TECHNICAL NOTE
ORP/CSD-75-4

PRELIMINARY FINDINGS RADON DAUGHTER LEVELS IN STRUCTURES CONSTRUCTED ON RECLAIMED FLORIDA PHOSPHATE LAND

THE UNITED STATES
ENVIRONMENTAL PROTECTION AGENCY
OFFICE OF RADIATION PROGRAMS

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PREFACE

The Office of Radiation Programs of the Environmental Protection Agency carries out a national program designed to evaluate public health impact from ionizing and nonionizing radiation, and to promote development of control necessary to protect the public health and the environment. This report of preliminary study findings was prepared to expeditiously provide Federal, State, and local agencies, as well as the public with information concerning a situation that poses a potentially significant public health problem. Readers of this report are encouraged to inform the Office of Radiation Programs of any omissions or errors.

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Deputy Assistant Administrator
for Radiation Programs (AW-458)

ACKNOWLEDGMENT

The Office of Radiation Programs gratefully acknowledges the contributions of the staffs of its Criteria and Standards Division, the Radiation Office – Las Vegas, and the Eastern Environmental Radiation Facility, as well as the staffs of the Florida Division of Health – Radiological and Occupational Health Section and the Polk County Health Department. Without the contributions of these professionals and the cooperation of the residents of Polk County, this study would not have been possible.

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I. INTRODUCTION

Naturally-occurring radionuclides such as uranium, thorium and their progeny, tritium, carbon-14, and potassium-40 are ubiquitous in the environment. Certain geological deposits contain relatively large concentations of uranium and thorium which are mined and milled solely for their uranium content. In the western U.S., deposits of this nature generally average about 0.2 percent uranium. Other geological formations, such as marine phosphate deposits, contain uranium (about .01 to .02 percent) in concentrations significantly greater than normal rock or soil but in concentrations too low to be processed economically solely for uranium at this time.

While these naturally-occurring radionuclides are confined to the earth's crust, they are covered with several feet of overburden which minimizes their impact on the biosphere except for possible dissolution into groundwaters. However, the mining and processing of ores (such as phosphate rock) strips away the protective overburden. This may present situations that potentially increases the radiation exposure to the population from processing and mining wastes, as well as finished and by-product materials.

The U.S. Environmental Protection Agency (EPA) has the mission of protecting public health and the environment. In this regard, EPA's Office of Radiation Programs (ORP) is conducting, with the assistance of several Federal as well as State agencies, a program to evaluate the radiological impact of industries and activities which may cause potential increases in population exposure due to the addition of naturally-occurring radionuclides into the biosphere. The Office of Radiation Programs has initiated this effort by conducting a comprehensive study of the release of radiation and radioactive materials directly and indirectly from the phosphate industry, thusly the radiological impact of phosphate mining, processing, use, and related activities of the industry are being assessed. In the study, determinations will be made on the effectiveness of present standards and controls and in areas where such controls are deemed to be insufficient, appropriate standards and guides will be developed. The overall study has been sub-divided into tasks involving the evaluation of effluents, emissions, products, by-products, on-site exposures and reclaimed land uses. Efforts are presently underway in all of these areas.

The purpose of this report is to present the preliminary findings from the evaluation of the use of reclaimed land for construction of residential and other structures in the State of Florida, particularly Polk County.

II. SUMMARY AND CONCLUSIONS

To determine the significance of radium-226 in reclaimed land on the radon daughter levels in structures built on the land, a limited field study was conducted. A sample of about 125 structures was selected in Polk County. About two-thirds of the structures were believed built on reclaimed land and the remainder were believed not on reclaimed land. Track-etch films and TLD air sampler techniques were used to measure radon daughter levels. In addition, gamma surveys of each structure were made.

In general, the data from this study coupled with existing information indicates that radium-226 concentrations in soil beneath structures significantly affects the radon daughter levels within the structures. The data collected over a five-week period suggests that structures built on reclaimed land have radon daughter levels significantly greater than structures not built on reclaimed land.

The health risk associated with the presence of increased concentrations of radon and its daughter products is difficult to assess. Although epidemiological data indicate a substantial increase in the incidence of lung cancer among uranium miners exposed to concentrations of radon daughters, use of these results to estimate the potential risk in this case is difficult. Despite uncertainties in health effects at relatively low levels of exposure, it is prudently assumed that living in a structure with elevated radon daughter levels increases an occupant's risk of lung cancer proportionate to the levels within the structure and the number of years of exposure. Continuous exposure to the highest level measured (0.2 working levels) for ten years may increase the normal risk of lung cancer for an occupant of the structure by a factor of about two.

It must be emphasized that the findings presented in this report are preliminary and require substantial additional study before overall definitive levels can be ascertained. Further, additional investigations should be performed to better evaluate the background levels in areas with phosphate rock underground and areas without phosphate deposits. Nevertheless, based on these findings, consideration should be immediately given to providing the State of Florida with the recommendation that continued use of reclaimed land for construction of new structures be discouraged.

III. RADIOACTIVITY IN POLK COUNTY LAND

In 1973, over 91 percent of the U.S. phosphate mine rock production came from Florida with the remainder coming from Tennessee and several western States (1). Figure I illustrates the primary Florida phosphate deposit areas. Florida land-pebble phosphate deposits are characterized by pebbles and fine phosphatic sand dispersed in a nonphosphatic sandy clay. This matrix, varying in thickness from I to 50 feet but averaging about 16 feet, is covered by an overburden of quartz sand and clay that averages 20 feet in thickness (2).

The standard mining practice in the Florida land-pebble phosphate fields is to strip the overburden and mine the phosphate matrix with draglines. Electric-powered walking draglines with 35 to 49 cubic yard buckets work in cuts varying from 150 to 250 feet in width and from a few hundred yards to a mile or more in length. The cuts are from 50 to 70 feet deep. Overburden is stacked on unmined ground adjacent to the initial cut by means of a dragline, until successive cuts allow it to be cast into adjacent mined-out cuts. As each cut is stripped of overburden and then mined, the ore is stacked in a suction well or sluice pit that has been prepared on unmined ground. High pressure water is used to produce a slurry of about 40 percent solids from the matrix. This slurry is then pumped via pipe to the washer plant. In this manner, a typical operation will mine about 400 acres of land per year, remove 13 million cubic yards of overburden, and mine 9 million yards of matrix per year.

Water is used in the beneficiation process, in addition to being used as a transportation medium. Both fresh water from deep wells and reclaimed water from slime settling ponds are used by the phosphate industry. Approximately 10,000 gallons of water are necessary to produce one ton of marketable phosphate rock. As the mining progresses, mined-out areas are used for the disposal of tailings and slimes, in addition to overburden. Approximately one ton of slimes and one ton of sand tailings must be disposed of for each ton of marketable phosphate rock produced. Some of the sand tailings and overburden is used to construct retaining dams in mined-out areas, behind which phosphatic clay slimes settle and dewater.

Beneficiation methods differ slightly and are dependent on screen analysis of the feed; the ratio of washer rock to flotation feed; the proportions of phosphate, sand and clay in the matrix; and equipment preferences. Through a series of screens, in closed circuit with hammer mills and log washers, the matrix is broken down to permit separation of the sand and clay from the phosphate-bearing pebbles. Three concentrations of marketable phosphate rock are produced: a 3/4-inch by 14-mesh pebble, a coarse 14 by 35-mesh fraction, and a fine 35 to 150-mesh fraction. The washed, oversize pebble fraction is a final product. The minus 14 plus 35-mesh fraction is called the coarse feed from which a coarse concentrate is obtained by gravity and flotation processes. The tailings or waste from this fraction is used in dam construction or land reclamation. The minus 35 plus 150-mesh fraction is processed through a flotation section to recover a fine concentrate. The waste, a clay slime, is impounded in areas that have been mined.

Uranium is present in the phosphate matrix at varying concentrations which average about 100-150 ppm (about 70-110 picocuries natural uranium per gram of matrix). The uranium is generally in equilibrium with its decay products at least through radium-226. This means that for each curie (3.7×10^{10} disintegrations per sec) of the parent radionuclide, there is one curie of the daughter radionuclides also present. The decay scheme of uranium-238 is shown in Figure 2.

