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Formerly Utilized MED/AEC Sites Remedial Action Program

Radiological Survey of the Seneca Army Depot Romulus, New York

February 1979

Final Report

Prepared for

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PREFACE

This series of reports results from a program initiated in 1974 by the Atomic Energy Commission (AEC) for determination of the condition of sites formerly utilized by the Manhattan Engineer District (MED) and the AEC for work involving the handling of radioactive materials. Since the early 1940's, the control of over 100 sites that were no longer required for nuclear programs has been returned to private industry or the public for unrestricted use. A search of MED and AEC records indicated that for some of these sites, documentation was insufficient to determine whether or not the decontamination work done at the time nuclear activities ceased is adequate by current guidelines.

The work reported in this document was conducted by the following members of the Health and Safety Research Division, Oak Ridge National Laboratory, Oak Ridge, Tennessee:

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RADIOLOGICAL SURVEY OF THE SENECA ARMY DEPOT, ROMULUS, NEW YORK

ABSTRACT

The results of a radiological survey of the Seneca Army Depot, Romulus, New York, are presented in this report. For a short period in the early 1940s, eleven munition bunkers on this site were used for storage of approximately 2000 barrels of pitchblende ore. The survey was undertaken to characterize the radiological status of the bunkers and to determine the extent of contamination in the area surrounding the bunkers, in the surface waters in the vicinity of the bunkers, and along a rail spur leading into the area. It appears from the survey results that residual radioactivity resulting from the storage of the uranium ore is confined almost entirely to the interiors of eight of the bunkers and to the outdoor areas near the entrances to these bunkers.

INTRODUCTION

At the request of the Department of Energy (then ERDA), a radiological survey was conducted at the Seneca Army Depot in Romulus, New York. The Seneca Army Depot covers approximately 10,000 acres, and in a large part, consists of munition bunkers. Approximately 2000 barrels of pitchblende ore were stored in eleven of these bunkers during a short period in the early 1940s. After removal of the uranium ore, normal storage of ammunition in these bunkers was resumed and apparently has been continued up to the time of this survey. The bunkers are used for storage and are occupied for only brief periods by Army personnel. The present survey was undertaken to characterize the radiological status of the bunkers in which the ore was stored and to determine the extent of the spread of radioactivity in the area surrounding the bunkers, in the surface waters in the vicinity of the bunkers, and along a rail spur over which the ore was transported to and from the facility.

The survey was conducted by three members of the Health and Safety Research Division, Oak Ridge National Laboratory, during the period, September 10-23, 1976. The survey consisted of (1) direct readings of alpha and beta radiation levels on surfaces in each of the bunkers, (2) measurements of transferable alpha and beta radiation levels on surfaces in the bunkers, (3) measurements of external gamma radiation levels in the bunkers and at one meter above the surface in the immediate vicinity of the bunkers, (4) concentrations of uranium and some of its daughter products in soil samples taken in the vicinity of the bunkers, (5) radon and radon daughter concentrations in air samples taken in the bunkers, (6) radioactivity in surface waters in the vicinity of the bunkers, and (7) radioactivity along the rail spur and loading docks which were used when the ore was moved into and away from the site.

RADIOLOGICAL SURVEY TECHNIQUES

Measurement of Residual Alpha and Beta-Gamma Radiation Levels

In each bunker, both direct and transferable radioactivity levels were measured in each of the areas indicated in Fig. 1. Direct readings on the floor, wall, and ceiling surfaces were made with portable gas-flow proportional survey meters for measurement of alpha radiation, and with Geiger-Mueller survey meters for measurement of beta-gamma radiation. These instruments are described in Appendix I. Survey meters were also used to measure alpha radiation levels on the roof vents of the bunkers. Both the average reading and the maximum reading are reported in Tables 1-12 for each area surveyed. Transferable radioactivity levels in the buildings were measured using standard smear techniques and smear counters described in Appendix I; the measurements are presented in Tables 1-12.

Direct readings of alpha radioactivity which were less than 100 dpm/100 cm^2 are reported in Tables 1-12 as " <100." Transferable alpha radioactivity levels less than 10 dpm/100 cm^2, transferable beta-gamma radioactivity less than 100 dpm/100 cm^2, and direct readings of beta-gamma dose rates less than 0.03 mrad/hr, are reported in an analogous manner.

Measurement of Radon and Radon Daughter Concentrations in the Bunkers

For the measurement of instantaneous radon concentrations in the air, samples were taken using evacuated 95-ml glass flasks (known as Lucas Chambers) coated inside with a uniform layer of zinc sulfide. Sample counting was delayed 3 to 4 hr to allow the radon daughters to attain equilibrium. Scintillations from the zinc sulfide were then counted for 1000 sec with a system which utilizes a photomultiplier tube and associated electronics. A calibration performed at ORNL using a known radon concentration indicated that the proper conversion factor is approximately 2.02 pCi/liter per cpm. The Lucas Chamber and its counting system are described in Appendix II.

Measurements were also made to determine the concentration of airborne radon daughters in the bunkers. Air was pumped for five minutes at approximately 12 liters/min through a membrane filter with a maximum pore size of 0.4 μ. The filter was counted using an alpha spectrometry technique refined by Kerr.[1] This technique is described in Appendix II.

Measurements of External Gamma Radiation Levels

External gamma radiation levels, which include natural background, were measured with scintillation survey meters; these instruments are described in Appendix I. Readings were taken in each bunker at one meter above the floor at the center of each of the areas F1 through F16 (Fig. 1). Measurements also were made at one meter above the surface in the immediate vicinity of the bunkers and along the previously mentioned rail spur (see Figs. 3 and 4).

Measurement of Radium and Uranium in the Soil

Soil samples were collected at several locations in the vicinity of the bunkers (see Figs. 2A-2L), and a residue sample was taken from a drain trough in Bunker E0804. The samples were packaged in plastic bags or bottles before being transported to Oak Ridge, where they were dried for 24 hr at 110°C and then pulverized to a particle size of -35 mesh (500 μm). Next, aliquots from each sample were transferred to plastic bottles or petri dishes, weighed, and counted using a Ge(Li) detector. The spectra obtained were analyzed by computer techniques. Descriptions of the Ge(Li) detector and the soil counting techniques are given in Appendix III. Radium concentrations were determined for all the samples; in addition, ^{238}U, ^{232}Th, ^{227}Ac, and ^{40}K concentrations were determined for selected samples.

Measurement of Radioactivity in Surface Water

Water samples were collected from two drainage areas for determination of radium, uranium, and thorium content. These samples were taken at locations W9 and W10, shown in Fig. 3. The samples were analyzed at ORNL using sequential separation techniques.

SURVEY RESULTS

Background Measurements

Background measurements were taken in and around Bunker C0912, which has never been used for storage of radioactive materials. This building is located approximately 1.5 miles from the bunkers in which uranium ore was stored. Radiation measurements in this bunker were made using the same techniques employed in bunkers used for ore storage; results are listed in Table 12. All direct readings of alpha radioactivity in this building were less than 100 dpm/100 cm^2, and all transferable alpha readings were less than 10 dpm/100 cm^2. Direct readings of beta-gamma radiation levels in the bunker were less than 0.03 mrad/hr, and all smears showed less than 100 dpm/100 cm^2 for beta-gamma radiation. External gamma radiation measurements at one meter above the floor were approximately 10 μR/hr throughout the bunker. Two measurements of instantaneous radon concentrations in the air in Bunker C0912 averaged 1.2 pCi/liter (see Table 13), and the radon daughter concentration measured approximately 0.014 WL* (Table 14).

At one meter above the asphalt, grass, and soil surfaces outside Bunker C0912, the external gamma radiation readings were in the range of

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*A working level (WL) 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 alpha particle energy.

8-10 μR/hr (Fig. 2L). A soil sample taken about 40 ft northeast of the bunker door showed concentrations of uranium and radium of 1.6 pCi/g and 0.8 pCi/g, respectively (see Tables 15 and 16).

Alpha and Beta-Gamma Radioactivity in the Bunkers

Direct readings of alpha and beta-gamma radiation levels (including natural background) in Bunkers E0801-0811 are given in Tables 1 through 11. Also presented are measurements of transferable radioactivity. In Bunkers E0801 (Table 1), E0802 (Table 2), and E0803 (Table 3), all measured radiation levels were similar to the background levels measured in Bunker C0912 (Table 12). There was no indication from these measurements that radioactive materials had been stored in these three bunkers.

The highest levels of alpha contamination were detected in Bunker E0804 (Table 4), where direct readings as high as 1.3×10^5 dpm/100 cm^2 were found in small areas near the intersection of the floor and wall. In most areas of this building, alpha radioactivity was in the range of 200-2000 dpm/100 cm^2 by direct reading. Smear counts indicated that transferable alpha radioactivity in Bunker E0804 varied from background levels up to approximately 430 dpm/100 cm^2. Direct readings of beta-gamma radiation in this bunker were as high as 16 mrad/hr in small, isolated spots, but varied from background levels to 0.2 mrad/hr in most areas of the bunker. Transferable beta-gamma radioactivity in Bunker E0804 ranged from background levels to 240 dpm/100 cm^2.

The pattern of alpha and beta contamination in the four bunkers E0805, E0806, E0807, and E0808 (see Tables 5-8) was somewhat similar to that of Bunker E0804. Alpha radioactivity in these four buildings was generally in the range of 150-1000 dpm/100 cm^2 by direct reading but measured 5000-10,000 dpm/100 cm^2 in some isolated areas. However, in one spot on the floor in Bunker E0806, the level by direct reading was 7×10^4 dpm/100 cm^2. Transferable alpha was in the range of 10-40 dpm/100 cm^2 in most parts of these bunkers. Transferable beta was generally in the range of 0-200 dpm/100 cm^2 but averaged approximately 2000 dpm/100 cm^2 in one area of 15 m^2 (Fig. 1, block F15) in Bunker E0806. Direct readings of beta-gamma radiation in these buildings were usually below 0.1 mrad/hr but ranged as high as 4.57 mrad/hr in Bunker E0806 (Fig. 1, block F15).

In Bunkers E0809, E0810, and E0811 (Tables 9-11), direct readings of alpha radiation were well above 100 dpm/100 cm^2 in many areas. However, all direct readings of alpha radioactivity were below 5000 dpm/100 cm^2, and transferable alpha measurements were below 10 dpm/100 cm^2 in most areas. Transferable beta-gamma radioactivity in these three buildings was below 100 dpm/100 cm^2 in most areas but was in the range of 100-250 dpm/100 cm^2 in isolated spots.

The exterior surfaces of the bunkers were uncontaminated except for the outsides of the vents (on the roofs) which showed some alpha contamination (see Table 18). Soil is built up around each bunker; only the vent and the front of the structure are exposed. Direct readings of alpha radioactivity taken on the outsides of the vents on Bunkers A0804 and A0810, which are located about 4 miles from the bunkers in which uranium was stored, showed alpha contamination levels in the same range as the levels found on the vents of Bunkers E0801-0811 (see Table 18).

Radon and Radon Daughter Concentrations in the Bunkers

Air samples were analyzed by an alpha spectroscopy technique and revealed radon daughter concentrations in the range of 0.01-0.048 WL in Bunkers E0804-0811 and concentrations of less than 0.01 WL in Bunkers E0801-0803 (see Table 14). The highest concentration measured (0.048 WL in Bunker E0808) was about 3.5 times as high as the background measurement taken in Bunker C0912. All radon daughter measurements were instantaneous measurements taken during the daytime and were taken during a two-week period in September 1976.

The average concentration of radon measured in each of the Bunkers E0801, E0802, and E0803 was near the background level of approximately 1.2 pCi/liter measured in Bunker C0912. In the remaining bunkers, the radon concentrations were in the range of 2.2-6.4 pCi/liter (see Table 13). It should be noted that these measurements were taken over a short period of time; radon and radon daughter levels in a building may vary significantly over a period of several months.

The dose to individuals delivered by radon is small compared with the dose delivered by its daughter products (about 500 times less at equilibrium[2]). However, the measurement of radon concentrations in the buildings allows determination of the potential radon daughter levels, assuming minimum ventilation. An increment of 1 pCi/liter in the radon concentration in a poorly ventilated building might produce an increment as large as 0.0085 WL in the radon daughter concentration in that building.[3] As an illustration, the highest concentration of radon in samples taken in Bunker E0809 was 6.4 pCi/liter. Hence, with poor ventilation, the radon daughter concentration in the air in this building might be as high as 0.054 WL. This is only about 15% higher than the actual measured radon daughter concentration.

Measurements of External Gamma Radiation

In each bunker, external gamma radiation readings were taken at one meter above the floor near the center of each block indicated in Fig. 1. Most readings (see Tables 1-11) were near the background level measured in Bunker C0912. The highest readings were taken in Bunker E0811 and were about twice the background readings.

Measurements of external gamma radiation taken outdoors in the immediate vicinity of the bunkers are shown in Figs. 2A-2L. Except for some readings taken within 10-15 ft of the entrances to the bunkers, measurements were at background level.

External gamma radiation levels were measured on Loading Dock 600, which was used for the unloading of ore from rail cars, and on Loading Dock 305, about 1000 ft north of Dock 600 (see Figs. 3 and 4). External gamma radiation on both docks and along the railroad tracks leading away from the docks was at background level. Readings of 15 μR/hr were observed along a drainage ditch near Dock 600 (Fig. 4). Some local outcroppings of shale were observed in this area and may account for these readings.

Measurements of Radium Concentrations in Soil

Soil samples were collected at locations shown in Figs. 2A-2L. In addition, a residue sample was taken from a drain trough in Bunker E0804. Radium concentrations were measured in all samples (see Table 15), and concentrations of ^{238}U, ^{232}Th, ^{227}Ac, and ^{40}K were measured in selected samples (see Table 16). Most of the samples were taken near the entrances to the bunkers where survey meters indicated that radioactive contamination was highest.

The residue sample taken from the drain trough showed radium and uranium concentrations of 46,300 pCi/g and 67,070 pCi/g, respectively. The highest concentrations of radium in any soil sample collected outdoors was 7820 pCi/g in a sample taken near the entrance to Bunker E0804. Concentrations of radium and uranium in samples collected in the vicinity of Bunkers E0801-0803 were near background levels.

Results of Water Sample Analyses

The concentrations of uranium, radium, and thorium in water samples taken from surface water in the vicinity of the bunkers are listed in Table 17, which also gives the maximum permissible concentrations [4] in water (MPC_w) for each isotope tested. Sample W9 was taken from a small stream flowing near Bunker E0809, and Sample W10 is from a drainage ditch approximately 100 ft east of Bunker E0810 (see Fig. 3). In both samples, the concentration of each radionuclide tested was at least an order of magnitude below the MPC_w.

SUMMARY

The interior surfaces of at least eight of the bunkers have been contaminated with uranium ore; and, as a consequence, natural uranium and its daughters, including ^{226}Ra, may be found on these surfaces and on the outdoor surfaces near the entrances to these bunkers. In the only residue sample found in the bunkers, the ratio of the activity of

^{226}Ra to the activity of ^{238}U was 0.69. Although this may not represent the fraction of equilibrium of ^{226}Ra for other contaminated surfaces on the site, it must be assumed (since uranium ore was handled on this site) that a significant fraction of the alpha activity on the surfaces is due to ^{226}Ra. Since ANSI[5] and NRC[6] surface contamination limits for ^{226}Ra, among other nuclides, are 50 times more stringent than limits for ^{238}U, it appears that the limits for ^{226}Ra should be applied to this site. According to the NRC guidelines[6] (which are consistent with proposed ANSI standards[5]), average* and maximum* acceptable levels of fixed alpha contamination are 100 dpm/100 cm^2 and 300 dpm/100 cm^2, respectively, provided the principal contaminant is ^{226}Ra (see Appendix IV). Transferable alpha contamination should not exceed 20 dpm/100 cm^2, and transferable beta contamination limits should not exceed 1000 dpm/100 cm^2. Average and maximum limits for beta-gamma dose rates at 1 cm above a surface, according to NRC guidelines, are 0.2 mrad/hr and 1.0 mrad/hr, respectively.

Direct alpha readings exceeded 300 dpm/100 cm^2 in some areas in each of the eight bunkers E0804 through E0811, and transferable alpha contamination exceeded 20 dpm/100 cm^2 at some points in E0804, E0805, E0806, E0807, E0809, and E0810. Transferable beta contamination exceeding 1000 dpm/100 cm^2 was measured in one area of the floor of Bunker E0806. Beta-gamma dose rates of 1.0 mrad/hr or higher were measured in Bunkers E0804 and E0806.

The radon daughter concentrations measured in Bunkers E0801 through E0803 were below 0.01 WL. Radon daughter concentrations measured in

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*Measurements may not be averaged over more than 1 square meter. The maximum contamination level applies to an area of not more than 100 cm^2.

Bunkers E0804 through 0811 were in the range of 0.010 through 0.048 WL and exceeded 0.03 WL in Bunkers E0804, E0805, E0806, E0807, E0808, and E0809. These measurements represent instantaneous radon daughter concentrations measured during the daytime and were only exploratory in nature. Radon and radon daughter measurements taken over a short period of time may not accurately reflect average annual conditions.

