM ORE, ENVIRONMENTAL PROTECTION AGENCY,

July 9, 1971, 36 Fed. Reg. 1292 (1971)

UNDERGROUND MINING OF URANIUM ORE
RADIATION PROTECTION GUIDANCE FOR FEDERAL AGENCIES

On May 25, 1971, the Environmental Protection Agency published a notice in the FEDERAL REGISTER (36 F.R. 9480) concerning guidance for the protection of underground uranium miners. The notice stated: "The Administrator does not find a basis for mod-

ifying the guidance approved by the President that an annual exposure level of 4 WLM be effective as of July 1, 1971." The notice also stated that "All interested persons who desire to submit written comments for consideration in connection with this matter should send them to the Administrator, EPA, Washington, D.C. 20460, within 30 days after publication of this notice in the FEDERAL REGISTER. Comments received after that period will be considered if it is practicable to do so, but assurance of consideration cannot be given except as to comments filed within the period specified."

All written comments received on or before June 28, 1971, have been reviewed. Letters of comments have been received from industry, other Government agencies and a labor union. These comments are available for inspection at EPA Headquarters, 1626 K Street, NW., Washington, DC 20460.

Several questions were raised on the scientific basis for setting the guidance of 4 WLM per year and in particular challenged the validity of the PHS epidemiologic report.

The Environmental Protection Agency has fully considered the methodology of the PHS epidemiologic study on uranium miners as well as the limitations of the study data for the setting of standards for underground uranium miners.

In addition EPA has evaluated a considerable body of other scientific information, both experimental and epidemiologic, available on radiation induced lung cancer for its relevance to establishing radiation protection guidance for uranium miners. EPA has also taken into account reports from several expert and advisory groups [1] established to review and interpret the problem of radiation induced lung cancer.

Based on the reports of these expert groups and the other considerations noted above, EPA concludes that guidance not to exceed 4 WLM per year is warranted in order to afford adequate radiation protection of uranium miners. Furthermore, it is emphasized that the exposure levels of concern are not "low" in the context of usual occupational radiation protection practices; an annual exposure greater than 4 WLM would probably result in a dose in rems to the critical tissue of the lung that exceeds the occupational radiation standard generally accepted in the nuclear industry.

Therefore, it has been concluded that the comments suggesting

[1] The DHEW review group, May 1967; (2) NAS/NRC Advisory Committee to FRC 1968; to FRC 1968; (3) NAS/NRC Advisory Committee to FRC, 1970/71; (4) Subgroups I–A and I–B of the Interagency Uranium Mining Radiation Review Group, 1970/71; (5) NCRP Report 39, 1971; and (6) ICRP Publication 14, 1969.

that EPA should recommend less stringent radiation protection guidance than the present 4 WLM per year do not provide an adequate basis for doing so. Accordingly, EPA does not recommend any change in the guidance approved by the President and published in the FEDERAL REGISTER (34 F.R. 576, 35 F.R. 9218) of 4 WLM per year effective July 1, 1971.

Several comments were received which referred to the means of implementing the 4 WLM guidance. As the May 25, 1971, FEDERAL REGISTER notice indicated, decisions concerning the means of implementing the guidance for uranium mines, including any procedures for variances which may be made available to individual mining operators, must be made by the regulatory agencies which adopt this guidance. It should be noted that the Secretary of the Interior on June 30, 1971, signed proposed amendments to regulations under the Federal Metal and Nonmetallic Mine Safety Act. These proposed amendments relate to variances applicable to underground uranium mines. EPA will provide such comments as it deems appropriate on these proposed amendments directly to the Department of the Interior at a later date. Copies of all of the comments which EPA has received in response to the May 25, 1971, FEDERAL REGISTER notice and copies of this FEDERAL REGISTER notice have been sent to the Secretaries of the Interior and Labor under cover of a letter dated July 1, 1971.

Dated: July 1, 1971.

WILLIAM D. RUCKELSHAUS,
Administrator.

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