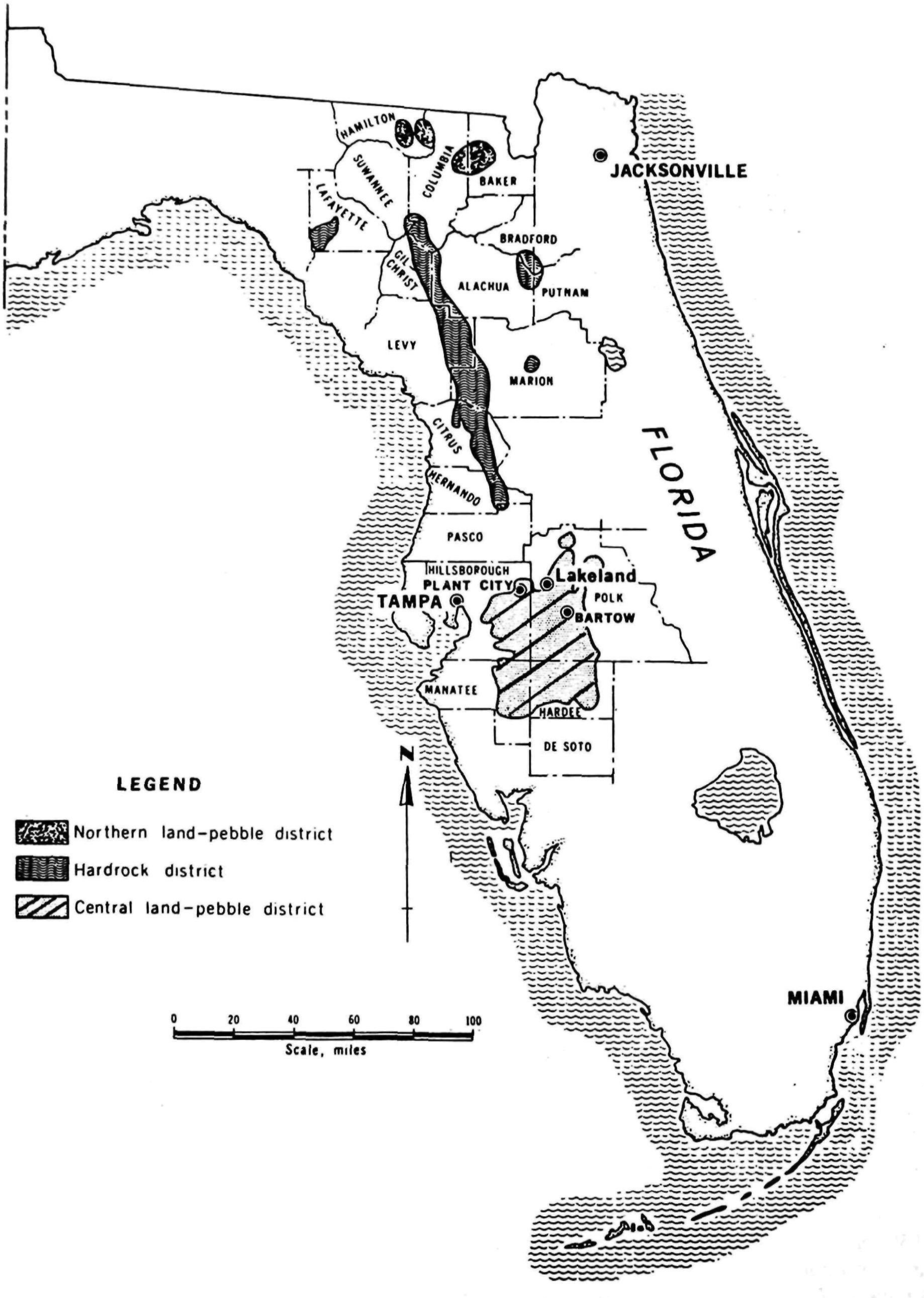
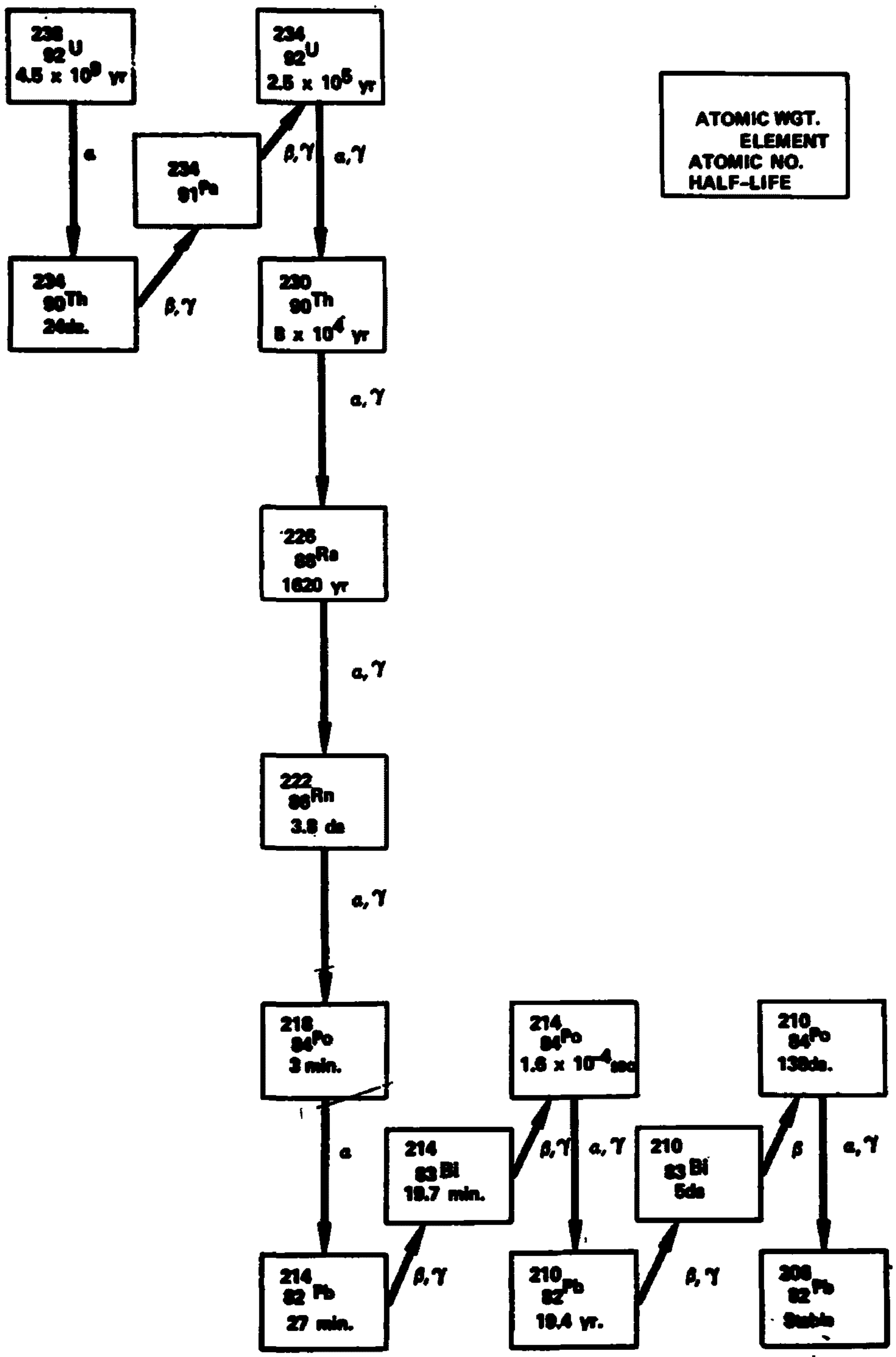


Figure 1 -- Phosphate deposits in Florida.

(From Bureau of Mines Circular 8653, Economic Significance of the Florida Phosphate Industry)

FIGURE 2

URANIUM - 238 DECAY SERIES



Radioactivity is also present in parts of the overburden. Figure 3 illustrates the general geological structure throughout much of the Florida land pebble district. A "leach zone" which is about five feet thick and covers much of the pebble deposits contains uranium in concentrations comparable to that of the matrix. Other portions of the overburden are expected to also contain some radioactivity, although not in as high concentrations (3). The radioactivity is generally associated with the phosphate compound structure since the uranium replaces the calcium in the apatite. Consequently, the marketable ore and slimes contain most of the phosphate. One-third of the phosphate originally contained in the matrix remains in the slimes. The remainder is primarily in the marketable rock.

Soil throughout the United States typically contains between 0.15 – 2.8 pCi radium-226 per gram, a highly radiotoxic member of the uranium decay series. Consequently, we would anticipate that Florida soils within several feet of the surface would normally contain about this concentration of radium-226 in areas that have been undisturbed by mining. However, anomalies might be observed in areas where surface waters may have exposed phosphate deposits or where such deposits are very close to the surface.