The situation at this site bears some resemblance to that encountered in Grand Junction, Colorado, where radium-bearing uranium mill tailings were used for private purposes, including construction of residence and commercial structures. At the request of the state of Colorado, the U. S. Surgeon General has developed a set of guidelines for use in considering the need for remedial action in such cases. These guidelines were adopted by ERDA as the basis for the Grand Junction Remedial Action Criteria, which has been codified as 10 CFR 712[7] (see Appendix IV). In considering the need for remedial action in structures where the radon daughter concentration exceeds background, it is recommended that indoor radon daughter concentrations be determined by "(1) average the results of six air samples each of at least 100-hours duration and taken at a minimum of four-week intervals throughout the year in a habitable area of a structure, or (2) utilizing some other procedure approved by the Commission." For structures other than residences, an observed average indoor radon daughter concentration level of 0.03 WL or greater above background will qualify the structure for consideration by ERDA and regulatory authorities of the need for remedial action. If it is determined that the Surgeon General's guidelines are applicable to this site, then the limited exploratory measurements made during this survey indicate the need for continued sampling over periods as recommended in 10 CFR 712, since measured radon daughter concentrations were found to exceed background levels by 0.03 WL or more in some of the bunkers. It should be pointed out that the bunkers are used for storage and are occupied for only brief periods of time, so that the measured radon daughter levels at present do not appear to constitute a health hazard. However, there is no guarantee that the bunkers will not be occupied for longer periods of time at some future date, and the average radon daughter levels may be significantly higher than the instantaneous concentrations measured during the survey.

External gamma radiation levels at one meter above the floor in the bunkers ranged from background levels (about 10 μR/hr) up to 21 μR/hr, with highest levels being measured in Bunkers E0810 and E0811. In some cases, external gamma radiation readings taken outdoors near the bunker entrances were above background levels. The highest external gamma radiation reading taken at one meter above the surface on the site was 31 μR/hr, near the entrance to Bunker E0806. (However, an open-window G-M meter reading taken at one cm above the ground in a small area near the entrance of Bunker E0804 revealed beta-gamma radiation of 27 mrad/hr.) All other external gamma radiation readings taken in the vicinity of the bunkers and along the railroad tracks where the uranium ore was loaded were in the range of 8-15 μR/hr.

Concentrations of radium as high as 7820 pCi/g were found in soil samples collected outdoors on the site. However, it appears that the only contaminated soil on the site is near the surface in small areas near the bunker entrances. Two surface water samples taken from the drainage areas near the bunkers showed uranium, radium, and thorium concentrations which were at least an order of magnitude below the maximum permissible concentrations.

An evaluation has been made of current radiation exposures at the Seneca Army Depot, and is presented in Appendix V (page 101) of this report. The purpose of this evaluation is to present information which will permit the reader to compare current radiation exposures from the site to normal background exposures for that part of New York, as well as to scientifically based guideline values established for the protection of radiation workers and members of the general public.

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2. M. Eisenbud, *Environmental Radioactivity*, (pp. 158-159,) McGraw-Hill, New York; 1963.

3. A. Toth, "Determining the Respiratory Dosage from RaA, RaB, and RaC Inhaled by the Population in Hungary," *Health Phys.* 23, 281 (1972).

4. Code of Federal Regulations, Title 10, Part 20, *Standards for Protection Against Radiation*, Appendix B.

5. Proposed American National Standard, ANSI N328-197, *Control of Radioactive Surface Contamination on Materials, Equipment, and Facilities to be Released for Uncontrolled Use*, 1976.

6. *Guidelines for Decontamination of Facilities and Equipment Prior to Release for Unrestricted Use or Termination of Licenses for Byproduct, Source, or Special Nuclear Material*, USNRC, December 1975.

7. Grand Junction Remedial Action Criteria, 10 CFR; Part 712, Federal Register, Vol. 41, No. 252-Thursday, December 30, 1976.

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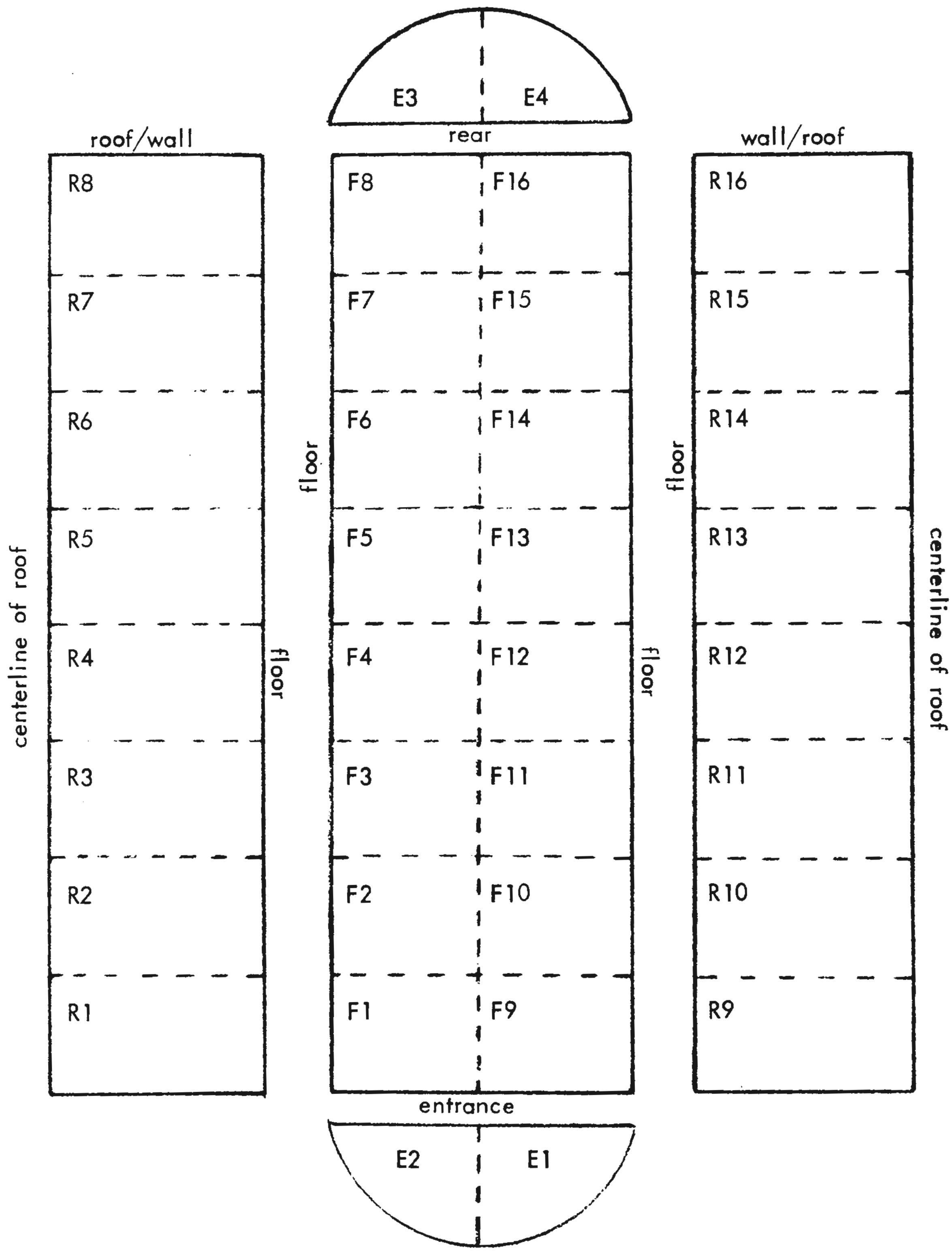
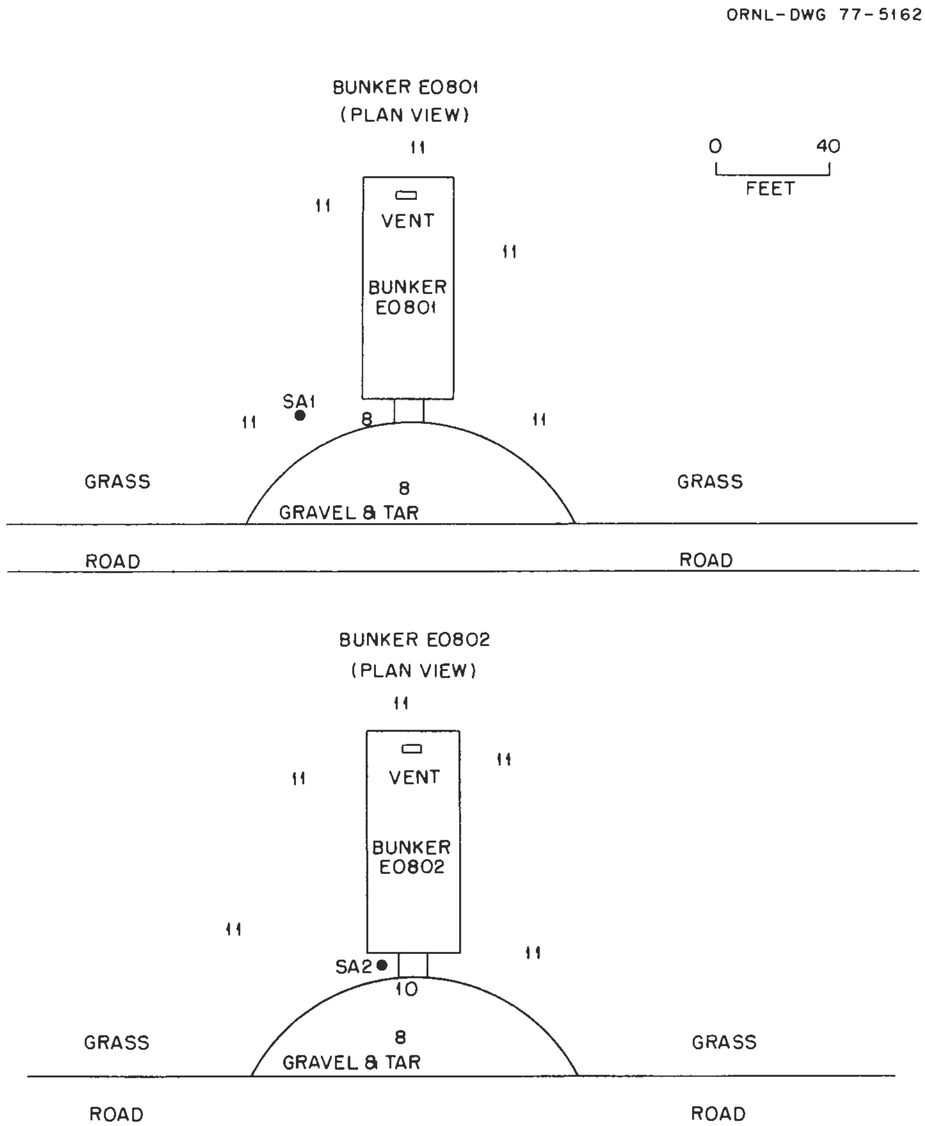
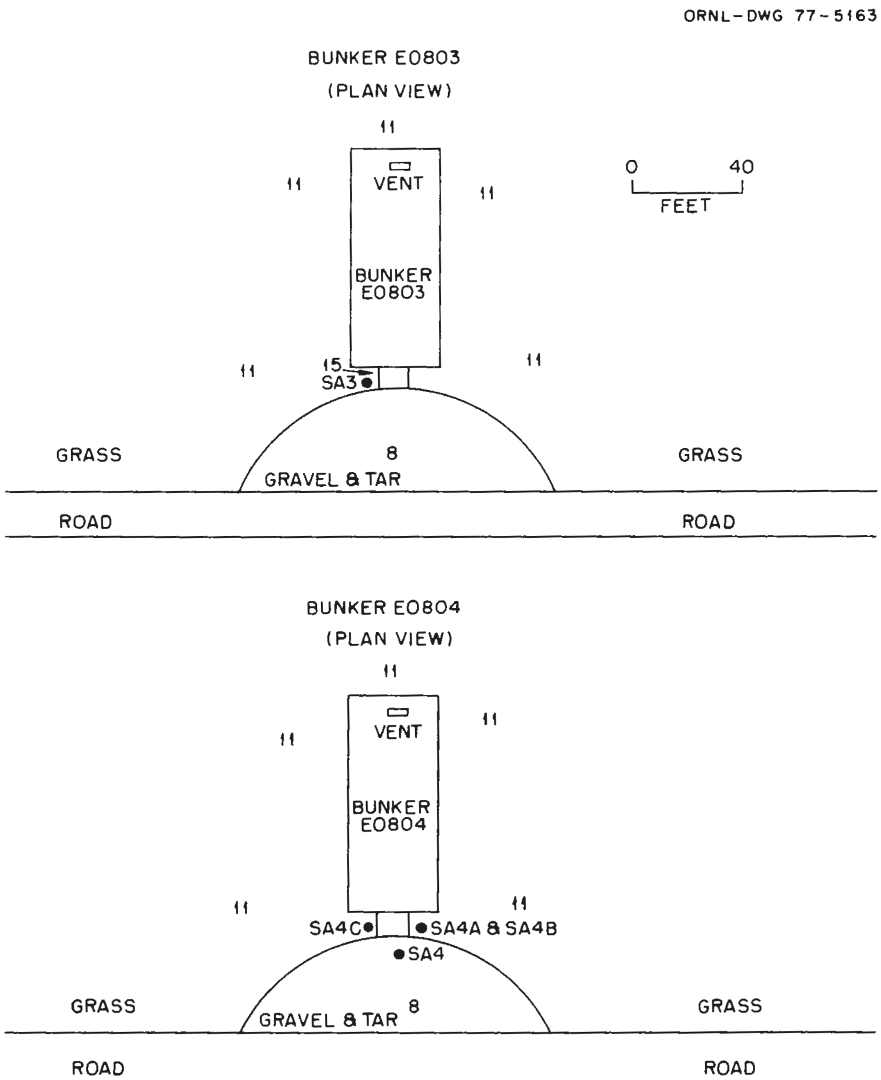


Fig. 1. Typical areas into which Bunkers were divided for survey purposes.



Figs. 2A & 2B. External gamma radiation readings (in μR/hr).

Note: Location of soil samples denoted by number and SA prefix.



Figs. 2C & 2D. External gamma radiation readings (in μR/hr).

Note: Location of soil samples denoted by number and SA prefix.

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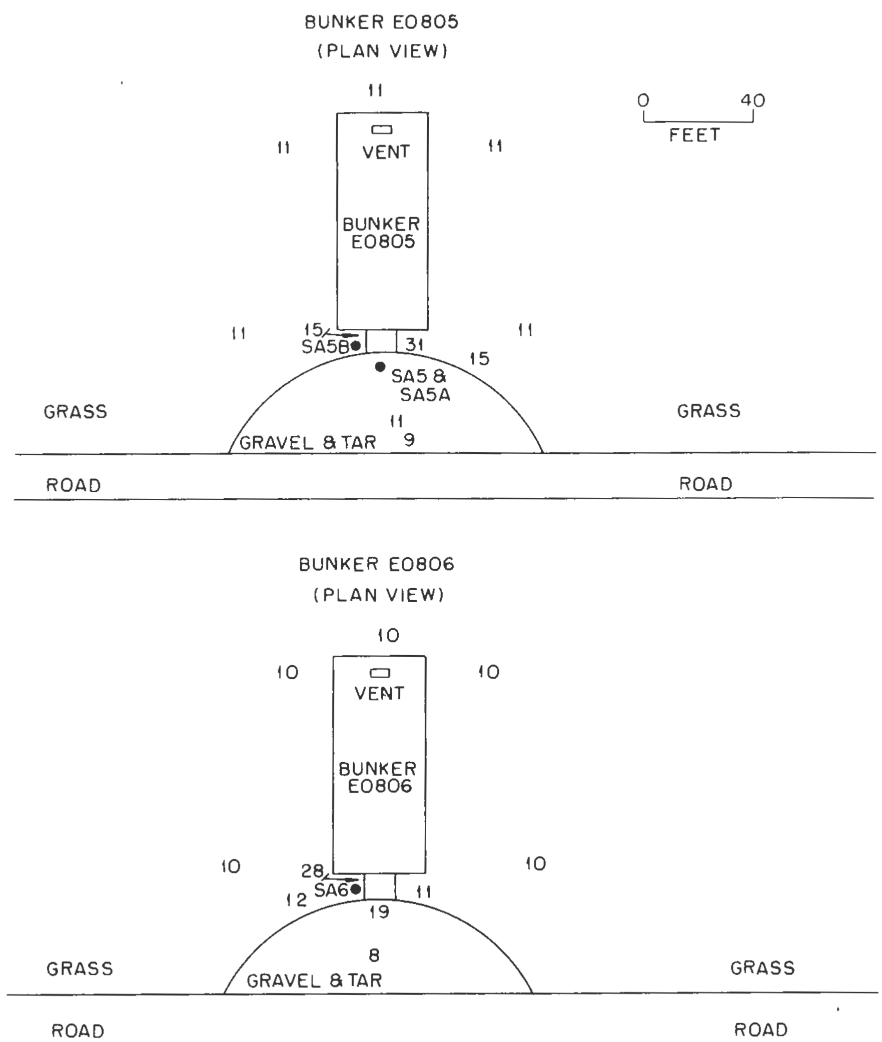
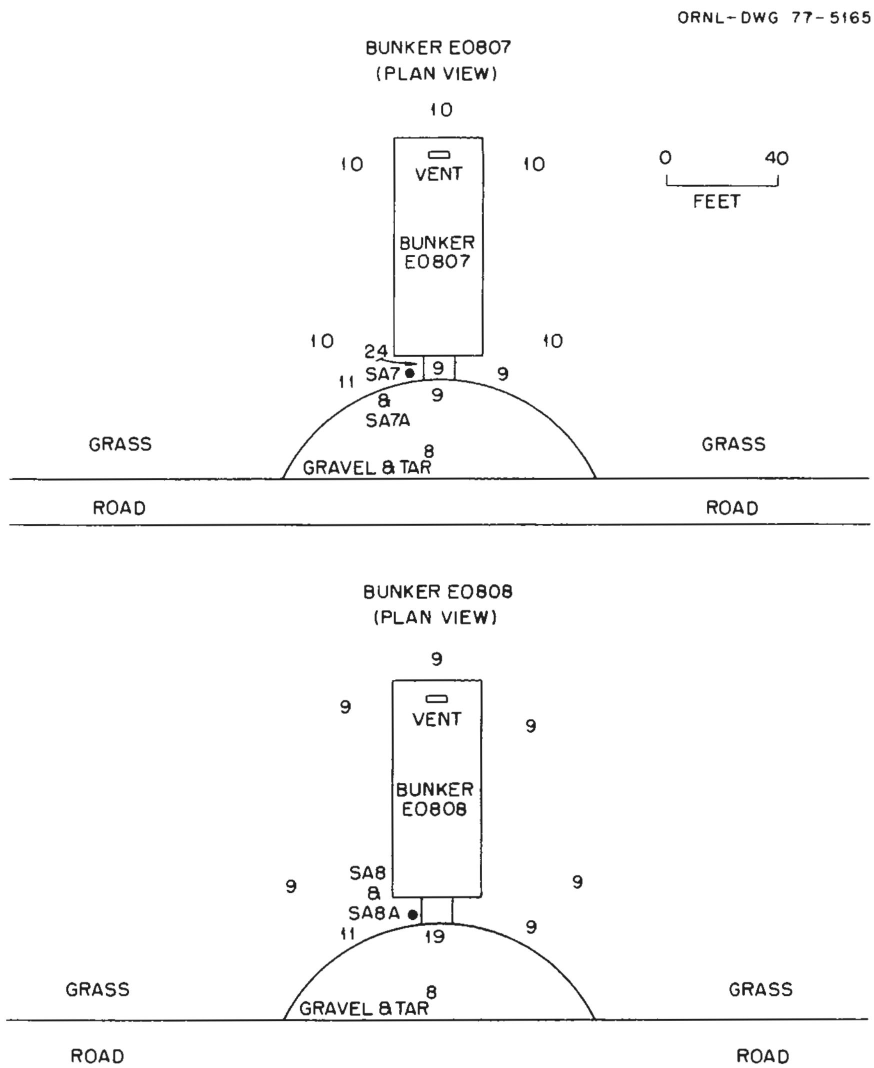