Since matrix and leach zone material are expected to contain about 40 pCi of radium-226 per gram, it is reasonable to expect that the radium concentrations in soil taken from reclaimed land sites to range between less than one to 40 pCi per gram depending upon the presence of either low activity overburden soil, leach zone material, matrix, sand tailings, or slimes. However, since all of these materials are blended together at most reclaimed land sites, an average soil activity of about 20 pCi per gram might be expected assuming 50 percent dilution of high activity material. One analysis has been made of reclaimed land soil showing a radium-226 concentration of 16 pCi per gram. Although this suggests about a 50 percent dilution, additional sampling must be conducted before definitive values of radium-226 concentrations in several reclaimed land soils can be ascertained with any reliability.

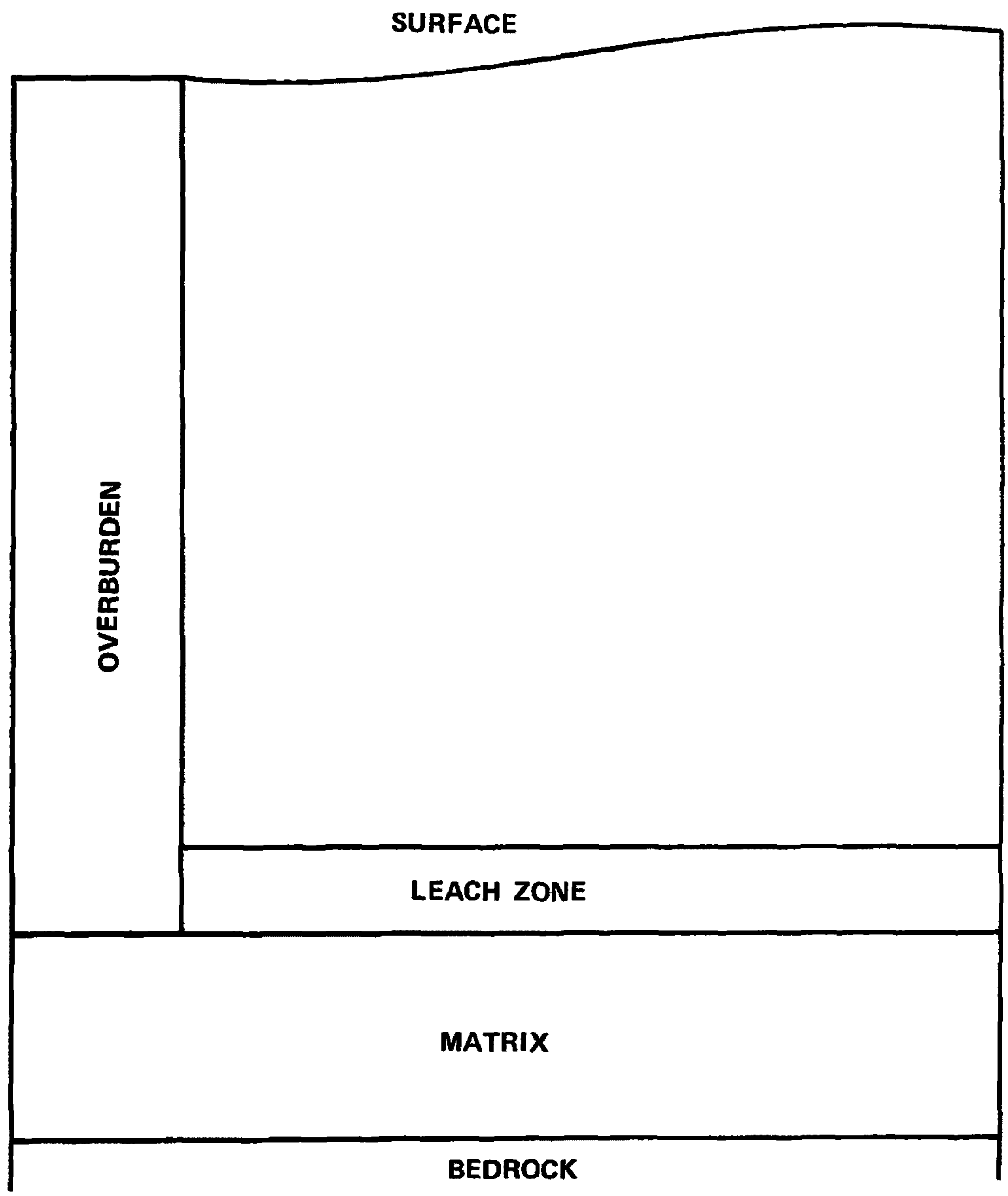
The presence of radium-226 and its daughters in soil presents a potential source of gamma exposure to individuals living or working above the soil. However, of much greater interest is exposure arising from the release of radon-222; a noble gas daughter of radium-226. This decay product has a 3.85 day half-life. It may diffuse through the soil into the atmosphere, where the radon-222 levels are highly variable being influenced by several factors including precipitation, barometric pressure, atmospheric thermal stability, and time of day.

Some measurements have been made by the State of Florida, Division of Health of atmospheric radon-222 levels in Polk County. Although atmospheric radon-222 levels are of some interest, of greater concern to public health importance is any buildup of radon in the air within closed structures constructed on reclaimed land.

Radon-222 that diffuses up through soil also readily diffuses through concrete slabs and other construction materials. Within a structure, the principal route of removal is by ventilation or leakage through the structure's walls, window frames, etc., where there exists a concentration gradient. Radioactive decay of the material as a removal process is generally small compared to ventilation and leakage. Radon-222 is probably not in equilibrium with its daughters in most situations within structures. Consequently, the level of radon and its daughters in a structure is primarily dependent upon the rate at which it diffuses into the structure and the rate at which it is removed by ventilation, leakage, and decay. Clearly, if ventilation is low, the radon and daughters

FIGURE 3

GENERAL ECONOMIC GEOLOGY OF FLORIDA LAND PEBBLE DEPOSITS



have the potential to significantly buildup within a structure. Figure 4 depicts the movement of radon and daughters into a structure. The impact of ambient environmental radon levels is expected to be only a fraction of the contribution originating from diffusion through the ground. However, data is lacking to quantify this fraction and further information is needed.

Different seasons of the year with various environmental conditions, such as thermal inversions, etc., may have a pronounced effect on the residence time of radon and its progeny in structures. This variable should also be investigated.

The depth of soil containing the elevated radium-226 is believed to be significant in determining the radon-222 source term (release rate) at the surface. The amount of radon diffusing into the environment from the soil is limited by several factors, including the time needed to diffuse from its position of origin to the surface. Since radon-222 has a half-life of 3.85 days, this significantly affects the depth from which it can contribute to environmental concentrations. Figure 5 illustrates the theoretical fraction of maximum exhalation versus the depth of the material (4). This graph was based on uranium mill tailings parameters but should generally approximate the situation with respect to reclaimed land. Radon generated at a depth of about ten feet or more does not significantly contribute to atmospheric levels. Consequently, it is the radium-226 concentration within the first ten feet that determines the amount of radon emanating into the environment. A slab foundation provides an additional barrier to the diffusing radon-222, thus effectively making the contributing soil depth less than ten feet. Specific quantification of this effective depth requires investigation under field conditions.