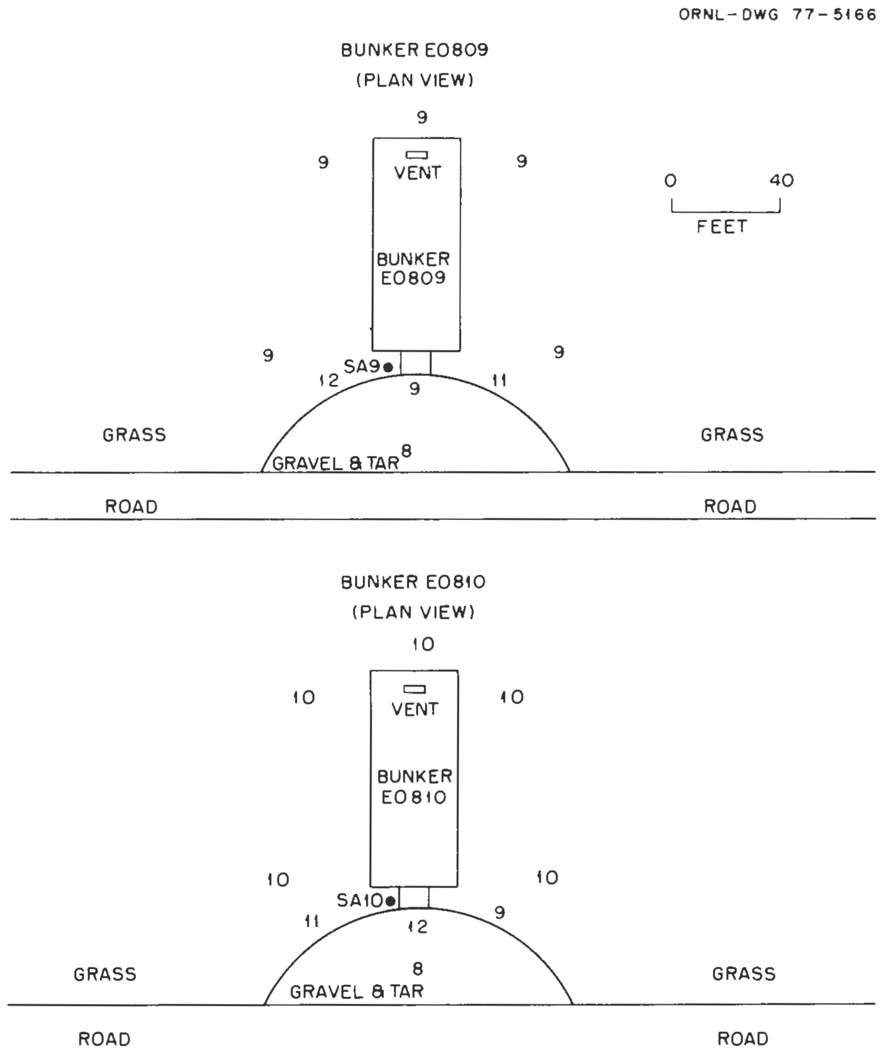
Figs. 2E & 2F. External gamma radiation readings (in μR/hr).

Note: Location of soil samples denoted by number and SA prefix.



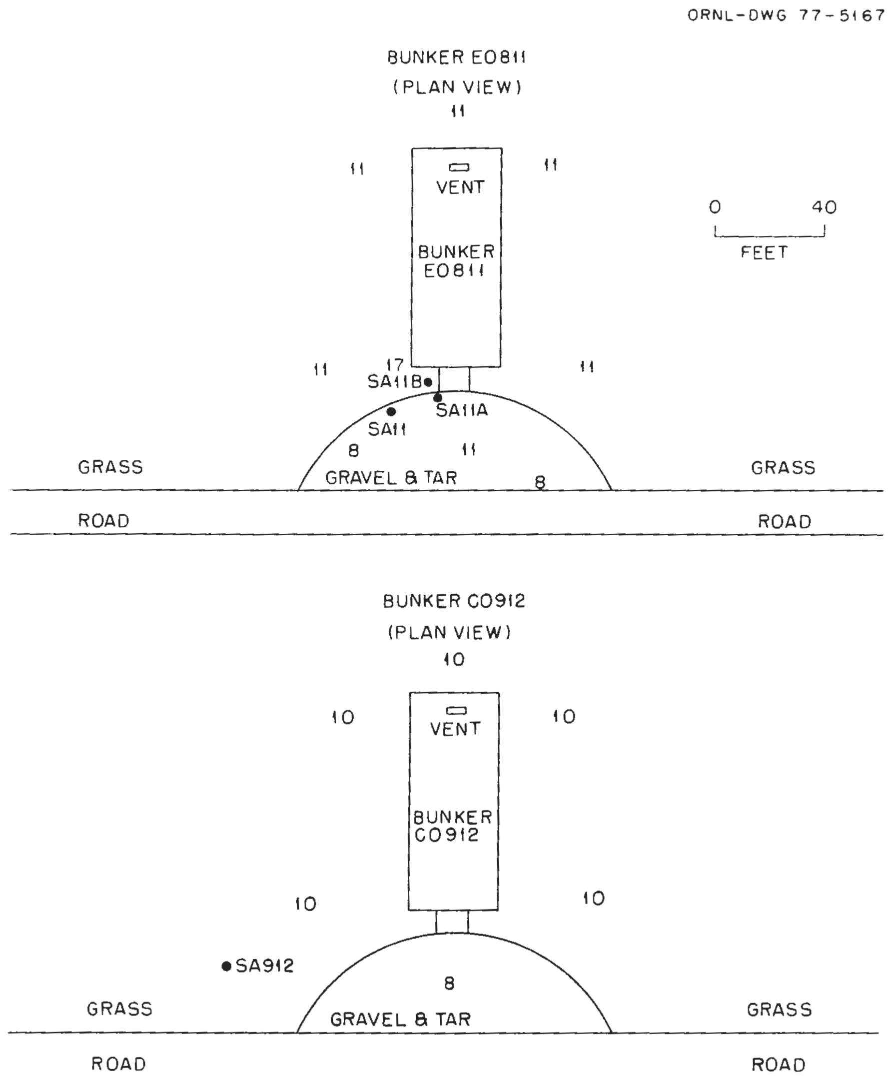
Figs. 2G & 2H. External gamma radiation readings (in μR/hr).

Note: Location of soil samples denoted by number and SA prefix.



Figs. 2I & 2J. External gamma radiation readings (in μR/hr).

Note: Location of soil samples denoted by number and SA prefix.



Figs. 2K & 2L. External gamma radiation readings (in μR/hr).

Note: Location of soil samples denoted by number and SA prefix.

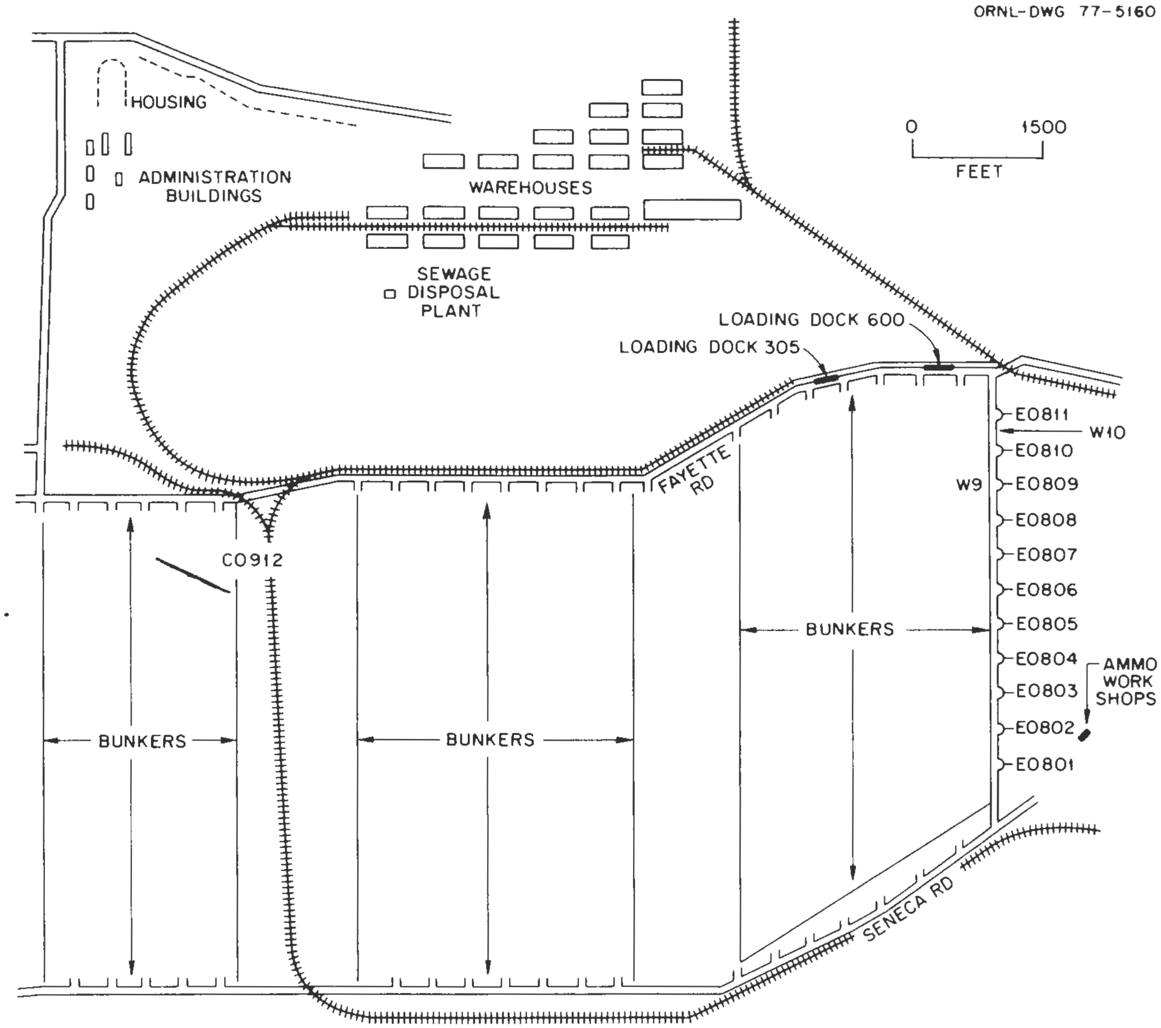


Fig. 3. Map of portion of Seneca Army Depot.

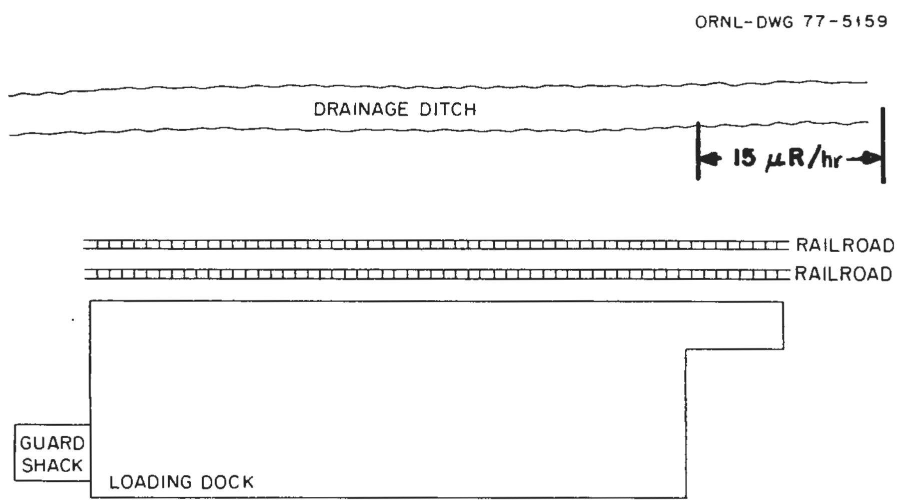


Fig. 4. Loading Dock 600 and nearby landmarks.

Table 1. Alpha, beta, and gamma radiation in Bunker E0801

Location	Direct alpha (dpm/100 cm²) average	Direct alpha (dpm/100 cm²) maximum	Transferable alpha (dpm/100 cm²)	Beta-gamma dose rate[a] (mrad/hr) average	Beta-gamma dose rate[a] (mrad/hr) maximum	Transferable beta (dpm/100 cm²)	External gamma at 1 m (μR/hr)
Floor							
F1	<100	<100	<10	<0.03	<0.03	<100	10
F2	<100	<100	<10	<0.03	<0.03	<100	10
F3	<100	<100	<10	<0.03	<0.03	<100	10
F4	<100	<100	<10	<0.03	<0.03	<100	10
F5	<100	<100	<10	<0.03	<0.03	<100	10
F6	<100	<100	<10	<0.03	<0.03	<100	10
F7	<100	<100	<10	<0.03	<0.03	<100	10
F8	<100	<100	<10	<0.03	<0.03	<100	10
F9	<100	<100	<10	<0.03	<0.03	<100	10
F10	<100	<100	<10	<0.03	<0.03	<100	10
F11	<100	<100	<10	<0.03	<0.03	<100	10
F12	<100	<100	<10	<0.03	<0.03	<100	10
F13	<100	<100	<10	<0.03	<0.03	<100	10
F14	<100	<100	<10	<0.03	<0.03	<100	10
F15	<100	<100	<10	<0.03	<0.03	<100	10
F16	<100	<100	<10	<0.03	<0.03	<100	10
Roof and side walls							
R1	<100	<100	<10	<0.03	<0.03	<100	
R2	<100	<100	<10	<0.03	<0.03	<100	
R3	<100	<100	<10	<0.03	<0.03	<100	
R4	<100	<100	<10	<0.03	<0.03	<100	
R5	<100	<100	<10	<0.03	<0.03	<100	
R6	<100	<100	<10	<0.03	<0.03	<100	
R7	<100	<100	<10	<0.03	<0.03	<100	
R8	<100	<100	<10	<0.03	<0.03	<100	
R9	<100	<100	<10	<0.03	<0.03	<100	
R10	<100	<100	<10	<0.03	<0.03	<100	
R11	<100	<100	<10	<0.03	<0.03	<100	
R12	<100	<100	<10	<0.03	<0.03	<100	

Table 1 (cont.). Alpha, beta, and gamma radiation in Bunker E0801

Location	Direct alpha average (dpm/100 cm^2)	Direct alpha maximum (dpm/100 cm^2)	Transferable alpha (dpm/100 cm^2)	Beta-gamma dose rate[a] average (mrad/hr)	Beta-gamma dose rate[a] maximum (mrad/hr)	Transferable beta (dpm/100 cm^2)	External gamma at 1 m (μR/hr)
R13	<100	<100	<10	<0.03	<0.03	<100	
R14	<100	<100	<10	<0.03	<0.03	<100	
R15	<100	<100	<10	<0.03	<0.03	<100	
R16	<100	<100	<10	<0.03	<0.03	<100	
				End walls			
E1	<100	<100	<10	<0.03	<0.03	<100	
E2	<100	<100	<10	<0.03	<0.03	<100	
E3	<100	<100	<10	<0.03	<0.03	<100	
E4	<100	<100	<10	<0.03	<0.03	<100	

[a]Includes gamma rays.