FIGURE 4

RECLAIMED LAND RADIATION EXPOSURE

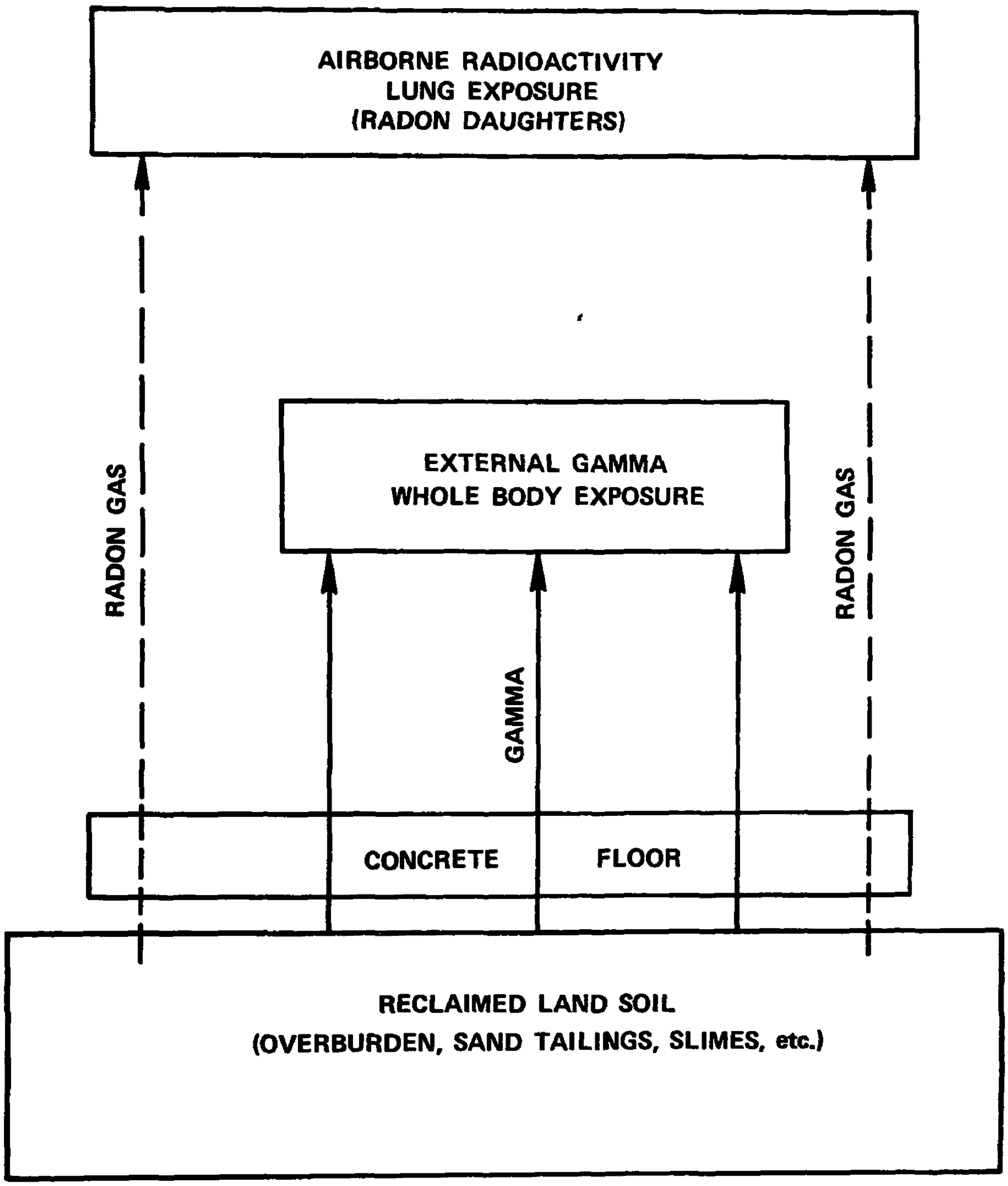
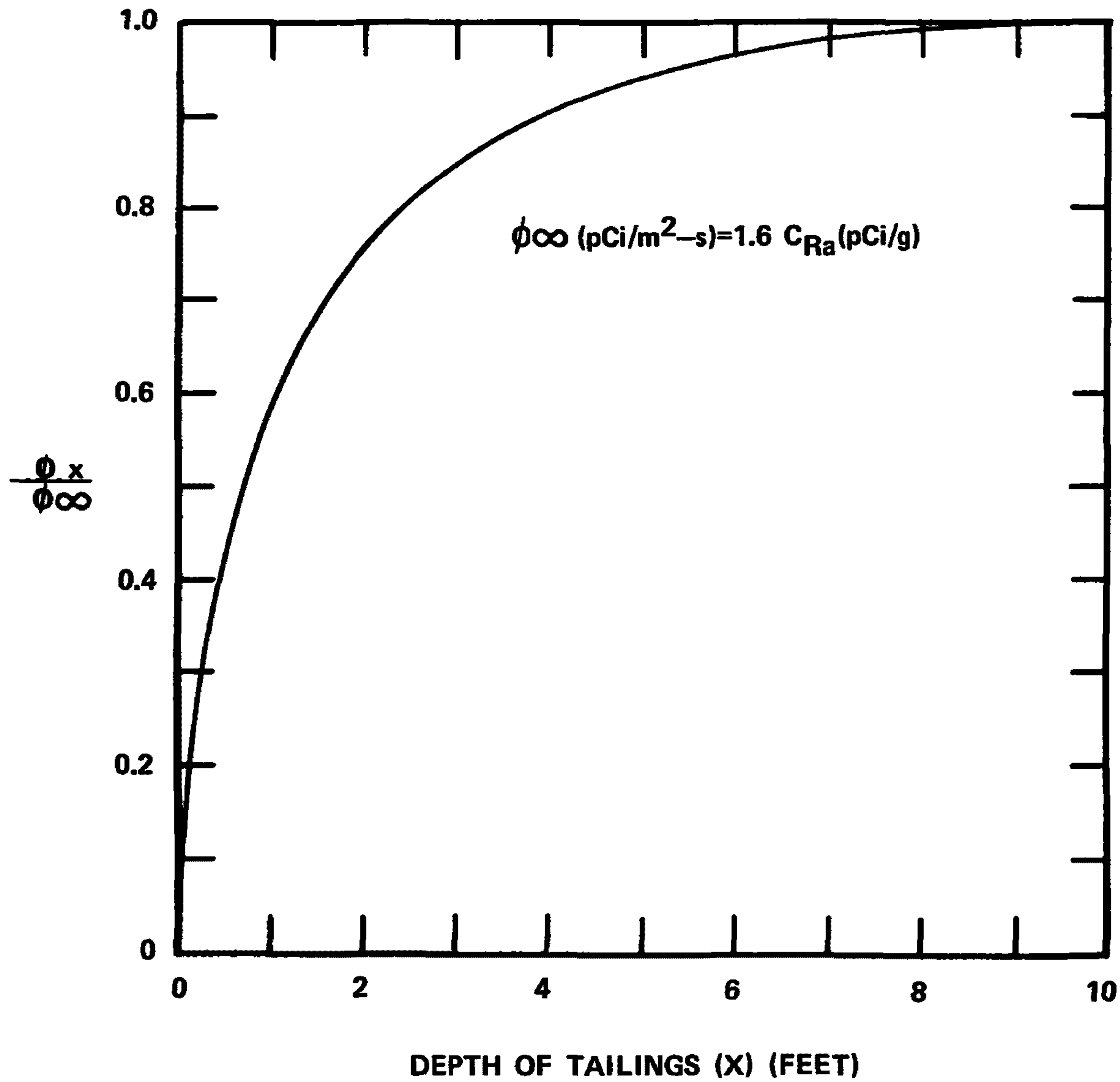


FIGURE 5

FRACTIONAL RADON EMANATION RATE VERSUS DEPTH OF BARE TAILINGS



FROM SCHIAGER, K.J., ANALYSIS OF RADIATION EXPOSURE ON OR NEAR URANIUM MILL TAILINGS PILES, RADIATION DATA AND REPORTS, VOL. 15, NUMBER 7, JULY 1974.

IV. STUDY DESIGN — RADON IN STRUCTURES

To determine the significance of radium-226 in reclaimed land on the radon daughter levels in structures built on the land, a limited field study was conducted. A sample was selected of structures believed built on reclaimed land and structures believed not built on reclaimed land. All structures selected for study were within Polk County and except for the variable of the study (i.e., reclaimed versus non-reclaimed land), were selected as randomly as practicable. The overall sample size was approximately 125 structures with two-thirds of them being reclaimed land sites and the remainder non-reclaimed land sites. This limited study was not intended to evaluate radon levels in all structures throughout the county but rather to give us a perspective of the problem if one existed and thereby point the way to further evaluation, if needed.

Two techniques were employed for measuring the radon daughter levels within structures, track-etch films, and TLD air samplers. The track-etch badge consists of a one-half inch by one inch plastic chip which is coated with cellulose nitrate. As radon and its decay products (radon daughters) are formed, alpha particles are produced. When the alpha particles strike the cellulose nitrate a record of its passage is made. The badges are each numbered and two of the badges are usually mounted on a cardboard card which can be positioned on a wall. The badges are left in place from six months to a year and collected. The badges are then dipped in a caustic solution (NaOH). This process is called etching and the alpha particle's passage becomes an etched track. These tracks are visible with the use of a light microscope.

Each badge, after etching, is read by a technician using a light microscope with a calibrated field. The number of tracks observed is recorded and the tracks per square millimeter (T/mm^2) can be calculated. This value is then compared to a calibration curve and the working level hours (WL-h) associated with the number of tracks observed is obtained. The WL* is then calculated using the number of hours the badge was in the sampling location.