Table 2. Alpha, beta, and gamma radiation in Bunker E0802

Location	Direct alpha average (dpm/100 cm²)	Direct alpha maximum (dpm/100 cm²)	Transferable alpha (dpm/100 cm²)	Beta-gamma dose rate[a] average (mrad/hr)	Beta-gamma dose rate[a] maximum (mrad/hr)	Transferable beta (dpm/100 cm²)	External gamma at 1 m (μR/hr)
				Floor			
F1	<100	<100	<10	<0.03	<0.03	<100	10
F2	<100	<100	<10	<0.03	<0.03	<100	10
F3	<100	<100	<10	<0.03	<0.03	<100	10
F4	<100	<100	<10	<0.03	<0.03	<100	10
F5	<100	<100	<10	<0.03	<0.03	<100	10
F6	<100	<100	<10	<0.03	<0.03	<100	10
F7	<100	<100	<10	<0.03	<0.03	<100	10
F8	<100	<100	<10	<0.03	<0.03	<100	10
F9	<100	<100	<10	<0.03	<0.03	<100	10
F10	<100	<100	<10	<0.03	<0.03	<100	10
F11	<100	<100	<10	<0.03	<0.03	<100	10
F12	<100	<100	<10	<0.03	<0.03	<100	10
F13	<100	<100	<10	<0.03	<0.03	<100	10
F14	<100	<100	<10	<0.03	<0.03	<100	10
F15	<100	<100	<10	<0.03	<0.03	<100	10
F16	<100	<100	<10	<0.03	<0.03	<100	10
				Roof and side walls			
R1	<100	<100	<10	<0.03	<0.03	<100	
R2	<100	<100	<10	<0.03	<0.03	<100	
R3	<100	<100	<10	<0.03	<0.03	<100	
R4	<100	<100	<10	<0.03	<0.03	<100	
R5	<100	<100	<10	<0.03	<0.03	<100	
R6	<100	<100	<10	<0.03	<0.03	<100	
R7	<100	<100	<10	<0.03	<0.03	<100	
R8	<100	<100	<10	<0.03	<0.03	<100	
R9	<100	<100	<10	<0.03	<0.03	<100	
R10	<100	<100	<10	<0.03	<0.03	<100	
R11	<100	<100	<10	<0.03	<0.03	<100	
R12	<100	<100	<10	<0.03	<0.03	<100	

Table 2 (cont.). Alpha, beta, and gamma radiation in Bunker E0802

Location	Direct alpha average (dpm/100 cm^2)	Direct alpha maximum (dpm/100 cm^2)	Transferable alpha (dpm/100 cm^2)	Beta-gamma dose rate[a] average (mrad/hr)	Beta-gamma dose rate[a] maximum (mrad/hr)	Transferable beta (dpm/100 cm^2)	External gamma at 1 m (μR/hr)
R13	<100	<100	<10	<0.03	<0.03	<100	
R14	<100	<100	<10	<0.03	<0.03	<100	
R15	<100	<100	<10	<0.03	<0.03	<100	
R16	<100	<100	<10	<0.03	<0.03	<100	
			End walls				
E1	<100	<100	<10	<0.03	<0.03	<100	
E2	<100	<100	<10	<0.03	<0.03	<100	
E3	<100	<100	<10	<0.03	<0.03	<100	
E4	<100	<100	<10	<0.03	<0.03	<100	

[a]Includes gamma rays.

Table 3. Alpha, beta, and gamma radiation in Bunker E0803

Location	Direct alpha average (dpm/100 cm²)	Direct alpha maximum (dpm/100 cm²)	Transferable alpha (dpm/100 cm²)	Beta-gamma dose rate[a] average (mrad/hr)	Beta-gamma dose rate[a] maximum (mrad/hr)	Transferable beta (dpm/100 cm²)	External gamma at 1 m (μR/hr)
Floor							
F1	<100	<100	<10	<0.03	<0.03	<100	10
F2	<100	<100	<10	<0.03	<0.03	<100	10
F3	<100	<100	<10	<0.03	<0.03	<100	10
F4	<100	<100	<10	<0.03	<0.03	<100	10
F5	<100	<100	<10	<0.03	<0.03	<100	10
F6	<100	<100	<10	<0.03	<0.03	<100	10
F7	<100	<100	<10	<0.03	<0.03	<100	10
F8	<100	<100	<10	<0.03	<0.03	<100	10
F9	<100	<100	<10	<0.03	<0.03	<100	10
F10	<100	<100	<10	<0.03	<0.03	<100	10
F11	<100	<100	<10	<0.03	<0.03	<100	10
F12	<100	<100	<10	<0.03	<0.03	<100	10
F13	<100	<100	<10	<0.03	<0.03	<100	10
F14	<100	<100	<10	<0.03	<0.03	<100	10
F15	<100	<100	<10	<0.03	<0.03	<100	10
F16	<100	<100	<10	<0.03	<0.03	<100	10
Roof and side walls							
R1	<100	<100	<10	<0.03	<0.03	<100	
R2	<100	<100	<10	<0.03	<0.03	<100	
R3	<100	<100	<10	<0.03	<0.03	<100	
R4	<100	<100	<10	<0.03	<0.03	<100	
R5	<100	<100	<10	<0.03	<0.03	<100	
R6	<100	<100	<10	<0.03	<0.03	<100	
R7	<100	<100	<10	<0.03	<0.03	<100	
R8	<100	<100	<10	<0.03	<0.03	<100	
R9	<100	<100	<10	<0.03	<0.03	<100	
R10	<100	<100	<10	<0.03	<0.03	<100	
R11	<100	<100	<10	<0.03	<0.03	<100	
R12	<100	<100	<10	<0.03	<0.03	<100	

Table 3 (cont.). Alpha, beta, and gamma radiation in Bunker E0803

Location	Direct alpha average (dpm/100 cm^2)	Direct alpha maximum (dpm/100 cm^2)	Transferable alpha (dpm/100 cm^2)	Beta-gamma dose rate[a] average (mrad/hr)	Beta-gamma dose rate[a] maximum (mrad/hr)	Transferable beta (dpm/100 cm^2)	External gamma at 1 m (μR/hr)
R13	<100	<100	<10	<0.03	<0.03	<100	
R14	<100	<100	<10	<0.03	<0.03	<100	
R15	<100	<100	<10	<0.03	<0.03	<100	
R16	<100	<100	<10	<0.03	<0.03	<100	
				End walls			
E1	<100	<100	<10	<0.03	<0.03	<100	
E2	<100	<100	<10	<0.03	<0.03	<100	
E3	<100	<100	<10	<0.03	<0.03	<100	
E4	<100	<100	<10	<0.03	<0.03	<100	

[a]Includes gamma rays.

Table 4. Alpha, beta, and gamma radiation in Bunker E0804

Location	Direct alpha average (dpm/100 cm^2)	Direct alpha maximum (dpm/100 cm^2)	Transferable alpha (dpm/100 cm^2)	Beta-gamma dose rate[a] average (mrad/hr)	Beta-gamma dose rate[a] maximum (mrad/hr)	Transferable beta (dpm/100 cm^2)	External gamma at 1 m (μR/hr)
Floor							
F1	1350	18,000	72	0.09	16.0	<100	12
F2	750	2,900	66	0.09	0.92	<100	12
F3	1000	3,000	88	0.10	2.28	<100	12
F4	1200	9,000	88	0.10	3.43	<100	12
F5	1250	10,000	80	0.17	5.71	<100	12
F6	1650	70,000	102	0.17	4.57	<100	12
F7	750	1,500	62	0.09	0.23	<100	10
F8	750	2,800	20	0.09	0.17	<100	10
F9	1500	4,000	44	0.09	2.86	<100	12
F10	1500	8,000	54	0.12	0.86	<100	12
F11	2000	6,000	56	0.12	0.29	<100	12
F12	1200	9,000	46	0.09	0.63	<100	12
F13	700	2,000	42	0.09	0.14	<100	11
F14	600	2,000	30	0.09	0.12	<100	11
F15	600	1,500	48	0.06	0.17	<100	11
F16	450	2,000	18	0.06	0.17	<100	11
Roof and side walls							
R1	200	1,000	240	0.05	0.12	240	
R2	200	1,000	48	0.05	0.12	240	
R3	200	1,000	150	0.05	0.12	240	
R4	700	20,000	132	0.05	1.03	240	
R5	700	20,000	144	0.05	1.03	<100	
R6	700	130,000	432	0.05	4.57	200	
R7	200	1,000	<10	<0.03	0.12	<100	
R8	200	1,000	<10	<0.03	0.12	<100	
R9	200	500	<10	<0.03	0.12	<100	
R10	200	500	<10	<0.03	0.12	<100	
R11	200	500	<10	<0.03	0.12	<100	
R12	200	500	<10	<0.03	0.12	<100	

Table 4 (cont.). Alpha, beta, and gamma radiation in Bunker E0804

Location	Direct alpha (dpm/100 cm^2) average	Direct alpha (dpm/100 cm^2) maximum	Transferable alpha (dpm/100 cm^2)	Beta-gamma dose rate[a] (mrad/hr) average	Beta-gamma dose rate[a] (mrad/hr) maximum	Transferable beta (dpm/100 cm^2)	External gamma at 1 m (μR/hr)
R12	200	500	<10	<0.03	0.12	<100	
R13	200	500	<10	<0.03	0.12	<100	
R14	200	500	<10	<0.03	0.12	<100	
R15	200	500	<10	<0.03	0.12	<100	
R16	200	500	<10	<0.03	0.12	<100	
				End walls			
E1	200	500	<10	<0.03	<0.03	<100	
E2	200	500	<10	<0.03	<0.03	<100	
E3	200	500	<10	<0.03	<0.03	<100	
E4	200	500	<10	<0.03	<0.03	<100	

[a]Includes gamma rays.

Table 5. Alpha, beta and gamma radiation in Bunker E0805

Location	Direct alpha average (dpm/100 cm^2)	Direct alpha maximum (dpm/100 cm^2)	Transferable alpha (dpm/100 cm^2)	Beta-gamma dose rate[a] average (mrad/hr)	Beta-gamma dose rate[a] maximum (mrad/hr)	Transferable beta (dpm/100 cm^2)	External gamma at 1 m (μR/hr)
				Floor			
F 1	400	1500	<10	0.10	0.14	<100	12
F 2	450	1200	<10	0.07	0.12	<100	12
F 3	150	700	<10	0.10	0.34	<100	12
F 4	250	1100	36	0.09	0.20	<100	10
F 5	200	600	<10	0.09	0.17	<100	12
F 6	250	800	<10	0.09	0.46	<100	12
F 7	250	1600	<10	0.09	0.86	<100	12
F 8	500	6000	<10	0.10	0.69	<100	10
F 9	300	1200	<10	0.07	0.09	<100	12
F10	300	900	<10	0.06	0.12	<100	10
F11	300	700	<10	0.06	0.09	<100	12
F12	200	500	<10	0.07	0.12	<100	12
F13	200	4000	<10	0.12	0.26	<100	12
F14	150	800	<10	0.10	0.17	<100	12
F15	150	1800	<10	0.10	0.20	<100	12
F16	400	3000	48	0.12	0.57	<100	10
				Roof & side walls			
R 1	200	400	<10	0.09	0.18	<100	
R 2	200	400	<10	0.09	0.18	<100	
R 3	200	400	<10	0.09	0.18	<100	
R 4	200	400	<10	0.09	0.18	<100	
R 5	200	400	<10	0.09	0.18	<100	
R 6	200	400	<10	0.09	0.18	<100	
R 7	200	400	<10	0.09	0.74	<100	
R 8	200	400	<10	0.09	0.18	<100	
R 9	200	400	<10	0.09	0.18	<100	

Table 5 (cont.). Alpha, beta and gamma radiation in Bunker E0805

Location	Direct alpha average (dpm/100 cm²)	Direct alpha maximum (dpm/100 cm²)	Transferable alpha (dpm/100 cm²)	Beta-gamma dose rate[a] average (mrad/hr)	Beta-gamma dose rate[a] maximum (mrad/hr)	Transferable beta (dpm/100 cm²)	External gamma at 1 m (μR/hr)
R10	200	400	<10	0.09	0.18	<100	
R11	200	400	<10	0.09	0.18	<100	
R12	200	400	<10	0.09	0.18	<100	
R13	200	400	<10	0.09	0.18	<100	
R14	200	400	<10	0.09	0.18	<100	
R15	200	400	<10	0.09	0.18	<100	
R16	200	400	<10	0.09	0.18	<100	
				End walls			
E 1	200	400	<10	0.09	0.18	<100	
E 2	200	400	<10	0.09	0.18	<100	
E 3	200	400	<10	0.09	0.18	<100	
E 4	200	400	<10	0.09	0.18	<100	

[a] Includes gamma rays.

Table 6. Alpha, beta and gamma radiation in Bunker E0806

Location	Direct alpha average (dpm/100 cm²)	Direct alpha maximum (dpm/100 cm²)	Transferable alpha (dpm/100 cm²)	Beta-gamma dose rate[a] average (mrad/hr)	Beta-gamma dose rate[a] maximum (mrad/hr)	Transferable beta (dpm/100 cm²)	External gamma at 1 m (μR/hr)
				Floor			
F 1	300	800	11	0.05	0.12	<100	12
F 2	500	2,200	<10	0.06	0.20	102	12
F 3	200	5,000	<10	0.07	0.34	<100	12
F 4	300	800	<10	0.06	0.12	<100	12
F 5	300	1,000	13	0.05	0.12	<100	12
F 6	300	2,500	<10	0.06	0.20	<100	12
F 7	300	1,500	13	0.06	0.14	<100	12
F 8	400	3,000	13	0.07	0.23	<100	12
F 9	800	2,000	14	0.07	0.17	<100	11
F10	800	3,000	<10	0.07	0.14	<100	11
F11	500	3,000	18	0.07	0.20	<100	12
F12	450	2,500	22	0.06	0.15	<100	12
F13	450	2,500	22	0.06	0.14	<100	12
F14	500	6,000	32	0.06	0.40	136	13
F15	1100	70,000	2530	0.09	4.57	2360	13
F16	350	3,000	28	0.06	0.20	<100	14
							12
				Roof & side walls			
R 1	300	400	<10	<0.03	<0.03	<100	
R 2	300	400	<10	<0.03	<0.03	<100	
R 3	300	400	<10	<0.03	<0.03	<100	
R 4	300	400	<10	<0.03	<0.03	<100	
R 5	300	400	<10	<0.03	<0.03	<100	
R 6	300	800	11	<0.03	<0.03	<100	
R 7	300	800	<10	<0.03	<0.03	<100	
R 8	300	500	13	<0.03	<0.03	<100	

Table 6 (cont.). Alpha, beta and gamma radiation in Bunker E0806

Location	Direct alpha average (dpm/100 cm^2)	Direct alpha maximum (dpm/100 cm^2)	Transferable alpha (dpm/1oo cm^2)	Beta-gamma dose rate[a] average (mrad/hr)	Beta-gamma dose rate[a] maximum (mrad/hr)	Transferable beta (dpm/100 cm^2)	External gamma at 1 m (μR/hr)
R 9	300	600	<10	<0.03	<0.03	<100	
R10	300	400	<10	<0.03	<0.03	<100	
R11	300	400	<10	<0.03	<0.03	<100	
R12	300	400	<10	<0.03	<0.03	<100	
R13	300	400	<10	<0.03	<0.03	<100	
R14	300	900	10	<0.03	<0.03	<100	
R15	300	1500	12	<0.03	<0.03	<100	
R16	300	1000	10	<0.03	<0.03	<100	
End walls							
E 1			<10			<100	
E 2			<10			<100	
E 3			<10			<100	
E 4			<10			<100	

[a]Includes gamma rays.

Table 7. Alpha, beta and gamma radiation in Bunker E0807

Location	Direct alpha average (dpm/100 cm²)	Direct alpha maximum (dpm/100 cm²)	Transferable alpha (dpm/100 cm²)	Beta-gamma dose rate[a] average (mrad/hr)	Beta-gamma dose rate[a] maximum (mrad/hr)	Transferable beta (dpm/100 cm²)	External gamma at 1 m (μR/hr)
				Floor			
F 1	125	650	<10	0.03	0.09	<100	12
F 2	100	2500	38	0.03	0.10	<100	14
F 3	100	600	<10	0.03	0.06	<100	12
F 4	100	1600	<10	0.03	0.14	<100	12
F 5	100	1200	<10	0.03	0.06	<100	14
F 6	100	500	<10	0.03	0.05	<100	14
F 7	150	300	<10	0.06	0.09	<100	10
F 8	250	9000	<10	0.07	0.68	<100	10
F 9	150	200	<10	0.05	0.09	<100	10
F10	150	300	<10	0.05	0.09	<100	10
F11	100	300	<10	0.05	0.09	<100	10
F12	200	2500	<10	0.05	0.20	<100	10
F13	300	1300	<10	0.05	0.09	<100	10
F14	150	700	<10	0.05	0.09	<100	10
F15	250	2500	<10	0.04	0.14	<100	10
F16	750	8000	<10	0.03	0.68	<100	10
				Roof & side walls			
R 1	125	200	<10	<0.03	<0.03	<100	
R 2	125	200	<10	<0.03	<0.03	<100	
R 3	125	200	<10	<0.03	<0.03	<100	
R 4	125	200	<10	<0.03	<0.03	<100	
R 5	125	200	<10	<0.03	<0.03	<100	
R 6	125	200	<10	<0.03	<0.03	<100	
R 7	125	200	<10	<0.03	<0.03	<100	
R 8	125	200	<10	<0.03	<0.03	<100	
R 9	125	200	<10	<0.03	<0.03	<100	

Table 7 (cont.). Alpha, beta and gamma radiation in Bunker E0807

Location	Direct alpha (dpm/100 cm^2) average	Direct alpha (dpm/100 cm^2) maximum	Transferable alpha (dpm/100 cm^2)	Beta-gamma dose rate[a] (mrad/hr) average	Beta-gamma dose rate[a] (mrad/hr) maximum	Transferable beta (dpm/100 cm^2)	External gamma at 1 m (μR/hr)
R10	125	200	<10	<0.03	<0.03	<100	
R11	125	200	<10	<0.03	<0.03	<100	
R12	125	200	<10	<0.03	<0.03	<100	
R13	125	300	<10	<0.03	<0.03	<100	
R14	125	200	<10	<0.03	<0.03	<100	
R15	125	200	<10	<0.03	<0.03	<100	
R16	125	200	<10	<0.03	<0.03	<100	
				End walls			
E 1	<100	250		<0.03	<0.03	<100	
E 2	<100	200		<0.03	<0.03	<100	
E 3	<100	150		<0.03	<0.03	<100	
E 4	<100	200		<0.03	<0.03	<100	