The badge has the advantage of being a passive dosimeter. That is, it is put in place and picked up, but no maintenance is required during the sampling period (no moving parts).

The badge, however, has the disadvantage of measuring or recording the alpha energy given off by radon, as well as polonium-218 (radium A) and polonium-214 (radium C). Since the alpha energy from radon is not a portion of the alpha energy used to determine the WL (the radon daughters and not the radon-222 itself, are the prime contributors to adverse health impact), the system must be calibrated so that the complement from radon can be substracted.

In the survey of structures built on reclaimed phosphate tailings, 85 were placed in structures believed to be built on reclaimed land and 40 were placed in structures built on non-reclaimed land. Structures surveyed consisted primarily of private dwellings; however, local health department buildings and a few office buildings were also surveyed.

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* WL - The working level is defined as the potential alpha energy from the short-lived daughters of radon which will produce 1.3×10^5 MeV in one liter of air.

Only one-half of the track-etch film is mailed to the lab for analysis, the other half is retained for backup checks and analysis, in the event that the other half is damaged or lost. A portion of the track-etch films presently in place are to be read after six-months exposure and the remainder after 12-months exposure.

The air sampling system used by the Environmental Protection Agency, Office of Radiation Programs (EPA/ORP) was developed by Colorado State University, Fort Collins, Colorado. It is known as the Radon Progeny Integrating Sampling Unit (RPISU) and utilizes the detection techniques of thermoluminescent dosimetry (TLD).

The air pump is located inside two pieces of polyvinyl chloride (PVC) pipe. The PVC pipes are of different diameters and the area behind the pipes is filled with sound deadening material. The pump is attached to a sampling head which is located outside of the pump housing. This sampling head, which is actually a hypodermic syringe filter holder, contains the TLD's. The filter head is made up at the EPA facility in Las Vegas, Nevada, and packaged in a small 3" x 5" envelope. This envelope also provides space for the entry of the necessary field data.

During operation, air is pulled through the sampling head and the particulate material containing the radon daughters is trapped on a one-half inch filter. A TLD (CaF:Dy) is located in the airstream directly before the filter and the alpha energy from the decay of the radon daughters is recorded by this TLD. A second TLD separated from the first by a stainless steel washer is also located in the filter head. The first TLD is referred to as the alpha (α) TLD and the second the gamma (γ) TLD.

The filter head is placed on the sampler and the starting sampler information consisting of the reading on a running time meter, a location number, date and time, and air flow (measured by a calibrated rotometer) is filled in on the envelope. The sampler is usually left in place for one week. Information on date, time, and flow rate at cut-off is entered on the envelope. The envelope with the filter head is then returned to Las Vegas. The head is taken apart, the TLD's read out on a Harshaw TLD reader, a data form completed and sent for computer analysis, and finished printout containing the calculated working level (WL) is retrieved.

The working level is calculated by providing a working level-liter/nanocoulomb (WL-1/nC) conversion factor for the TLD reader, nC readout for gamma and alpha TLD, the running time of the sample, the on and off air flow rates and the number of the rotometer used.

The net nC value is obtained by subtracting the gamma TLD nC (background gamma radiation) from the alpha TLD nC (alpha decay energy plus background). This value multiplied by the conversion factor and divided by the corrected air balance produces the WL value average for the period of exposure.

Since gamma levels give a rapid indication of the presence of anomalous radioactivity and further, might be used as a surrogate for measured radon levels in future work, gamma levels were measured at each structure visited and a map of the structure drawn indicating the various radiation levels. Sodium iodide scintillators (Ludlum Model 12S) were used to make these measurements.

V. APPLICABLE FEDERAL GUIDELINES

There are no Federal radiation protection guidelines specific to radium-226 in soil or radon daughter levels in structures. Recommendations of the former Federal Radiation Council* published in 1960 established annual limits of 500 millirems to an individual in the general population and 170 millirems to an average member of a suitable population size. However, it should be kept in mind that these limits specifically excluded natural background radiation, and therefore their applicability is not completely straightforward. Since exposures resulting from reclaimed land use are a direct result of man's alteration of the natural environment, they are not natural background; thus the FRC guidelines could be generally applicable to the incremental difference above normal background levels. In applying these guidelines, however, it is strongly emphasized that there are large uncertainties in deriving dose estimates for radon daughters.

A second relevant Federal guide is the U.S. Surgeon General's Guidelines for remedial action in Grand Junction, Colorado. A copy of these is included as Appendix A. These guidelines were developed in light of the FRC guides and information derived from uranium mine studies for use in establishing remedial action criteria for structures having uranium mill tailings under or around them. The guidelines include criteria for external gamma levels or indoor radon daughter levels. However, it must be emphasized that the Surgeon General's Guidelines are specific to the Grand Junction situation and should not be interpreted to be directly applicable in this or any other case.

The present Federal guideline for exposure of uranium miners to radon daughters is 4 WLM** per year as recommended by the Environmental Protection Agency in May 1971 (5). Although this occupational exposure guideline is not directly applicable to the situation of population exposure due to structures on reclaimed land, comparison of the levels observed in structures to the uranium miner standard could provide a perspective of the significance of the levels in the structures studied.

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* When the Environmental Protection Agency was established by Reorganization Plan No. 3 in 1970, the Federal Radiation Council was vested in EPA.

** A working level month (WLM) is defined as exposure to I WL for 170 hours (a working month). Continuous exposure to radon daughters at 1 WL for one year is equal to about 50 WLM.

VI. STRUCTURE STUDY FINDINGS

Although work is continuing in an effort to define the gamma radiation, radon and radon daughter levels in Polk County, investigations to date indicate that these levels are highly variable depending upon the existence of phosphate related material. In areas where no phosphate material is present, the total gamma radiation background is generally quite low, approximately 5 to 7 microroentgens per hour (μR/hr) and is about twice this range in areas where some phosphate rock is probably near the surface. Generally on known reclaimed land areas, levels of 2 to 10 times this range were observed, i.e., gamma radiation levels in the range of 10 to 80 μR/hr. Radon daughter levels in structures in background areas were generally about .004 WL. These radon daughter levels may not be valid in structures built on land where phosphate rock is near the surface.

To date, data on radon daughter levels from only five weeks of TLD air pump sampling are available. This data is listed in Table 1. The structures studied are listed in decreasing order of observed radon daughter concentrations. Structures that were believed to be on reclaimed land are noted with the symbol R. All other structures were believed not to be on reclaimed land. The highest radon daughter level measured was 0.2 WL. If this structure had that level continuously over a year, the resultant exposure would be about 10 WLM. However, it must be emphasized that these findings are preliminary and radon daughter levels must be determined for a period of a year before overall conclusions can be drawn regarding the specific annual exposure within a structure. Seasonal variations including more open window ventilation in spring and fall could have an impact on the levels observed over a period of one year.

Using the Surgeon General's Guidelines as an evaluation tool, the levels from Table I were arranged in Table 2 according to their percentile ranking with respect to the Guidelines. It is clear that as a group, structures on reclaimed land had greater radon daughter levels than structures not on reclaimed land.

If we assume that structures on reclaimed land will have radon daughter levels greater than 0.01 WL and structures not on reclaimed land will all have radon working levels below .01 (i.e., about 2.5 times a background level of .004 WL), we find three structures out of twelve on reclaimed land and two structures out of nine on non-reclaimed land that are contrary to the assumption. One of the structures built on reclaimed land that had levels below .01 WL was observed not to have air conditioning. Consequently, since this structure has had its windows open during the study period, the excellent ventilation probably kept the radon daughters levels down. No plausible explanation for the lower observed levels in the other two structures is known at this time. Of the two structures on non-reclaimed land that exhibited levels greater than .01 WL, one was observed to have elemental phosphorous slag alongside the structure. Since this slag contains about 50-60 pCi per gram of radium-226, radon from this material may be contributing to the levels observed in the structure. However, because of the gamma levels observed in these two structures (i.e., greater than 10 μR/hr), there may be phosphate rock near the surface under them which is providing a source of radon for the structures. Clearly, these factors need further study to better explain the observed anomalies.