[a]Includes gamma rays

Table 8. Alpha, beta and gamma radiation in Bunker E0808

Location	Direct alpha average (dpm/100 cm^2)	Direct alpha maximum (dpm/100 cm^2)	Transferable alpha (dpm/100 cm^2)	Beta-gamma dose rate[a] average (mrad/hr)	Beta-gamma dose rate[a] maximum (mrad/hr)	Transferable beta (dpm/100 cm^2)	External gamma at 1 m (μR/hr)
				Floor			
F 1	125	300	<10	0.03	0.10	<100	10
F 2	175	400	<10	0.05	0.12	<100	15
F 3	250	450	<10	0.04	0.12	<100	15
F 4	300	2000	<10	0.06	0.40	<100	15
F 5	150	300	<10	0.04	0.10	<100	15
F 6	250	500	<10	0.04	0.12	<100	12
F 7	250	500	<10	0.05	0.12	<100	10
F 8	300	2000	<10	0.06	0.17	<100	10
F 9	150	300	<10	0.05	0.14	<100	10
F10	250	600	<10	0.05	0.17	<100	15
F11	300	900	<10	0.03	0.05	187	12
F12	450	3000	<10	0.06	0.10	<100	15
F13	250	8000	<10	0.06	0.57	<100	15
F14	450	2100	<10	0.04	0.10	136	12
F15	250	800	<10	0.03	0.06	<100	15
F16	350	1800	<10	0.06	0.09	<100	12
				Roof & side walls			
R 1	150	360	<10	<0.03	<0.03	<100	
R 2	150	360	<10	<0.03	<0.03	<100	
R 3	150	360	<10	<0.03	<0.03	<100	
R 4	150	360	<10	<0.03	<0.03	170	
R 5	150	360	<10	<0.03	<0.03	<100	
R 6	150	360	<10	<0.03	<0.03	<100	
R 7	150	360	<10	<0.03	<0.03	<100	
R 8	150	360	<10	<0.03	<0.03	<100	
R 9	150	360	<10	<0.03	<0.03	<100	

Table 8 (cont.). Alpha, beta and gamma radiation in Bunker E0808

Location	Direct alpha average	Direct alpha maximum	Transferable alpha	Beta-gamma dose rate[a] average	Beta-gamma dose rate[a] maximum	Transferable beta	External gamma at 1 m
	(dpm/100 cm^2)		(dpm/100 cm^2)	(mrad/hr)		(dpm/100 cm^2)	(μR/hr)
R10	150	360	<10	<0.03	<0.03	109	
R11	150	360	<10	<0.03	<0.03	109	
R12	150	360	<10	<0.03	<0.03	109	
R13	150	360	<10	<0.03	<0.03	109	
R14	150	360	<10	<0.03	<0.03	109	
R15	150	360	<10	<0.03	<0.03	109	
R16	150	360	<10	<0.03	<0.03	<100	
End walls							
E 1	75	300	<10	<0.03	<0.03	<100	
E 2	150	360	<10	<0.03	<0.03	<100	
E 3	150	360	<10	<0.03	<0.03	<100	
E 4	150	360	<10	<0.03	<0.03	<100	

[a]Includes gamma rays.

Table 9. Alpha, beta and gamma radiation in Bunker E0809

Location	Direct alpha average (dpm/100 cm^2)	Direct alpha maximum (dpm/100 cm^2)	Transferable alpha (dpm/100 cm^2)	Beta-gamma dose rate[a] average (mrad/hr)	Beta-gamma dose rate[a] maximum (mrad/hr)	Transferable beta (dpm/100 cm^2)	External gamma at 1 m
				Floor			
F 1	350	2100	<10	0.05	0.20	<100	12
F 2	200	500	<10	0.10	0.12	<100	14
F 3	300	500	<10	0.03	0.09	<100	14
F 4	250	500	13	0.06	0.12	<100	14
F 5	250	500	15	0.05	0.09	102	12
F 6	500	1200	13	0.03	0.11	<100	10
F 7	900	1800	13	0.06	0.14	<100	10
F 8	300	1200	11	0.03	0.12	<100	12
F 9	250	600	<10	0.05	0.12	<100	10
F10	200	950	38	0.06	0.14	<100	10
F11	200	600	<10	0.05	0.13	<100	10
F12	400	1300	28	0.06	0.16	<100	10
F13	250	900	17	0.06	0.14	<100	10
F14	400	1100	21	0.07	0.17	<100	10
F15	400	1400	34	0.05	0.18	<100	12
F16	450	1400	36	0.07	0.23	<100	10
				Roof & side walls			
R 1	100	300	<10	<0.03	<0.03	<100	
R 2	100	300	<10	<0.03	<0.03	<100	
R 3	100	300	13	<0.03	<0.03	<100	
R 4	100	300	<10	<0.03	<0.03	<100	
R 5	100	300	<10	<0.03	<0.03	<100	
R 6	100	300	<10	<0.03	<0.03	<100	
R 7	100	300	<10	<0.03	<0.03	<100	
R 8	100	300	<10	<0.03	<0.03	<100	
R 9	100	300	<10	<0.03	<0.03	<100	

Table 9 (cont.). Alpha, beta and gamma radiation in Bunker E0809

Location	Direct alpha average	Direct alpha maximum	Transferable alpha	Beta-gamma dose rate[a] average	Beta-gamma dose rate[a] maximum	Transferable beta	External gamma at 1 m
	(dpm/100 cm^2)		(dpm/100 cm^2)	(mrad/hr)		(dpm/100 cm^2)	(μR/hr)
R10	100	300	<10	<0.03	<0.03	<100	
R11	100	300	<10	<0.03	<0.03	102	
R12	100	300	<10	<0.03	<0.03	<100	
R13	100	300	<10	<0.03	<0.03	<100	
R14	100	300	<10	<0.03	<0.03	<100	
R15	100	300	<10	<0.03	<0.03	<100	
R16	100	300	<10	<0.03	<0.03	<100	
				End walls			
E 1	150	250	<10	<0.03	<0.03	<100	
E 2	150	250	<10	<0.03	<0.03	<100	
E 3	150	300	<10	<0.03	<0.03	<100	
E 4	150	300	<10	<0.03	<0.03	<100	

[a]Includes gamma rays.

Table 10. Alpha, beta and gamma radiation in Bunker E0810

Location	Direct alpha (dpm/100 cm^2) average	Direct alpha (dpm/100 cm^2) maximum	Transferable alpha (dpm/100 cm^2)	Beta-gamma dose rate[a] (mrad/hr) average	Beta-gamma dose rate[a] (mrad/hr) maximum	Transferable beta (dpm/100 cm^2)	External gamma at 1 m (μR/hr)
Floor							
F 1	250	600	<10	0.03	0.05	<100	17
F 2	450	2000	<10	0.05	0.09	<100	17
F 3	750	4000	<10	0.05	0.69	170	14
F 4	450	600	<10	0.03	0.06	<100	14
F 5	350	1400	<10	0.04	0.09	<100	14
F 6	350	1200	<10	0.03	0.09	<100	19
F 7	650	1600	14	0.05	0.11	<100	14
F 8	350	3000	<10	0.03	0.29	<100	14
F 9	150	400	<10	0.03	0.09	102	12
F10	350	900	<10	0.03	0.11	119	14
F11	450	1400	<10	0.03	0.14	102	14
F12	500	900	<10	0.03	0.10	119	14
F13	450	1000	<10	0.03	0.09	119	14
F14	400	700	<10	0.03	0.03	<100	14
F15	1000	2500	<10	0.06	0.11	170	14
F16	650	1500	22	0.05	0.69	204	14
Roof and side walls							
R 1	<100	150	<10	<0.03	<0.03	136	
R 2	<100	150	<10	<0.03	<0.03	<100	
R 3	<100	150	<10	<0.03	<0.03	<100	
R 4	<100	150	<10	<0.03	<0.03	<100	
R 5	<100	150	<10	<0.03	<0.03	<100	
R 6	<100	150	<10	<0.03	<0.03	<100	
R 7	<100	150	<10	<0.03	<0.03	136	
R 8	<100	150	<10	<0.03	<0.03	170	
R 9	<100	150	<10	<0.03	<0.03	153	

Table 10 (cont.). Alpha, beta and gamma radiation in Bunker E0810

Location	Direct alpha average (dpm/100 cm^2)	Direct alpha maximum (dpm/100 cm^2)	Transferable alpha (dpm/100 cm^2)	Beta-gamma dose rate[a] average (mrad/hr)	Beta-gamma dose rate[a] maximum (mrad/hr)	Transferable beta (dpm/100 cm^2)	External gamma at 1 m (μR/hr)
R10	<100	150	<10	<0.03	<0.03	<100	
R11	<100	150	<10	<0.03	<0.03	136	
R12	<100	150	<10	<0.03	<0.03	136	
R13	<100	150	<10	<0.03	<0.03	<100	
R14	<100	150	<10	<0.03	<0.03	<100	
R15	<100	150	<10	<0.03	<0.03	<100	
R16	<100	150	<10	<0.03	<0.03	<100	
End walls							
E 1	<100	200	<10	<0.03	<0.03	153	
E 2	<100	<100	<10	<0.03	<0.03	<100	
E 3	<100	<100	<10	<0.03	<0.03	<100	
E 4	<100	<100	<10	<0.03	<0.03	<100	

[a]Includes gamma rays.

Table 11. Alpha, beta and gamma radiation in Bunker E0811

Location	Direct alpha average (dpm/100 cm^2)	Direct alpha maximum (dpm/100 cm^2)	Transferable alpha (dpm/100 cm^2)	Beta-gamma dose rate[a] average (mrad/hr)	Beta-gamma dose rate[a] maximum (mrad/hr)	Transferable beta (dpm/100 cm^2)	External gamma at 1 m (μR/hr)
				Floor			
F 1	550	800	<10	0.03	0.03	<100	19
F 2	550	1600	<10	0.06	0.15	<100	19
F 3	550	1000	<10	0.04	0.06	102	19
F 4	700	1000	<10	0.04	0.04	112	19
F 5	550	1000	<10	0.05	0.06	<100	17
F 6	550	600	<10	0.03	0.03	119	17
F 7	400	500	<10	0.03	0.05	<100	17
F 8	550	600	<10	0.03	0.05	<100	19
F 9	400	800	<10	0.06	0.09	<100	19
F10	500	3000	<10	0.06	0.09	102	21
F11	600	1000	<10	0.06	0.07	<100	19
F12	400	800	<10	0.06	0.10	<100	14
F13	400	800	<10	0.06	0.07	<100	14
F14	400	1200	<10	0.06	0.07	<100	14
F15	500	1000	<10	0.06	0.07	<100	14
F16	300	800	<10	0.06	0.09	<100	14
				Roof and side walls			
R 1	150	300	<10	<0.03	<0.03	<100	
R 2	150	300	<10	<0.03	<0.03	170	
R 3	150	300	<10	<0.03	<0.03	<100	
R 4	150	300	<10	<0.03	<0.03	255	
R 5	150	300	<10	<0.03	<0.03	255	
R 6	150	300	<10	<0.03	<0.03	255	
R 7	150	300	<10	<0.03	<0.03	<100	
R 8	150	300	<10	<0.03	<0.03	102	
R 9	150	300	<10	<0.03	<0.03	102	

Table 11 (cont.). Alpha, beta and gamma radiation in Bunker E0811

Location	Direct alpha average (dpm/100 cm^2)	Direct alpha maximum (dpm/100 cm^2)	Transferable alpha (dpm/100 cm^2)	Beta-gamma dose rate[a] average (mrad/hr)	Beta-gamma dose rate[a] maximum (mrad/hr)	Transferable beta (dpm/100 cm^2)	External gamma at 1 m (μR/hr)
R10	150	300	<10	<0.03	<0.03	102	
R11	150	300	<10	<0.03	<0.03	<100	
R12	150	300	<10	<0.03	<0.03	<100	
R13	150	300	<10	<0.03	<0.03	<100	
R14	150	300	<10	<0.03	<0.03	<100	
R15	150	300	<10	<0.03	<0.03	102	
R16	150	300	<10	<0.03	<0.03	<100	
				End walls			
E 1	200	500		<0.03	<0.03	102	
E 2	200	500		<0.03	<0.03	<100	
E 3	150	300		<0.03	<0.03	<100	
E 4	150	300		<0.03	<0.03	102	

[a]Includes gamma rays.

Table 12. Alpha, beta, and gamma radiation in Bunker C0912

Location	Direct alpha (dpm/100 cm²) average	Direct alpha (dpm/100 cm²) maximum	Transferable alpha (dpm/100 cm²)	Beta-gamma dose rate[a] (mrad/hr) average	Beta-gamma dose rate[a] (mrad/hr) maximum	Transferable beta (dpm/100 cm²)	External gamma at 1 m (μR/hr)
			Floor				
F1	<100	<100	<10	<0.03	<0.03	<100	10
F2	<100	<100	<10	<0.03	<0.03	<100	10
F3	<100	<100	<10	<0.03	<0.03	<100	10
F4	<100	<100	<10	<0.03	<0.03	<100	10
F5	<100	<100	<10	<0.03	<0.03	<100	10
F6	<100	<100	<10	<0.03	<0.03	<100	10
F7	<100	<100	<10	<0.03	<0.03	<100	10
F8	<100	<100	<10	<0.03	<0.03	<100	10
F9	<100	<100	<10	<0.03	<0.03	<100	10
F10	<100	<100	<10	<0.03	<0.03	<100	10
F11	<100	<100	<10	<0.03	<0.03	<100	10
F12	<100	<100	<10	<0.03	<0.03	<100	10
F13	<100	<100	<10	<0.03	<0.03	<100	10
F14	<100	<100	<10	<0.03	<0.03	<100	10
F15	<100	<100	<10	<0.03	<0.03	<100	10
F16	<100	<100	<10	<0.03	<0.03	<100	10
			Roof and side walls				
R1	<100	<100	<10	<0.03	<0.03	<100	
R2	<100	<100	<10	<0.03	<0.03	<100	
R3	<100	<100	<10	<0.03	<0.03	<100	
R4	<100	<100	<10	<0.03	<0.03	<100	
R5	<100	<100	<10	<0.03	<0.03	<100	
R6	<100	<100	<10	<0.03	<0.03	<100	
R7	<100	<100	<10	<0.03	<0.03	<100	
R8	<100	<100	<10	<0.03	<0.03	<100	
R9	<100	<100	<10	<0.03	<0.03	<100	
R10	<100	<100	<10	<0.03	<0.03	<100	
R11	<100	<100	<10	<0.03	<0.03	<100	
R12	<100	<100	<10	<0.03	<0.03	<100	

Table 12 (cont.). Alpha, beta, and gamma radiation in Bunker C0912

Location	Direct alpha average (dpm/100 cm²)	Direct alpha maximum (dpm/100 cm²)	Transferable alpha (dpm/100 cm²)	Beta-gamma dose rate[a] average (mrad/hr)	Beta-gamma dose rate[a] maximum (mrad/hr)	Transferable beta (dpm/100 cm²)	External gamma at 1 m (μR/hr)
R13	<100	<100	<10	<0.03	<0.03	<100	
R14	<100	<100	<10	<0.03	<0.03	<100	
R15	<100	<100	<10	<0.03	<0.03	<100	
R16	<100	<100	<10	<0.03	<0.03	<100	
End walls							
E1	<100	<100	<10	<0.03	<0.03	<100	
E2	<100	<100	<10	<0.03	<0.03	<100	
E3	<100	<100	<10	<0.03	<0.03	<100	
E4	<100	<100	<10	<0.03	<0.03	<100	

[a]Includes gamma rays.

Table 13. Concentrations of radon measured in bunkers

Bunker Number	Location inside bunker	^{222}Rn (pCi/liter)
C0912	Rear	0.5
C0912	Front	1.8
E0801	Rear	1.0
E0801	Front	1.8
E0802	Rear	1.5
E0802	Front	1.0
E0803	Rear	1.4
E0803	Front	1.6
E0804	Rear	5.5
E0804	Front	2.6
E0805	Rear	3.2
E0805	Front	3.9
E0806	Rear	3.9
E0806	Front	5.8
E0807	Rear	2.5
E0807	Front	3.2
E0808	Rear	5.3
E0808	Front	5.9
E0809	Rear	6.4
E0809	Front	6.1
E0810	Rear	4.2
E0810	Front	4.6
E0811	Rear	3.8
E0811	Front	2.4

Table 14. Radon daughter concentrations in the bunkers

Bunker	Concentration[a]
C0912	0.013 WL
E0801	0.008 WL
E0802	0.007 WL
E0803	0.009 WL
E0804	0.041 WL
E0805	0.046 WL
E0806	0.047 WL
E0807[b]	0.027 WL
E0807[b]	0.046 WL
E0808	0.048 WL
E0809	0.037 WL
E0810	0.016 WL
E0811[c]	0.018 WL
E0811[c]	0.010 WL
E0811[c]	0.017 WL

[a]A working level (WL) 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 alpha particle energy.

[b]Two measurements were taken in this bunker.

[c]Three measurements were taken in this bunker

Table 15. Concentrations of ^{226}Ra in soil samples

Sample number	Depth (in.)	^{226}Ra (pCi/g)
SA1	0-6	1.0
SA2	0-10	0.9
SA3	0-12	0.7
SA4	20	1.0
SA4A	0-6	7820
SA4B	6-16	260
SA4C	0-12	4.6
SA5	Surface	288
SA5A	12	15.2
SA5B	0-12	31.1
SA6	0-6	16.0
SA7	0-6	48.2
SA7A	6-10	29.9
SA8	0-6	215
SA8A	6-10	71.2
SA9	0-6	15.4
SA10	0-6	275
SA10B	0-6	1.1
SA11	3-6 [a]	210
SA11A	Surface [b]	2330
SA11B	0-4	4.6
SE0804	Surface [c]	46,300
SA912	Surface	0.8

[a] Taken from under asphalt.
[b] Asphalt sample.
[c] Taken from a drain trough inside Bunker E0804.

Table 16. Concentrations of ^{238}U, ^{232}Th, and ^{40}K in selected soil samples

Sample number	Depth (in.)	^{238}U (pCi/g)	^{232}Th (pCi/g)	^{40}K (pCi/g)
SA1	0-6	2.0	0.9	19.8
SA2	0-10	1.7	1.0	20.5
SA3	0-12	0.7	0.9	21.6
SA5A	12	11.8	0.5	11.6
SA5B	0-12	25.8	1.3	19.8
SA6	0-6	8.5	1.2	17.4
SA7A	6-10	8.9	1.0	20.0
SA8	0-6	60.1	N.F.[a]	N.F.
SA9	0-6	8.6	N.F.	8.0
SA10B	0-6	2.1	1.1	21.2
SE0804	Surface[b]	67,070	N.F.	N.F.
SA912	Surface	1.6	0.8	13.7

[a]N.F. = not found.

[b]Taken from a drain trough inside Bunker E0804.

Table 17. Radionuclide concentrations in water samples (measurments given in pCi/mℓ)

Sample	^{226}Ra	^{227}Th	^{230}Th	^{232}Th	^{234}U	^{235}U	^{238}U
W9	$8.1x10^{-4}$	$2.3x10^{-4}$	$\leq 4.5x10^{-5}$	$<4.5x10^{-5}$	$5.9x10^{-4}$	$1.4x10^{-4}$	$4.5x10^{-4}$
W10	$5.9x10^{-4}$	$1.6x10^{-4}$	$\leq 4.5x10^{-5}$	$<4.5x10^{-5}$	$1\ x10^{-3}$	$\leq 1.8x10^{-4}$	$8.1x10^{-4}$
MPC_w (Soluble)	$3\ x10^{-2}$	7	2	2	30	30	40

Table 18. Direct readings of alpha contamination on outsides of vents (on roofs of bunkers)

Bunker	Maximum reading (in dpm/100 cm^2)
E0801	400
E0802	700
E0803	500
E0804	1000
E0805	500
E0806	1000
E0807	400
E0808	400
E0809	600
E0810	600
E0811	400
A0804	700
A0810	700

APPENDIX I

DESCRIPTION OF RADIATION SURVEY METERS AND SMEAR COUNTERS

RADIATION SURVEY METERS

Alpha Survey Meters

Two types of alpha survey meters are used to measure alpha radioactivity on surfaces. One type of instrument uses a ZnS scintillator and the other uses a gas-flow proportional counter to detect the alpha radiation.

The alpha scintillation survey meter consists of a large area (100 cm^2) ZnS detector with a photomultiplier tube in the probe which is coupled to a portable scaler/ratemeter (see Fig. I-A). The ZnS detector is covered with a 5-mil aluminized mylar sheet in order to make the instrument light-tight. The mylar, in turn, is covered with a grid to prevent puncturing the detector when surveying over rough surfaces. This instrument is capable of measuring alpha surface contamination levels of a few dpm/100 cm^2 but must be used in the scaler mode for this purpose. It is highly selective for densely ionizing radiation such as alpha particles; the instrument is relatively insensitive to beta and gamma radiation.

The gas-flow proportional counter uses propane gas as the detection medium. Through front panel meter readings, it can be used to measure alpha contamination levels from a few hundred dpm/100 cm^2 to several hundred thousand dpm/100 cm^2. If individual pulses are counted, this instrument can also be used for measurements down to a few dpm/100 cm^2. The probe has a surface area of approximately 61 cm^2 and has a 2.5-mil aluminized mylar covering with a protective grid. Due to the protective grid, the active area of the probe is 50 cm^2. It is relatively insensitive to other than alpha radiation. This instrument, shown in Fig. I-B, is manufactured by the Eberline Instrument Company as their model PAC-4G meter with a probe.

Both of these instruments are calibrated at ORNL using ^{239}Pu alpha sources. While each instrument is individually calibrated, the calibration factors are typically 5-6 dpm/cpm.

Beta Survey Meter

A portable Geiger-Mueller (G-M) survey meter is the primary instrument for measuring beta-gamma radioactivity. The G-M tube is a halogen-quenched stainless steel tube having a 30 mg/cm^2 wall thickness and presenting a cross-sectional area of approximately 10 cm^2. Since the G-M tube is sensitive to both beta and gamma radiation, measurements are taken in both an open window and a closed-window configuration. Beta radiation cannot penetrate the closed window, and, thus, the beta reading can be determined by taking the difference between the open and closed window readings. This meter is shown in Fig. I-C.

The G-M survey meter was calibrated at ORNL for gamma radiation using an NBS standard Ra source. The gamma calibration factor is typically of the order of 2600 cpm per mR/hr.

In order to assess beta-gamma surface dose rates from uranium contaminated surfaces using this instrument, a field calibration was performed. The G-M survey meter was compared with a Victoreen Model 440 ionization chamber (see Fig. I-D) and was found to produce 1750 cpm per mrad/hr with a 25% standard deviation for a wide variety of surfaces, including concrete, wood, pavement, bricks, and steel beams.

Gamma Scintillation Survey Meter

A portable survey meter using a NaI scintillation probe is used to measure low-level gamma radiation exposure. The scintillation probe is a 3.2 x 3.8-cm NaI crystal coupled to a photomultiplier tube. This probe is connected to a Victoreen Model Thyac III ratemeter (see Fig. I-E). This unit is capable of measuring radiation levels from a few μR/hr to several hundred μR/hr. This instrument is calibrated at ORNL with an NBS standard ^{226}Ra source. Typical calibration factors are of the order of 300 cpm per μR/hr.

SMEAR COUNTERS

Alpha Smear Counter

This detector assembly, used for the assay of alpha emitters on smear paper samples, consists of a light-tight sample holder, a zinc sulfide phosphor and a photomultiplier tube. The detector assembly is used with N/M modular electronic components. The electronics package consisted of a preamplifier, an ORTEC 456 high voltage power supply, a Tennelec TC 211 linear amplifier and a Tennelec TC 545 counter-timer. The alpha smear counter used in the field is calibrated daily using an alpha source with a known disintegration rate.

Beta Smear Counter

The beta smear counter consists of a thin mica window (∿ 2 mg/cm^2) G-M tube mounted on a sample holder and housed in a 23-cm diam x 35-cm high lead shield. Located under the counter window is a slotted sample holder, accessible through a hinged door on the shield. An absorber can be interposed in the slot between the sample and the counter window to determine relative beta and gamma contributions to the observed sample counting rate. The electronics for this counter is housed in a portable NIM bin and consists of a Tennelec TC 148 preamplifier, an ORTEC 456 high voltage power supply and a Tennelec TC 545 counter-timer. This unit is used in the field to measure beta activity on smear papers and was calibrated daily using a beta standard of known activity. The instruments used for measuring alpha and beta activity on smear papers are shown in Fig. I-F.

The mobile laboratories shown in Fig. I-G are used during each formal survey to serve as a control center, and to house instruments and other equipment needed during the survey. Each lab is equipped with its own electric generator, mobile radio-telephone, and contains a wide range of well maintained and calibrated instruments. One of the mobile labs has its own microcomputer for data reduction in remote locations.

ORNL Photo 6705-76

Fig. I-A. Alpha scintillation survey meter.

ORNL Photo 6715-76

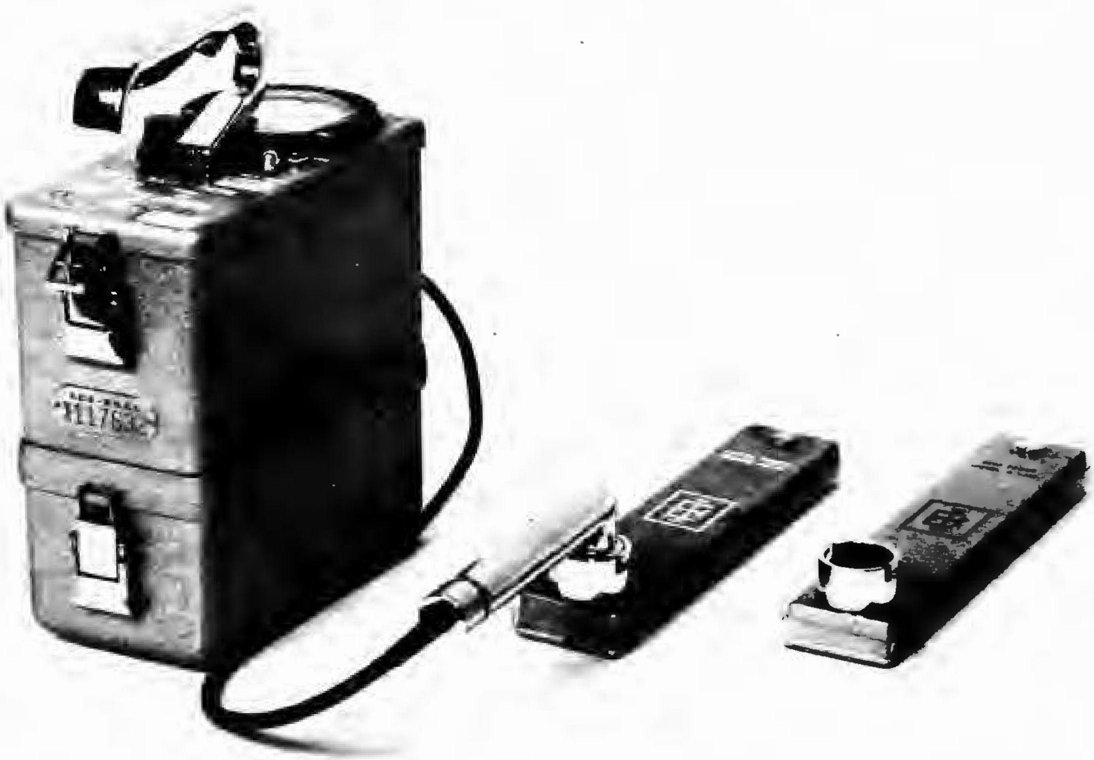


Fig. I-B. Gas-flow proportional alpha survey meter.

ORNL Photo 6704-76

Fig. I-C. Geiger-Mueller survey meter.

ORNL Photo 6710-76

Fig. I-D. Victoreen Model 440 ionization chamber.

ORNL Photo 6707-76

Fig. I-E. Gamma scintillation survey meter.

ORNL Photo 1070-78

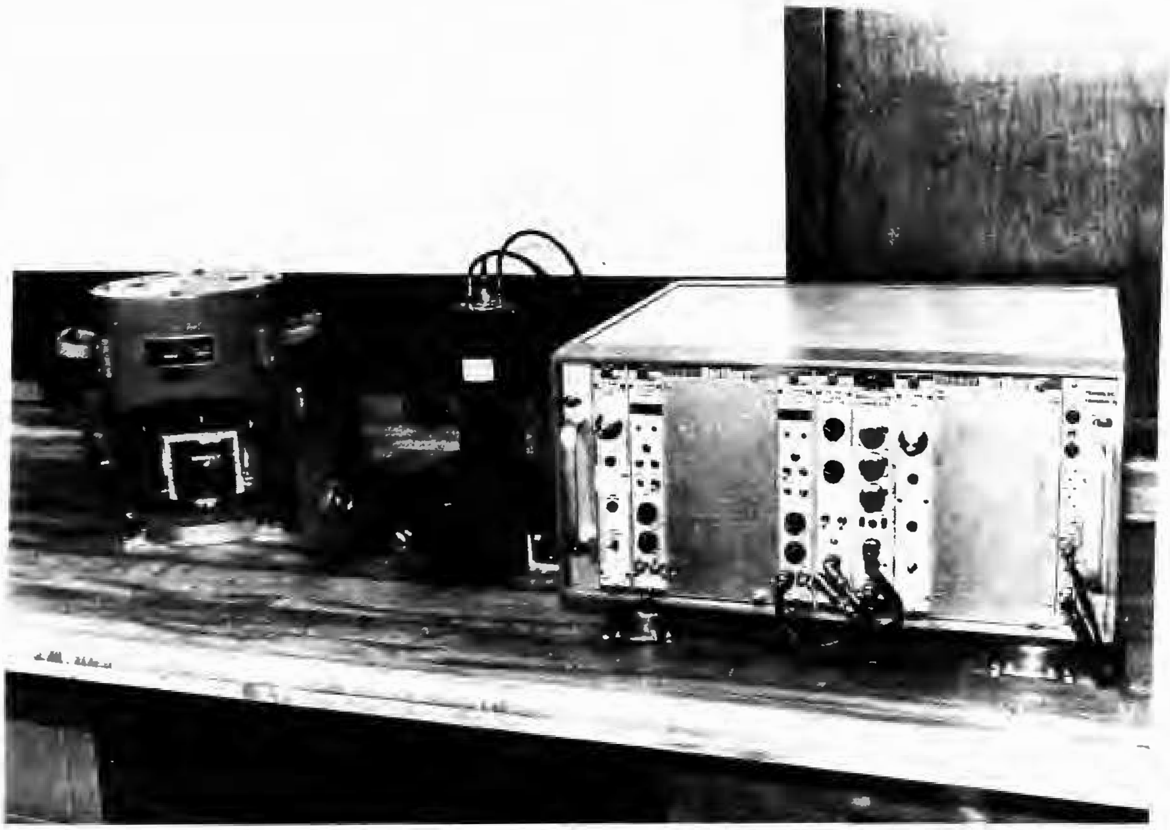


Fig. I-F. Smear counter and associated electronics. The beta counter is on the left and the alpha counter is on the right.

ORNL Photo 1068-78

Fig. I-G. Mobile labs used for logistic support during surveys.

APPENDIX II

DESCRIPTION OF THE TECHNIQUES FOR THE MEASUREMENT OF RADON AND RADON DAUGHTER CONCENTRATIONS IN AIR

Technique for the Measurement of ^{222}Rn Progeny Concentrations in Air

An alpha spectrometry technique has been refined by Kerr[1,2] for the measurement of ^{222}Rn progeny concentrations in air. From one integral count of the ^{218}Po alpha activity and two integral counts of the ^{214}Po alpha activity, the concentrations in air of ^{218}Po, ^{214}Bi and ^{214}Pb may be calculated.

Particulate ^{222}Rn daughters attached to airborne dust are collected on a membrane filter with a pore size of 0.4 μ. A sampling time of 5 min and a flow rate of 12 LPM are used. This filter sample is then placed under a silicon surface barrier detector and counted. The detector and counting system used for radon daughter measurements are shown in Fig. II-A. Usually, counting of this kind is performed with a vacuum between the sample and the detector which requires a complicated sample holder and time-consuming sample changing methods. Experiments at this laboratory have shown that ease in sample handling is obtained with little loss in resolution when helium is used as a chamber fill gas.[3] In this counter, helium is flowed between the diode and the filter sample, which are separated by a distance of 0.5 cm. One integral count of the ^{218}Po alpha activity is obtained from 2 to 12 min, and two integral counts of the ^{214}Po activity are obtained from 2 to 12 min and 15 to 30 min, respectively. All counting intervals are referenced to t = 0 at the end of sampling.

The equations describing the ^{222}Rn progeny atoms collection rates on the filter are of the form

$$\frac{dn_i(t)}{dt} = C_i v + \lambda_{i-1} n_{i-1}(t) - \lambda_i n_i(t) , \quad (1)$$

where

n_i = number of the i^{th} species of atom on the filter as a function of time,

λ_i = radioactive decay constant of the i^{th} species (min^{-1}),

C_i = concentration of the i^{th} species (atoms $liter^{-1}$), and

v = air sampling flow rate (liters min^{-1}).

The solution of Eq. (1) is of the form

$$y = e^{-ax} [y_0 = \int F(x) e^{ax} dx].$$

From the general form of the solution, specific equations can be obtained describing the number of each ^{222}Rn decay product collected on the filter as a function of time. Also by letting v = 0 in Eq. (1), a set of equations describing the decay on the filter of each ^{222}Rn progeny can be obtained. The equations describing the decay of ^{222}Rn progeny on the filter can be integrated and related to the integral counts obtained experimentally. Values for the total activities of ^{218}Po, ^{214}Pb, and ^{214}Bi on the filter at the end of sampling are obtained by applying matrix techniques. The airborne concentrations are obtained by solving the equations describing the atom collection rates on the filter. A computer program has been written to perform these matrix operations, to calculate the air concentrations of the radon progeny, and to estimate the accuracy of the calculated concentrations.

Technique for the Measurement of Radon Concentrations in the Air

A Lucas Chamber (Fig. II-B) consists of a 95-ml glass flask, coated inside with a uniform layer of zinc sulfide. For measurements of radon concentration in the air, the flask is evacuated to a pressure of 50 μ. The flask is then taken to a location where a sample is desired and the collection valve is opened. After collection of air in the flask, sample counting is delayed 3 to 4 hr to allow the radon daughters to attain equilibrium. Alpha particles from the radon daughters produce scintillations in the zinc sulfide. The sample is normally counted for 1000 sec with a photomultiplier tube assembly. A calibration performed at ORNL using a known radon concentration indicated that the conversion factor is 2.02 pCi/liter per cpm. After the sample has been counted, the flask is again evacuated to 50 μ to prevent contamination.

References

II-1. G. D. Kerr, *Measurement of Radon Progeny Concentrations in Air by Alpha-Particle Spectrometry*, ORNL/TM-4924 (July 1975).

II-2. G. D. Kerr, "Measurement of Radon Progeny Concentrations in Air," *Trans. Am. Nuc. Soc.* 17, 541 (1973).