TABLE 1

PRELIMINARY FLORIDA RADON DAUGHTER DATA

LOCATION NO.	RADON DAUGHTERS (WL)			INSIDE (μR/hr.) AVG. (HIG)	OUTSIDE (μR/hr.) AVG. (HOG)
98[R]	.2013	.2083		20 (24)	36 (40)
110[R]	.1050	.1169		12 (15)	26 (50)
107[R]	.1011			15 (16)	40 (50)
105[R]	.0737	.0277		10 (13)	25 (35)
94[R]	.0410	.0252	.0254	12 (15)	35 (40)
76[R]	.0302			16 (16)	25 (35)
172	.0247			13 (15)	19 (60)
103[R]	.0234			9 (10)	10 (12)
169	.0218			10 (10)	13 (18)
51[R]	.0105			9 (10)	(14)
118[R](No A/C)	.0100			7 (7)	17 (40)
50[R]	.0071			12 (15)	(70 in road)
170	.0057			7 (10)	5 (8)
175	.0053			4 (4)	4 (5)
84[R](No A/C)	.0052			27 (28)	35 (40)
112[R]	.0048	.0041	.0030	9 (11)	22 (26)
134	.0042			3 (5)	3 (4)
176	.0039			4 (5)	6 (7)
180	.0036			(4)	(6)
135	.0002			3 (3)	3 (4)
136	.0002			4 (4)	4 (4)

1. [R]–BELIEVED TO BE ON RECLAIMED LAND.
2. THESE GAMMA MEASUREMENTS HAVE NOT BEEN CORRECTED FOR BACKGROUND WHICH IS ABOUT 5-7μR/hr.
3. HIG – HIGH INSIDE GAMMA
4. HOG – HIGH OUTSIDE GAMMA

TABLE 2

PERCENTILE RANGE OF RADON DAUGHTER LEVELS - (FLORIDA)

AUGUST 1975

RECLAIMED LAND (n=12)

$\geq$ .05 WL : 33.3%

.05 $\geq X \geq$ .01 WL : 41.7%

$<$ .01 WL : 25.0%

NON-RECLAIMED LAND (n=9)

$\geq$ .05 WL : -0-

.05 $\geq X \geq$ .01 WL : 22.2%

$<$ .01 WL : 77.8%

TOTAL (n=21)

$\geq$ .05 WL : 19.0%

.05 $\geq X \geq$ .01 WL : 33.3%

$<$ .01 WL : 47.7%

VII. HEALTH RISK ESTIMATE

Internal and, to a lesser extent, external sources of ionizing radiation may cause adverse health effects to occupants in areas of high radium and radon concentrations. The dose due to external sources is primarily from radium daughter products that emit gamma rays capable of penetrating all tissues of the body. Penetrating radiation can cause somatic and genetic effects in humans. Somatic effects which might be expected include leukemia and solid tumors, such as bone, breast, and lung cancers. Genetic effects will appear as congenital defects in the children of exposed parents. Internal exposure will be due primarily to alpha particles from radon daughter decay products, the chain of radionuclides that follow radon-222 in the uranium radium decay series. The radon daughters deposit in and irradiate parts of the lung, particularly the basement membranes of the bronchial airways. The expected response to this irradiation is an increase in lung cancers (6).

Risk Estimates for External Radiation

In the case of external penetrating radiation, data presented in the NAS-BEIR report provides the following estimates (6):

200 estimated excess cancer deaths/10^6 man-rem
200 estimated excess nonfatal cancers/10^6 man-rem
200 excess congential abnormalities per rem/10^6 live births.

These estimates are based on the assumption that the number of health effects observed at relatively high doses and dose rates can be extrapolated linearly to the low levels of radiation usually found in the environment.

External exposure to natural background radiation in Florida is about 65 millirem per year, except in regions containing anomalous sources (7). The annual population dose from natural external background radiation is 65,000 man-rem per year per million exposed persons. Based on the uncertain but prudent assumption that there is no threshold dose necessary to induce radiation carcinogenesis, an estimated 13 cancer fatalities annually could be attributed to a total population dose of 65,000 man-rem.

Risk Estimates for Internal Radiation

The lung cancer risk from inhaled radon and its daughter products is almost all due to the radon daughters which cause over 95 percent of the dose delivered to the bronchial tree, rather than radon itself. Almost all of the relevant clinical experience is based on the increased cancer incidence experienced by uranium miners who were exposed to radon in an occupational environment quite different from residential situations. There is a possibility that these miners may also have been exposed to other carcinogens (not related to radiation) in their work which increased the incidence of observed lung cancers. On the other hand, the dose to critical lung tissues from a given concentration of radon daughters may be less for miners than for persons exposed in more normal environments. The BEIR Committee estimated that the dose to miners is a factor of two less that that received by other persons, due to the miners occupationally induced chronic bronchitis which increased the thickness of the mucous layer overlaying the basement membrane of the larger bronchi (6). Because of the short range of alpha particles in tissue, the bronchial dose is a sensitive function of the distance they penetrate (8).

An additional factor acting to reduce the dose to miners from a given radon daughter concentration is that miner's exposure to radon daughters is usually expressed in a unit used for monitoring purposes, namely "working level." This unit does not take into account the difference in concentration of the various radon daughters or the presence of radioactive ions not attached to dust particles. Such unattached ions have an increased probability of residence in the bronchial tube and therefore deliver a greater dose. Since the concentration of the unattached ions is very low in mines because of the high dust loading, the dose to miners from radon daughters may be as much as a factor of four lower than in a "clean air" environment (8). Therefore, the risk estimates given below, based on uranium miner experience are likely to be low. To a residental population, the dose and the resultant cancer incidence may be several times larger (4 to 8) because of cleaner (less dust loading) ambient air and deeper alpha particle penetration into the bronchial membrane.

Cancer risks from exposure to radon daughters are usually quantified relative to working level month which is the cumulative exposure over a period of time. A working level month corresponds to a 170 hour exposure to radon daughter concentration of one working level, since for miners an 8-hour workday is assumed. Residential occupancy may be up to 24 hours per day. Therefore, a full year's exposure to one working level corresponds to about 50 working level months.

Although the lung cancers observed in uranium miners occur most frequently in highly exposed persons, not all of the clinical experience is based on heavily exposed persons. In particular observations of uranium miner populations in Czechoslovakia, where, on the whole, radon daughter concentration in mines is lower than in the U.S., have provided a source for risk estimates at relatively low exposure levels. Sevc and Placek found excess lung cancer in Czech miners after exposure of less than 100 working level months (9). These exposures extended over as long as 40 years, indicating that effects may occur at exposure rates as low as 2 to 2.5 working level months per year. Their study is not complete, some miners are still alive, and additional follow-up may disclose lung cancers related to even lower exposures.

In 1973, Vaskov reported that in miners and workers in radon mineral baths, exposed to 0.036 to 3.2 WLM per year, there was an increase in the number of abnormal cells (metaplastic and dyskariotic) found in the sputum compared to similar workers not exposed to radon (10). The exact significance of such abnormal cells in sputum is not known, but they are often precursors of lung cancer. These observations strengthen the case for suspecting that lung cancers may be adverse sequelae even to rather low concentrations of radon and its daughter products.

The cancer risk from radon daughters is better expressed in terms of the percentage increase in the expected cancer incidence, i.e., relative risk, rather than the absolute number of cancers expected per working level month of exposure. However, the health characteristics of the population at risk are important in using a relative risk coefficient to estimate the risk from radon exposure. The cancers occurring in uranium miners were in males and current incidence of lung cancer in U.S. males and females are substantially different. Another factor is habitual cigarette smoking. Most of the observed lung cancers in both U.S. uranium miners and the U.S. population occurs in smokers. Archer has indicated that from the study of U.S. miners, the absolute cancer risk from radon among non-smokers may be a factor of 2 to 10 less than for cigarette smoking miners (II). Although the relative risk coefficient for lung cancer from radon exposure is thought to be relatively independent of smoking history, it is more meaningful when applied to groups having comparable cancer incidence so that the true population at risk can be ascertained (12). For example, in the South Atlantic States, lung cancer mortality (which differs only slightly from incidence rates), is reported to be about 34 deaths per year per 100,000 persons for males and 4.6 for females (13). However, cigarette smokers are included in these totals and therefore a further breakdown is desirable. From the Surgeon General's Report on the Effects of Cigarette Smoking it is estimated that lung cancer mortality in the South Atlantic States is about 47 annual deaths per 100,000 persons among smoking males; 5 deaths annually per 100,000 among non-smoking males; 6 deaths annually per 100,000 among smoking females; and 3 deaths annually per 100,000 among non-smoking females (13).