II-3. P. T. Perdue, W. H. Shinpaugh, J. H. Thorngate and J. A. Auxier, "A Convenient Counter for Measuring Alpha Activity of Smear and Air Samples," *Health Phys.* 26, 114 (1974).

ORNL Photo 1077-78

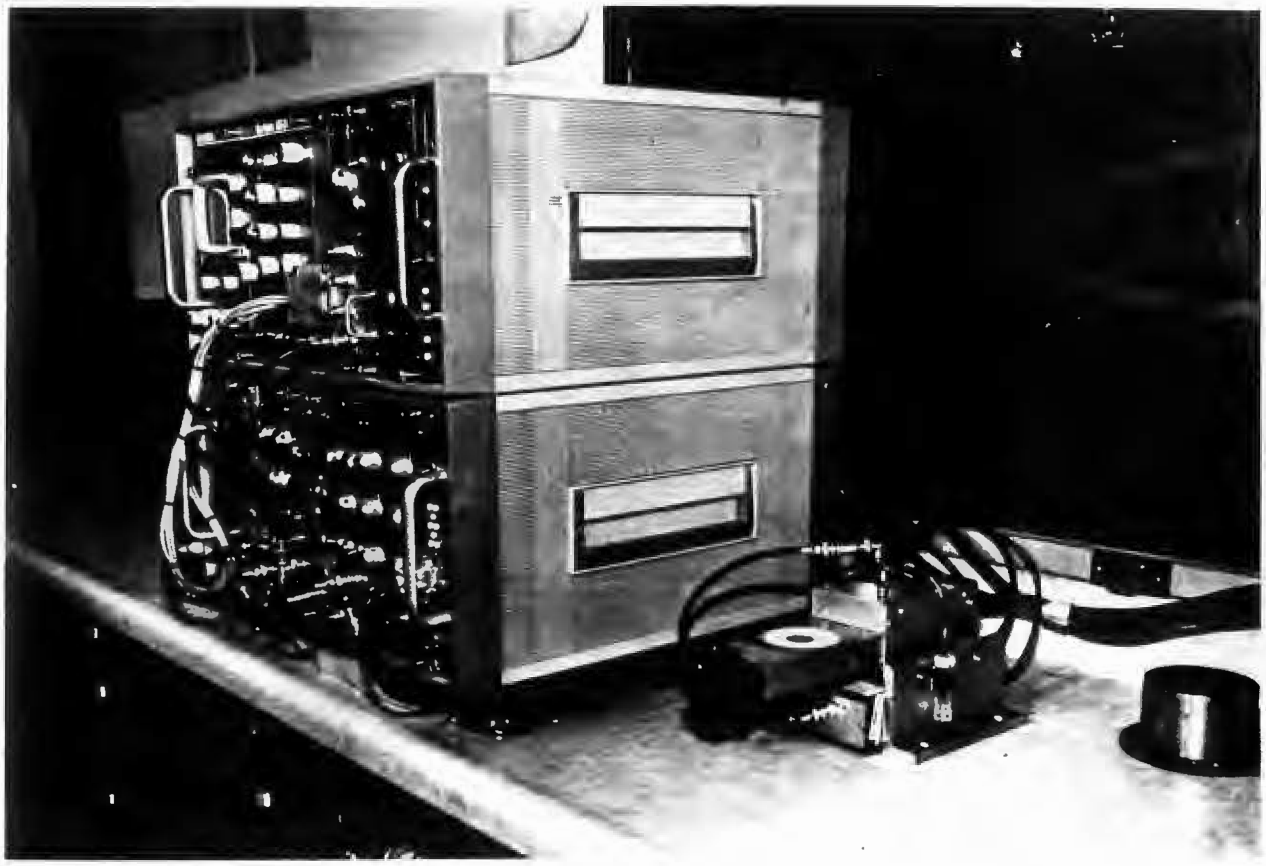


Fig. II-A. System used for measurement of radon daughter concentrations.

ORNL Photo 1083-78

Fig. II-B. Lucas Chamber.

APPENDIX III

DESCRIPTION OF GeLi DETECTOR AND

SOIL COUNTING PROCEDURES

DESCRIPTION OF (GeLi) DETECTOR SYSTEM

A holder for twelve 30-cc polyethylene bottles (standard containers for liquid scintillation samples) and a background shield have been designed for use with a 50-cc Ge(Li) detector system in laboratory counting of radioactivity in environmental samples (see Fig. III-A). During counting of the samples, the holder is used to position ten of the sample bottles around the cylindrical surface of the detector, parallel to and symmetric about its axis, and two additional bottles across the end surface of the detector, perpendicular to and symmetric with its axis. With a 300-cc sample and a graded shield developed for use with the system, it is possible to measure 1 pCi/g of ^{232}Th or ^{226}Ra with an error of ± 10% or less.

Pulses are sorted by a 4096-channel computer based analyzer (see Fig. III-B), stored on magnetic tape, and subsequently entered into a computer program which uses an iterative least squares method to identify radionuclides corresponding to those gamma-ray lines found in the sample. The program relies on a library of radioisotopes which contains approximately 700 isotopes and 2500 gamma-rays and which runs continuously on the IBM-360 system at ORNL. In identifying and quantifying ^{226}Ra, six principal gamma-ray lines are analyzed. Most of these are from ^{214}Bi and correspond to 295, 352, 609, 1120, 1765, and 2204 KeV. An estimate of the concentration of ^{238}U is obtained from an analysis of the 93 KeV line from its daughter ^{234}Th.

ORNL Photo 2172-75

Fig. III-A. Holder for Ge(Li) detector system samples.

ORNL Photo 6719-76

Fig. III-B. Computer-based 4096 channel analyzer.

APPENDIX IV

GRAND JUNCTION REMEDIAL ACTION CRITERIA, 10 CFR 712

AND

NRC GUIDELINES FOR SURFACE CONTAMINATION LIMITS

GUIDELINES FOR DECONTAMINATION OF FACILITIES AND EQUIPMENT PRIOR TO RELEASE FOR UNRESTRICTED USE OR TERMINATION OF LICENSES FOR BYPRODUCT, SOURCE, OR SPECIAL NUCLEAR MATERIAL

U. S. Nuclear Regulatory Commission
Division of Fuel Cycle
and Material Safety
Washington, D. C. 20555

November 1976

The instructions in this guide in conjunction with Table IV-1 specify the radioactivity and radiation exposure rate limits which should be used in accomplishing the decontamination and survey of surfaces or premises and equipment prior to abandonment or release for unrestricted use. The limits in Table IV-1 do not apply to premises, equipment, or scrap containing induced radioactivity for which the radiological considerations pertinent to their use may be different. The release of such facilities or items from regulatory control will be considered on a case-by-case basis.

1. The licensee shall make a reasonable effort to eliminate residual contamination.

2. Radioactivity on equipment or surfaces shall not be covered by paint, plating, or other covering material unless contamination levels, as determined by a survey and documented, are below the limits specified in Table IV-1 prior to applying the covering. A reasonable effort must be made to minimize the contamination prior to use of any covering.

3. The radioactivity on the interior surfaces of pipes, drain lines, or ductwork shall be determined by making measurements at all traps, and other appropriate access points, provided that contamination at these locations is likely to be representative of contamination on the interior of the pipes, drain lines, or ductwork. Surfaces of premises, equipment, or scrap which are likely to be contaminated but are of such size, construction, or location as to make the surface inaccessible for purposes of measurement shall be presumed to be contaminated in excess of the limits.

4. Upon request, the Commission may authorize a licensee to relinquish possession or control of premises, equipment, or scrap having surfaces contaminated with materials in excess of the limits specified. This may include, but would not be limited to, special circumstances such as razing of buildings, transfer or premises to another organization continuing work with radioactive materials, or conversion of facilities to a long-term storage or standby status. Such request must:

   a. Provide detailed, specific information describing the premises, equipment or scrap, radioactive contaminants, and the nature, extent, and degree of residual surface contamination.

   b. Provide a detailed health and safety analysis which reflects that the residual amounts of materials on surface areas, together with other considerations such as prospective use of the premises, equipment or scrap, are unlikely to result in an unreasonable risk to the health and safety of the public.

5. Prior to release of premises for unrestricted use, the licensee shall make a comprehensive radiation survey which establishes that contamination is within the limits specified in Table IV-1. A copy of the survey report shall be filed with the Division of Fuel Cycle and Material Safety, USNRC, Washington, D.C. 20555, and also the Director of the Regional Office of the Office of Inspection and Enforcement, USNRC, having jurisdiction. The report should be filed at least 30 days prior to the planned date of abandonment. The survey report shall:

    a. Identify the premises.

    b. Show that reasonable effort has been made to eliminate residual contamination.

    c. Describe the scope of the survey and general procedures followed.

    d. State the findings of the survey in units specified in the instruction.

Following review of the report, the NRC will consider visiting the facilities to confirm the survey.

TABLE IV-1

ACCEPTABLE SURFACE CONTAMINATION LEVELS

NUCLIDES[a]	AVERAGE[b c f]	MAXIMUM[b d f]	REMOVABLE[b e f]
U-nat, U-235, U-238, and associated decay products	5,000 dpm α/100 cm^2	15,000 dpm α/100 cm^2	1,000 dpm α/100 cm^2
Transuranics, Ra-226, Ra-228, Th-230, Th-228, Pa-231, Ac-227, I-125, I-129	100 dpm/100 cm^2	300 dpm/100 cm^2	20 dpm/100 cm^2
Th-nat, Th-232, Sr-90 Ra-223, Ra-224, U-232, I-126, I-131, I-133	1,000 dpm/100 cm^2	3,000 dpm/100 cm^2	200 dpm/100 cm^2
Beta-gamma emitters (nuclides with decay modes other than alpha emission or spontaneous fission) except SR-90 and other noted above.	5,000 dpm $\beta\gamma$/100 cm^2	15,000 dpm $\beta\gamma$/100 cm^2	1,000 dpm $\beta\gamma$/100 cm^2

[a]Where surface contamination by both alpha- and beta-gamma-emitting nuclides exists, the limits established for alpha- and beta-gamma-emitting nuclides should apply independently.

[b]As used in this table, dpm (disintegrations per minute) means the rate of emission by radioactive material as determined by correcting the counts per minute observed by an appropriate detector for background, efficiency, and geometric factors associated with the instrumentation.

[c]Measurements of average contaminant should not be averaged over more than 1 square meter. For objects of less surface area, the average should be derived for each such object.

[d]The maximum contamination level applies to an area of not more than 100 cm^2.

[e]The amount of removable radioactive material per 100 cm^2 of surface area should be determined by wiping that area with dry filter or soft absorbent paper, applying moderate pressure, and assessing the amount of radioactive material on the wipe with an appropriate instrument of known efficiency. When removable contamination on objects of less surface area is determined, the pertinent levels should be reduced proportionally and the entire surface should be wiped.

[f]The average and maximum radiation levels associated with surface contamination resulting from beta-gamma emitters should not exceed 0.2 mrad/hr at 1 cm and 1.0 mrad/hr at 1 cm, respectively, measured through not more than 7 milligrams per square centimeter of total absorber.

Excerpts from

Proposed

ANSI N328-197

Proposed American National Standard

Control of Radioactive Surface Contamination on Materials, Equipment, and Facilities to be Released for Uncontrolled Use

Secretariat

Health Physics Society

Property shall not be released for uncontrolled use unless documented measurements show the total and removable contamination levels to be no greater than the values in Table IV-2 or Table IV-3. (Table IV-3 is easier to apply when the contaminants cannot be individually identified.)

Where potentially contaminated surfaces are not accessible for measurement (as in some pipes, drains, and ductwork), such property shall not be released pursuant to this standard, but made the subject of case-by-case evaluation. Credit shall not be taken for coatings over contamination.

TABLE IV-2

SURFACE CONTAMINATION LIMITS

The levels may be averaged* over the 1 m^2 provided the maximum activity in any area of 100 cm^2 is less than 3 times the limit value.

Nuclide	Limit (Activity) dpm/100 cm^2 Total	Removable
Group 1: Nuclides for which the nonoccupational MPC_a† is 2 x 10^{-13} Ci/m^3 or less or for which the nonoccupational MPC_w‡ is 2 x 10^{-7} Ci/m^3 or less; includes Ac-227; Am-241; -242m, -243; Cf-249; -250, -251, -252; Cm-243, -244, -245, -246, -247, -248; I-125, -129; Np-237; Pa-231; Pb-210; Pu-238, -239 -240, -242, -244; Ra-226, -228; Th-228, -230.§	100	20
Group 2: Those nuclides not in Group 1 for which the nonoccupational MPC_a† is 1 x 10^{-12} Ci/m^3 or less or for which the nonoccupational MPC_w‡ is 1 x 10^{-6} Ci/m^3 or less; includes Es-254; Fm-256; I-126, -131, -133; Po-210; Ra-223; Sr-90; Th-232; U-232.§	1,000	200
Group 3: Those nuclides not in Group 1 or Group 2.	5,000	1,000

*See note following Table 2 on application of limits.

†MPC_a: Maximum Permissible Concentration in Air applicable to continuous exposure of members of the public as published by or derived from an authoritative source such as NCRP, ICRP or NRC (10 CFR Part 20, Appendix B, Table 2, Column 1).

‡MPC_w: Maximum Permissible Concentration in Water applicable to members of the public.

§Values presented here are obtained from 10 CFR Part 20. The most limiting of all given MPC values (e.g. soluble vs. insoluble) are to be used. In the event of the occurrence of mixture of radionuclides, the fraction contributed by each constituent of its own limit shall be determined and the sum of the fractions must be less than 1.

TABLE IV-3

ALTERNATE SURFACE CONTAMINATION LIMITS

(All alpha emitters, except U-nat and Th-nat are considered as a group)

The levels may be averaged over 1 m^2* provided the maximum activity in any area of 100 cm^2 is less than 3 times the limit value.

Nuclide	Limit (Activity) dpm/100 cm^2 Total	Removable
If the contaminant cannot be identified; or if alpha emitters other than U-nat and Th-nat are present; or if the beta emitters comprise Ac-227, Ra-226, Ra-228, I-125 and I-129.	100	20
If it is known that all alpha emitters are generated from U-nat and Th-nat; and beta emitters are present which, while not identified, do not include Ac-227, I-125, I-129, Ra-226 and Ra-228.	1,000	200
If it is known that alpha emitters are generated only from U-nat and Th-nat; and the beta emitters, while not identified, do not include Ac-227, I-125, I-129, Sr-90, Ra-223, Ra-228, I-126, I-131 and I-133.	5,000	1,000

*NOTE ON APPLICATION OF TABLES 1 AND 2 TO ISOLATED SPOTS OR ACTIVITY:

For purposes of averaging, any m^2 of surface shall be considered to be contaminated above the limit, L, applicable to 100 cm^2 if:

a. From measurements of a representative number, n, of sections, it is determined that $1/n \sum_{n} Si \geq L$, where Si is the dpm/100 cm^2 determined from measurement of section i; or

b. On surfaces less than 1 m^2, it is determined that $1/n \sum_{n} Si \geq AL$, where A is the area of the surface in units of m^2; or

c. It is determined that the activity of all isolated spots or particles in any area less than 100 cm^2 exceeds 3L.

SURGEON GENERAL'S GUIDELINES
Part 712
Grand Junction Remedial Action Criteria

Federal Register, Vol. 41, No. 253, pp. 56777-8, Thursday, December 30, 1976

PART 712 - GRAND JUNCTION REMEDIAL ACTION CRITERIA

712. 1 Purpose

(a) The regulations in this part establish the criteria for determination by ERDA of the need for, priority of and selection of appropriate remedial action to limit the exposure of individuals in the area of Grand Junction, Colo., to radiation emanating from uranium mill tailing which have been used as construction-related material.

(b) The regulations in this part are issued pursuant to Publ. L. 92-314 (86 Stat. 222) of June 16, 1972.

713.2 Scope

The regulations in this part apply to all structures in the area of Grand Junction, Colo., under or adjacent to which uranium mill tailings have been used as a construction-related material between January 1, 1951, and June 16, 1972, inclusive.

712.3 Definitions

As used in this part:

(a) "Administrator" means the Administrator of Energy Research and Development or his duly authorized representative.

(b) "Area of Grand Junction, Colo.," means Mesa County, Colo.

(c) "Background" means radiation arising from cosmic rays and radioactive material other than uranium mill tailings.

(d) "ERDA" means the U.S. Energy Research and Development Administration or any duly authorized representative thereof.

(e) "Construction-related material" means any material used in the construction of a structure.

(f) "External gamma radiation level" means the average gamma radiation exposure rate for the habitable area of a structure as measured near floor level.

(g) "Indoor radon daughter concentration level" means that concentration of radon daughters determined by: (1) Averaging the results of 6 air samples, each of at least 100 hours duration, and taken at a minimum of 4-week intervals throughout the year in a habitable area of a structure, or (2) utilizing some other procedure approved by the Commission.

(h) "Milliroentgen (mR) means a unit equal to one-thousandth (1/1000) of a roentgen which roentgen is defined as an exposure dose of X or gamma radiation such that the associated corpuscular emission per 0.001293 gram of air produces, in air, ions carrying one electrostatic unit of quantity of electricity of either sign.

(i) "Radiation" means the electromagnetic energy (gamma) and the particulate radiation (alpha and beta) which emanate from the radioactive decay of radium and its daughter products.

(j) "Radon daughters" means the consecutive decay products of radon-222. Generally, these include Radium A (polonium-218), Radium B (lead-218), Radium C (bismuth-214), and Radium C (polonium-214).

(k) "Remedial action" means any action taken with a reasonable expectation of reducing the radiation exposure resulting from uranium mill tailings which have been used as construction-related material in and around structures in the area of Grand Junction, Colo.