W. Jacobi has recently analyzed the combined results from the U.S. uranium miner experience, as reported in the BEIR report and the Czechoslovakia experience (14). At cumulative exposure less than a few hundred working levels, his analysis shows that: (a) the two sets of observations agree quite well with each other even though the radon daughter concentration at which the U.S. miners were exposed was much higher, (b) the excess of observed over expected cancer mortality increases approximately linearly with the cumulative exposure, and (c) the relative risk coefficient is "nearly equal for both groups," 0.9 percent for each working level month. The 95 percent confidence band for this risk coefficient is $\pm$ 0.3. Therefore, assuming the risk coefficient is 0.9 percent per working level months, II0 working level months cumulative exposure would be expected to increase the observed lung cancer mortality by 100 percent, i.e., double the normal incidence.

It should be noted that most of these data are based on adult white males including cigarette smokers and care should be used when applying this relative risk estimate to other population groups. It would be desirable to apply these estimates to appropriate control groups by multiplying the risk coefficient by the lung cancer incidence observed in homogenous groups having the same characteristics and lung cancer mortality, i.e., non-smoking adult males, smoking males, non-smoking adult females, etc. Without performing these comparisons the higher risk to smokers will be underestimated and the risk to women, children, and non-smokers will be exaggerated.

In using these risk coefficients and the linear nonthreshold hypothesis to project potential health effects from radon daughter exposures, it is useful to consider the limited conclusions reached by Jacobi in his study (14).

> "Taking into account the limits of error in the presently, available data for both groups therefore do not indicate the existence of a practical exposure threshold above 100 - 200 WLM. The data also do not allow a reliable, quantitative distinction between a linear or nonlinear relationship between LC-incidence and cumulative radon exposure. The mean regression lines .... indicate, that a linear relationship in the considered exposure range cannot be excluded. At

the present time the recommendation of an exposure limit should be based therefore on the assumption of a linear exposure-risk curve.

It follows ....., that the mean, relative risk coefficient is nearly equal for both groups of uranium miners and results to $\alpha(rel) = 0.009 \pm 0.003$ WLM^{-1}, corresponding with a mean "doubling exposure" of about 110 WLM. For comparison it should be noted, that the mean natural background level of radon daughters in air leads to an cumulative exposure of about 4 – 5 WLM during a lifetime of 70 years. This means that only a few percent of the observed LC-mortality in our population can be attributed to irradiation of the lung by inhaled radon daughters, if a linear extrapolation down to these low exposure values is generally accepted."

From the data in Table 1, the highest observed level was 0.2 WL. At this level, exposure for one year would result in a radon daughter exposure of about 10 WLM. Over an eleven year period this would result in a cumulative exposure of 110 WLM. Based on our assumptions, this cumulative exposure could result in increasing the risk of lung cancer by a factor of two. Exposures to various levels of radon daughters for differing time periods would modify the potential health risk in proportion to the exposure levels and residence time. Figure 6 illustrates the estimated lung cancer mortality relative to the normal lung cancer mortality for different radon daughter levels and exposure periods.

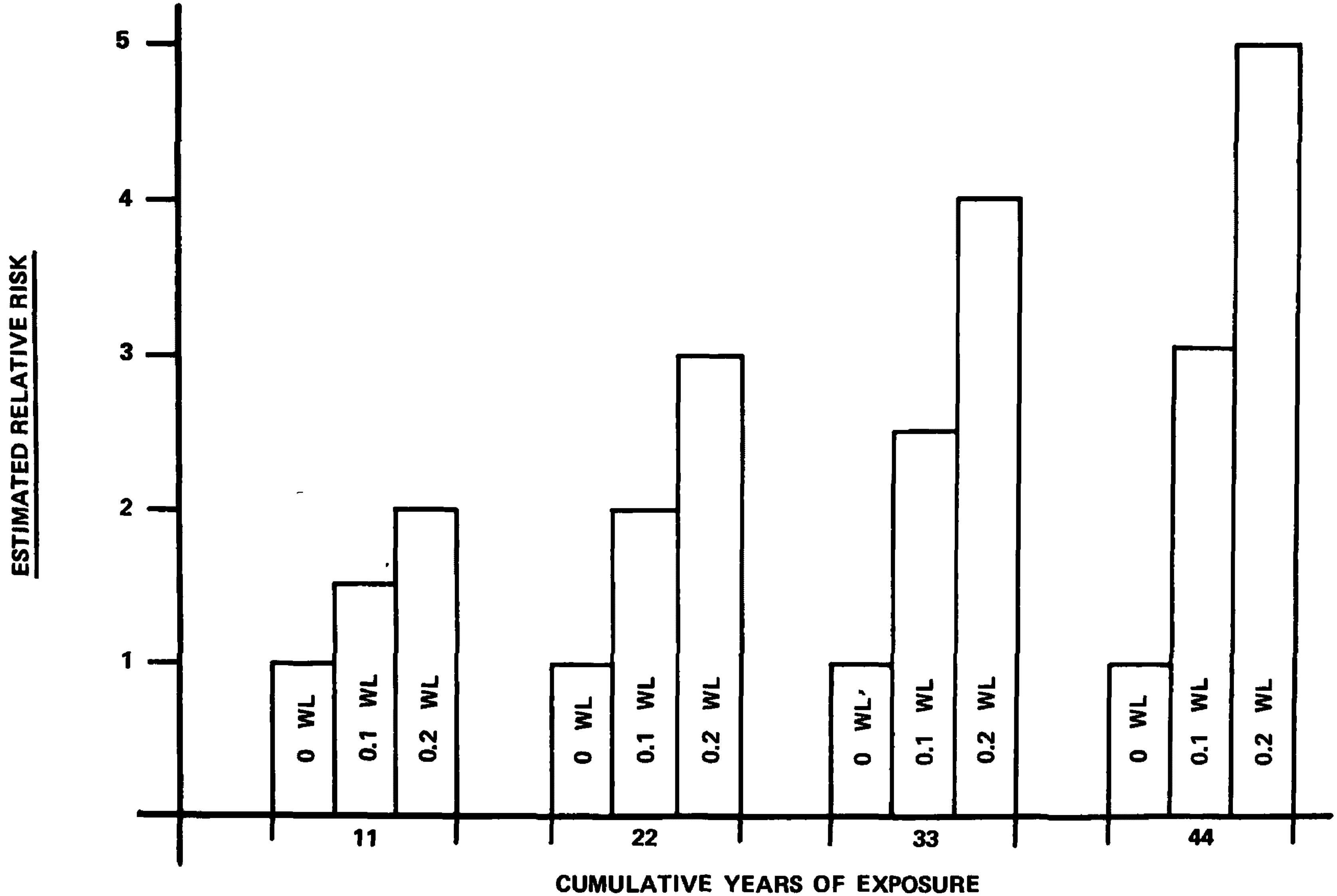

FIGURE 6

TOTAL ESTIMATED LUNG CANCER MORTALITY RELATIVE TO NORMAL LUNG CANCER MORTALITY AS A FUNCTION OF RADON DAUGHTER EXPOSURE LEVELS AND YEARS OF CONTINUOUS EXPOSURE

VIII. EXTENT OF RECLAIMED LAND USE

To date, approximately 25,000 acres of phosphate mine land has been reclaimed in Florida (2). Initial estimates from maps provided by the Polk County Health Department indicate that about 20,000 acres have been reclaimed in Polk County and is used in the following proportions:

USE	PERCENTAGE
Residential	29
Commercial or Industrial	8
Farming	16
Grazing	41
Miscellaneous	6

The Polk County Health Department has initially estimated for us that between 500 and 1000 structures presently exist on reclaimed land within the county. Some of these structures have existed for over twenty years, whereas others are presently under construction. From field studies, we observed that generally the older structures, i.e., constructed over ten years ago were of either crawl space or slab construction but generally did not have air conditioning, particularly central air conditioning. Whereas newer houses and particularly those now being constructed are on concrete slabs, possess a more airtight design, and have central air conditioning. Consequently, it would be anticipated that radon daughter levels would be highest in the newer air conditioned structures.

At the present, about 90,000 acres of land have been mined for phosphate rock (2). The industry is currently mining about 4700 acres per year. If we assume that 40–50 percent of the mined land can be potentially reclaimed (the remainder will be used to store slimes) and that the Florida phosphate industry will continue for at least 30 years, these will be about 50,000 to 70,000 additional acres available for reclaiming. Further, if slime dewatering systems are developed, slime ponds will not be needed and about 140,000 additional acres will be available for reclaiming. Consequently, a vast amount of land will be made available for societal use. The radiological impact of this land must be considered when determining the activities for which it will be used.

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A P P E N D I X   A

DEPARTMENT OF HEALTH, EDUCATION, AND WELFARE
PUBLIC HEALTH SERVICE
WASHINGTON, D.C. 20201

JUL 27 1970

Dr. R. L. Cleere
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4210 E. 11th Avenue
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Dear Dr. Cleere:

I am pleased to respond to your letter of January 29 in which you asked Dr. M. W. Carter, Director of our Southwestern Radiological Health Laboratory, for Public Health Service and/or U.S. Atomic Energy Commission assistance in providing exposure guidelines applicable to homes with high concentrations of radon progeny.

The enclosed graded recommendations for action have been developed within the framework of existing Federal Radiation Council guidance for occupational exposure to airborne concentrations of radon and its daughters (progeny). Also, graded action levels applicable to external gamma radiation are included.

You will note in the accompanying Explanatory Notes that these recommendations apply specifically to dwellings constructed with or on uranium mill tailings. Further qualifications in the Explanatory Notes should be consulted before these recommendations are applied.

The specific information which your Department is developing on the variability of radon daughter concentrations in dwellings and on optimum control measures will be essential towards making those decisions necessary in applying the recommendations.

These recommendations have been directed to the Atomic Energy Commission for comment. Because of the urgency attached to your receiving the recommendations as soon as possible, they have been forwarded to you in advance of receiving AEC views and comments. We will advise you of the AEC response when received.

Sincerely yours,

Acting Surgeon General

RECOMMENDATIONS OF ACTION FOR RADIATION EXPOSURE LEVELS IN DWELLINGS CONSTRUCTED ON OR WITH URANIUM MILL TAILINGS

External Gamma Radiation

Level	Recommendations
Greater than 0.1 mR/hr	Remedial action indicated
From 0.05 to 0.1 mR/hr	Remedial action may be suggested
Less than 0.05 mR/hr	No action indicated

Indoor Radon Daughter Products

Level	Recommendations
Greater than 0.05 WL	Remedial action indicated
From 0.01 to 0.05 WL	Remedial action may be suggested
Less than 0.01 WL	No action indicated

EXPLANATORY NOTES

1. These recommendations are written specifically for dwellings constructed on or with uranium mill tailings. This situation may involve continuous exposure of members of the public to radon daughter product activities and whole-body gamma irradiation levels in excess of the background radiation levels found within dwellings in the area not constructed with or on uranium mill tailings.

2. Although the initial concern was the presence of radon daughter product activities within these dwellings, preliminary surveys have indicated that, in some instances, the gamma radiation levels were of prime importance. Thus, recommendations are made concerning both types of radiation. The recommendation applicable to a particular dwelling will be determined by whichever type of radiation has the higher level.

3. Three levels for action are recommended for both external gamma and radon daughter product exposures. This graded system of actions is proposed to allow latitude in the middle ranges for the judgment of the on-site investigators.

4. The external gamma and radon daughter product levels proposed constitute exposures which are in addition to the natural background levels found within dwellings in the area not constructed on or with uranium mill tailings. In the Grand Junction, Colorado, area these levels are approximately 0.01 mR/hr (approximately 90 mrem/yr) and 0.004 Working Levels (WL) (approximately 0.2 CWLM/yr) respectively (1).

5. The expected health effects of concern will be different for the two types of radiation, i.e., leukemia for whole body gamma radiation exposure and lung cancer for exposure to inhaled radon daughter products. This expectation is based, in part, on findings derived from population studies such as the Japanese atomic bomb survivors and uranium miners. These specific health effects are considered to be mutually exclusive. The basis for this assumption is that the expected radiation contribution to whole body exposure from inhaled

radon and daughter products would be considerably less than the direct exposure from external gamma radiation at the levels encountered in the dwellings. Conversely, the external gamma radiation contribution to the lung dose is considered to comprise a negligible additional risk of lung cancer.

6 a. A Working Level (WL) is the term used to describe radon daughter product activities in air. This term is defined as any combination of short-lived radon daughter products in 1 liter of air that will result in the ultimate emission of 1.3×10^5 MeV of potential alpha energy (2). The numerical value of the WL is derived from the alpha energy released by the total decay through Ra C' of the short-lived radon daughter products, Ra A, Ra B and Ra C, at radioactive equilibrium with 100 pCi of ^{222}Rn per liter of air (3).

6 b. A Working Level Month (WLM) is the term used to express the occupational exposure incurred in one working month of 170 hours by a uranium miner laboring in an atmosphere containing radon daughter products; i.e., one working month in a mine atmosphere containing 1 WL of radon daughter products equals 1 WLM.

6 c. Cumulative Working Level Months (CWLM) is the term used to express the total accumulated occupational exposure to radon daughter products in air; i.e., an air concentration of radon daughter products of 1 WL would, in one working month, equal 1 WLM, and in 1 year or 12 months would equal 12 CWLM.

6 d. Since occupational exposures are based upon 170 hours per month and continuous exposure involves approximately 170 hours per

week, then an occupational exposure to an air concentration of 1 WL is equivalent to continuous exposure to 0.25 WL.

7. These recommendations are based on the assumption of a linear, non-threshold dose-effect relationship. The lack of definitive information precludes allowances for possible differences in radiosensitivity due to age, sex, or other biological characteristics.

8. No action is indicated when the external gamma exposure rate is less than 0.05 mR/hr and the radon daughter product activity is less than 0.01 WL since under conditions of continuous exposure these levels would result in maximum annual exposures of approximately 400 mrem and 0.5 CWLM, respectively. The maximum annual value of 400 mrem is less than the dose limits recommended for an individual member of the general public by the FRC (4) and ICRP (5) for whole body exposure to external gamma irradiation.

The ICRP (5) recommends that the annual dose limit for members of the public shall be 1/10 of the corresponding annual occupational maximum permissible dose. The maximum annual value of 0.5 CWLM of radon daughter product exposure is approximately 1/10 of the 4 CWLM annual occupational exposure limit recommended by the FRC (6) for implementation on 1 January 1971, and less than 1/20 of the annual occupational exposure limit of 12 CWLM recommended for uranium miners in the present FRC regulations (4).

9. Remedial action may be suggested in the case of external gamma exposure rates of 0.05-0.10 mR/hr or radon daughter product activities of 0.01-0.05 WL since under conditions of continuous exposure

these levels would result in maximum annual exposures of approximately 400-900 mrem and 0.5-2.5 CWLM. The upper limit of these ranges exceeds the strictly applied recommendations of the FRC and ICRP for exposures of an individual member of the public. However, this extension seems justified in situations in which unforeseen exposures have occurred, since as stated by ICRP (5) "in general it will be appropriate to institute countermeasures only when their social cost and risk will be less than those resulting from the exposure." It is further stated by the ICRP (5) that very low levels of risk are implied in the dose limits for members of the public and that it is likely to be of minor consequence to their health if the dose limits are marginally or even substantially exceeded.

10. Remedial action is indicated at gamma exposures greater than 0.1 mR/hr or at radon daughter product activities greater than 0.05 WL. Under conditions of continuous exposure, these levels would result in minimum annual exposures of 900 mrem and 2.5 CWLM. All values above these would indicate the necessity for remedial action, since at these levels the maximum annual exposures recommended by the FRC and ICRP for an individual member of the public is exceeded.

11. With respect to the external gamma irradiation, from the estimates published by ICRP (7), it can be interpolated that the annual risk of leukemia under conditions of continuous exposure to 500 mrem per year is an increased incidence of about 10 cases per year per million persons exposed. The natural annual incidence of leukemia for all ages is given by ICRP (8) as 10-100 cases per million persons.

With respect to radon daughter product exposures, it has been estimated by Archer and Lundin (9) that an exposure of 120 CWLM to a group of white adult males in the United States appears to approximately double the normal lung cancer incidence which for this population is about 2-3 cases per year per 10,000 persons. At an annual exposure of 2.5 CWLM, 48 years would be required to reach 120 CWLM.

12. It is considered that implementation of these recommendations for the various exposure ranges would make it highly unlikely that any serious health effects would result from exposure to radon daughter products or external gamma irradiation in this particular situation.

13. It is suggested that remedial action be taken only after an adequate number of measurements taken under a diversity of temporal and climatic conditions have clearly established that the average exposure is in excess of 0.1 mR/hr or 0.05 WL.

14. It is recognized that some time lapse will be inherent in establishing that radiation levels in excess of 0.1 mR/hr or 0.05 WL exist and in instituting corrective measures. However, it is considered that the additional health risks from continued exposure over this time period are of lesser consequence than the economic and social discomfitures of precipitous action.

APPROVED:

Jesse L. Steinfeld, M.D.
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Public Health Service

27 July 1970
Date

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