(l) "Surgeon General's guidelines" means radiation guidelines related to uranium mill tailings prepared and released by the Office of the U.S. Surgeon General, Department of Health, Education and Welfare on July 27, 1970.

(m) "Uranium mill tailings" means tailings from a uranium mill operation involved in the Federal uranium procurement program.

(n) "Working Level" (WL) means 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.

712.4 Interpretations

Except as specifically authorized by the Administrator in writing, no interpretation of the meaning of the regulations in this part by an officer or employee of ERDA other than a written interpretation by the General Counsel will be recognized to be binding upon ERDA.

712.5 Communications

Except where otherwise specified in this part, all communications concerning the regulations in this part should be addressed to the Director, Division of Safety, Standards, and Compliance, U.S. Energy Research and Development Administration, Washington, D.C. 20545.

712.6 General radiation exposure level criteria for remedial action

The basis for undertaking remedial action shall be the applicable guidelines published by the Surgeon General of the United States. These guidelines recommend the following graded action levels for remedial action in terms of external gamma radiation level (EGR) and indoor radon daughter concentration level (RDC) above background found within dwellings constructed on or with uranium mill tailings:

EGR	RDC	Recommendation
Greater than 0.1 mR/hr.	Greater than 0.05 WL.	Remedial action indicated
From 0.05 to 0.1 mR/hr.	From 0.01 to 0.05 WL.	Remedial action may be suggested.
Less than 0.05 mR/hr.	Less than 0.01 WL.	No remedial action indicated.

712.7 Criteria for determination of possible need for remedial action

Once it is determined that a possible need for remedial action exists, the record owner of a structure shall be notified of that structure's eligibility for an engineering assessment to confirm the need for remedial action and to ascertain the most appropriate remedial measure, if any. A determination of possible need will be made if as a result of the presence of uranium mill tailings under or adjacent to the structure, one of the following criteria is met:

(a) Where ERDA approved data on indoor radon daughter concentration levels are available:

(1) For dwellings and schoolrooms: An indoor radon daughter concentration level of 0.01 WL or greater above background.

(2) For other structures: An indoor radon daughter concentration level of 0.03 WL or greater above background.

(b) Where ERDA approved data on indoor radon daughter concentration levels are not available:

(1) For dwellings and schoolrooms:

(i) An external gamma radiation level of 0.05 mR/hr. or greater above background.

(ii) An indoor radon daughter concentration level of 0.01 WL or greater above background (presumed).

(A) It may be presumed that if the external gamma radiation level is equal to or exceeds 0.02 mR/hr. above background, the indoor radon daughter concentration level equals or exceeds 0.01 WL above background.

(B) It should be presumed that if the external gamma radiation level is less than 0.001 mR/hr. above background, the indoor radon daughter concentration level is less than 0.01 WL above background and no possible need for remedial action exists.

(C) If the external gamma radiation level is equal to or greater than 0.001 mR/hr. above background but is less than 0.02 mR/hr. above background, measurements will be required to ascertain the indoor radon daughter concentration level.

(2) For other structures: (i) An external gamma radiation level of 0.15 mR/hr. above background averaged on a room-by-room basis.

(ii) No presumptions shall be made on the external gamma radiation level/indoor radon daughter concentration level relationship. Decisions will be made in individual cases based upon the results of actual measurements.

712.8 Determination of possible need for remedial action where criteria have not been met

The possible need for remedial action may be determined where the criteria in 712.7 have not been met if various other factors are present. Such factors include, but are not necessarily limited to, size of the affected area, distribution of radiation levels in the affected area, amount of tailings, age of individuals occupying affected area, occupancy time, and use of the affected area.

712.9 Factors to be considered in determination of order or priority for remedial action

In determining the order or priority for execution of remedial action, consideration shall be given, but not necessarily limited to, the following factors:

(a) Classification of structure. Dwellings and schools shall be considered first.

(b) Availability of data. Those structures for which data on indoor radon daughter concentration levels and/or external gamma radiation levels are available when the program starts and which meet the criteria in 712.7 will be considered first.

(c) Order of application. Insofar as feasible remedial action will be taken in the order which the application is received.

(d) Magnitude of radiation level. In general, those structures with the highest radiation levels will be given primary consideration.

(e) Geographical location of structures. A group of structures located in the same immediate geographical vicinity may be given priority consideration particularly where they involve similar remedial efforts.

(f) Availability of structures. An attempt will be made to schedule remedial action during those periods when remedial action can be taken with minimum interference.

(g) Climatic conditions. Climatic conditions or other seasonable considerations may affect the scheduling of certain remedial measures.

712.10 Selection of appropriate remedial action

(a) Tailings will be removed from those structures where the appropriately averaged external gamma radiation level is equal to or greater than 0.05 mR/hr. above background in the case of dwellings and schools and 0.15 mR/hr. above background in the case of other structures.

(b) Where the criterion in paragraph (a) of this section is not met, other remedial action techniques, including but not limited to sealants, ventilation, and shielding may be considered in addition to that of tailings removal. ERDA shall select the remedial action technique or combination of techniques, which it determines to be the most appropriate under the circumstances.

ENVIRONMENTAL PROTECTION AGENCY
Title 40-Part 141
Drinking Water Regulations-Radionuclides

Interim Primary Drinking Water Reguations
Promulgation of Regulations on Radionuclides
Federal Register, Vol. 41, No. 133, pp. 28402-9 Friday, July 9, 1976

Part 141.15 Federal Register
Vol 41, No. 133, p 28404, Friday, July 9, 1976

Maximum contaminant levels for ^{226}Ra, ^{228}Ra, and gross alpha particle radioactivity.

(a) Combined ^{226}Ra and ^{228}Ra - 5 pCi/liter.

(b) Gross alpha particle activity (including ^{226}Ra but excluding radon and uranium) - 15 pCi/liter.

APPENDIX V

EVALUATION OF RADIATION EXPOSURES

EVALUATION OF RADIATION EXPOSURES AT THE SENECA ARMY DEPOT ROMULUS, NEW YORK

The U. S. Department of Energy has determined that the Seneca Army Depot in Romulus, New York, is presently contaminated with radioactive residues resulting from previous uses of this property. The depot covers approximately 10,000 acres and consists primarily of munition bunkers. Eleven of these bunkers were used for the storage of approximately 2000 barrels of pitchblende ore during a short period in the early 1940's. Upon removal of the ore, the bunkers reverted back to storage sites for ammunition and have continued in this function since that time. These bunkers are occupied for only brief periods by Army personnel, resulting in a total of approximately 20 to 30 man-hours of occupancy per month.

Contamination at the Seneca site is due primarily to natural uranium and radium-226. Employees at this site receive slight radiation exposures from this contamination primarily because of infrequent occupancy of contaminated bunkers. The principal means of exposures within the bunkers is the inhalation of radon-222 and its short-lived daughters. Additional exposures received by ingestion (e.g., eating or drinking in one of the bunkers) are relatively small compared with inhalation of radon and daughters. A summary of radiation exposures at the Seneca site is provided in Table V-1 along with appropriate guidelines and background values.

The naturally occurring radionuclides present at the Seneca site are also present in minute quantities throughout our environment. Concentrations of these radionuclides in normal soils, air, water, food, etc., are referred to as background concentrations. Radiation exposures resulting from this environmental radioactivity are referred to as background exposures. These background exposures are not caused by any human activity and, to a large extent, can be controlled only through man's moving to areas with lower background exposures. Each and every human receives some background exposure daily.

The use of radioactive materials for scientific, industrial, or medical purposes may cause radiation exposures above the background level to be received by workers in the industry and, to a lesser extent, by members of the general public. Scientifically based guidelines have been developed to place an upper limit on these additional exposures. Limits established for exposures to the general public are much lower than the limits established for workers in the nuclear industry.

Uranium-238 is believed to have been created when the earth was formed. It is still present today because it takes a very long time to decay. The half-life is a measure of the time required for radioactive decay; for uranium-238 it is 4.5 billion years. Thus, if 4.5 billion years ago you had a curie[a] of uranium-238, today you would have one-half curie; 4.5 billion years hence, this would only be one-fourth curie of uranium-238. As the uranium-238 decays, it changes into another substance, thorium-234. Thorium-234 is called the "daughter" of uranium-238. In turn, thorium-234 is the "parent" of protactinium-234. Radioactive decay started by uranium-238 continues as shown in Table V-2 until stable lead is formed. The "decay product" listed in Table V-2 is the radiation produced as the parent decays.

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[a]A curie is a unit defined for expressing the amount of radioactivity present in a substance; one curie represents 37 billion radioactive disintegrations per second.

External Gamma Exposures

As may be seen in Table V-2, several of the daughters of uranium-238 and radium-226 emit gamma radiation (gamma-rays are penetrating radiation like X-rays). Hence, the contaminated areas are sources of external gamma radiation exposure.

External gamma exposure rates measured at one meter above the ground outside the bunkers ranged from 8 to 31 microRoentgens per hour.[b] Exposure rates inside the bunkers ranged from 10 to 21 microRoentgens per hour. The range of average levels inside and outside bunkers is given in Table V-1. A typical chext X-ray (according to Department of Health, Education, and Welfare data) might yield an exposure of about 27,000 microRoentgens, which is equivalent to almost 900 hours of exposure to the maximum rate measured at the Seneca site (31 micro-Roentgens per hour). Background levels in the Romulus area average about 10 microRoentgens per hour.

The National Council on Radiation Protection and Measurements (NCRP) has recommended a maximum annual whole-body exposure of 500,000 microRoentgens for an individual in the general population. This value corresponds to 250 microRoentgens per hour for 2000 exposure hours (40 hours per week and 50 weeks per year). Thus, all external gamma exposures at the Seneca site are less than the guideline.

Inhalation of Radionuclides

As may be seen in Table V-2, radium-226 changes to radon-222 as a result of radioactive decay. Radon-222 is an inert gas which can seep from the ground and enter structures through floors, cracks, drains,

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[b] The Roentgen is a unit which was defined for radiation protection purposes for people exposed to penetrating gamma radiation. A micro-Roentgen is one-millionth of a Roentgen.

etc. If not diluted by additional pure ventilation air, the concentration can build up in closed areas of structures. Outdoor concentrations of radon are generally lower than those inside structures. Measurements made in the eleven bunkers used for uranium ore storage at the site indicate concentrations of radon which range from 0.5 to 6.4 picocuries[c] per liter of air. A concentration of 1.2 picocuries per liter was measured inside a "background" bunker in which ore had not been stored. The guideline value of 3.0 picocuries per liter, as given for the general public in 10 CFR 20,[d] was exceeded in eight of the eleven bunkers. Although the measurements taken do not represent long-term average radon concentrations, they do indicate that exposures in excess of guidelines can be expected if occupancy of the bunkers were to increase.

As may be seen in Table V-2, the decay of radon-222 produces a series of short-lived daughters. The concentration of radon daughters inside the "background" bunker was 0.013 working level (WL).[e] A guideline value for structures (other than dwellings or schools) used by members of the public is 0.03 WL given in 10 CFR 712.[f] Measurements at the Seneca site indicate that the concentration of radon daughters in the eleven bunkers

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[c]One picocurie is one million-millionth of a curie, previously defined.

[d]Title 10, Code of Federal Regulations, Part 20, is a regulatory document published by the Nuclear Regulatory Commission and may be found in the Federal Register.

[e]The working level is a unit which was defined for radiation protection purposes for uranium miners. It represents a specific level of energy emitted by the short-lived daughters of radon.

[f]Title 10, Code of Federal Regulations, Part 712, is a document published by the Energy Research and Development Administration (now Department of Energy) and may be found in the Federal Register.

range from 0.008 to 0.048 working level. Radon daughter concentrations measured in six of the eleven bunkers exceeded the 10 CFR 712 guideline. These radon daughter measurements, together with the radon concentration measurements, indicate that exposures in excess of guidelines can be expected if these bunkers were to be more frequently occupied.

Studies of the health of uranium and other hard rock miners have established that inhalation of large quantities of daughters of radon-222 over long periods of time increases an individual's risk of contracting lung cancer. The present federal guide value for uranium mine workers (given by the Environmental Protection Agency), when translated to the units discussed here, would limit mine workers to an exposure of 0.33 working levels, assuming exposure for 2000 hours per year, a typical work year. This level is significantly lower than the exposures received by most of the miners included in the health studies referred to above.

Other Considerations of Exposure

Water samples taken at the site indicate no significant contamination by radionuclides. Each sample was analyzed for a variety of radionuclides and the concentration of each radionuclide was well below the concentration guide in water (CG_w) as set forth in 10 CFR 20.

While no crops are currently grown on this site, use of the contaminated soil for such a purpose would produce additional human exposure through consumption of crops which have incorporated radium-226. Actions which involve considerable scraping of dry soil or contaminated bunker surfaces could lead to human exposure through inhalation of airborne radioactive dust.

Risk and Radiation Exposures

Risks resulting from radiation exposures should be considered within the context of other risks incurred in normal living. For simplicity, risks to health may be classified in four categories:

1. Unacceptable — problems with risk so high as to require immediate action, such as severe diseases where medical treatment is required to save a life.
2. Concerned — problems where people are willing to spend time and money to reduce potential hazards. Examples of this include the maintenance of public highways and signs, signals, fire departments, and rescue squads.
3. Recognized — problems where people may accept some inconvenience to avoid certain activities such as flying in airplanes, swimming alone, etc.
4. No great concern — problems with a low frequency of occurrence. There is an awareness of potential hazard, but an accompanying feeling that these problems occur only to other people.

An individual may be exposed to risks over which he can exercise some control (voluntary), and risks over which he feels he has no personal control or choice (involuntary).

Daily, an individual is confronted with decisions about risk which have an associted benefit — for example, driving a car. This can serve as an illustration that a voluntary, concerned risk may be deemed appropriate due to the desirable perceived benefit. As another example, an individual who smokes cigarettes has subjected himself to a risk of lung cancer which is about ten times higher than that for a nonsmoker.

For purposes of radiation protection, all radiation exposures are assumed to be capable of increasing an individual's risk of contracting cancer. A precise numerical value cannot be assigned with any certainty to a given individual's increase in risk attributable to radiation exposure. The reasons for this are numerous; they include the individual's age at onset of exposure, variability in latency period (time between exposure and physical evidence of disease), the individual's personal habits and state of health, previous or concurrent exposure to other cancer-causing agents, and the individual's family medical history. Because of these variables, large uncertainties would exist in any estimates of the number of increased cancers in the relatively small working population at the Seneca site.

The normal annual death rate[g] from lung cancer for all population groups in Seneca County (as of 1970) was 14.4 deaths per 100,000 population. At the same time, the annual death rates from lung cancer for all population groups in the United States and the state of New York were 21.1 and 24.2 deaths per 100,000 population, respectively. A one-year exposure to the guideline value for uranium miners (0.33 working level for 2000 hours) might increase the risk of death due to lung cancer by approximately four percent.

The annual death rate from all types of cancer among all population groups in Seneca County (as of 1970) was 115 deaths per 100,000 population. At the same time, the death rates from all types of cancer for all population groups in the United States and in the state of New York were 151 and 172 per 100,000 population, respectively.

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[g]Mortality statistics were obtained from data in *U.S. Cancer Mortality by County: 1950-1969*, prepared by the National Cancer Institute, 1973, available from the U.S. Government Printing Office.

A one-year exposure to penetrating gamma radiation of 500,000 micro-Roentgens might increase the risk of death due to all types of cancer by about one-tenth of a percent. Exposures in excess of these guideline values would be expected to result in proportionately higher increases in risk. Consequently, any action taken to reduce either the rate or the duration of radiation exposures would also reduce the risk attendant to that exposure.

Remedial Measures

The primary pathway by which employees at the Seneca Army Depot are exposed to radiation is by inhalation of radon and its short-lived daughters. These exposures occur primarily in bunkers which are contaminated as a result of uranium ore storage in the 1940's. Remedial measures could consist of thoroughly cleaning all floors, walls, ceilings, vents, and drains in these contaminated bunkers. Contaminated soil outside these bunkers could be removed and replaced with uncontaminated fill. Occupancy of the contaminated bunkers should remain restricted until these structures have been decontaminated. The Department of Energy is now actively evaluating these and other alternatives under a priority program designed to assure public protection.

SUMMARY

Eight bunkers at the Seneca Army Depot appear to be contaminated with residues containing naturally occurring uranium-238 and radium-226. This contamination is producing radon and radon daughter concentrations in the bunkers which could lead to increases in risk of contracting

lung cancer if occupancy of these bunkers were to increase. Consequently, some remedial measures are in order. The Department of Energy (DOE) has developed a coordinated plan which addresses the specific problems at the Seneca site. Currently, work is underway to implement the elements of this plan.

TABLE V-1

SUMMARY OF EXPOSURE DATA AT THE SENECA ARMY DEPOT
ROMULUS, NEW YORK

Exposure Source	Background Levels	Guideline Value for General Public	Guideline Value for Radiation Workers	Average Levels at Romulus site
Radon in air	Less than one picocurie[a] per liter of air outdoors, 1.2 picocuries per liter measured inside "background" bunker	Continuous exposure to 3 picocuries per liter of air	Exposure to 30 picocuries per liter of air for 40 hours per week and 50 weeks per year	Average concentrations ranged from 1.3 to 6.2 picocuries per liter of air inside bunkers used for uranium storage
Radon daughters in air	Less than 0.01 working level[b] outdoors, 0.013 working level measured inside "background" bunker	0.01 working level for residences and school rooms, and 0.03 working level for other structures	0.33 working level for uranium miners exposed for 40 hours per week and 50 weeks per year	Average concentrations ranged from 0.008 working level to 0.048 working level inside bunkers used for uranium storage
Gamma radiation from daughters of radium and uranium contamination	10 microRoentgens[c] per hour outdoors in the Romulus area; 10 microRoentgens per hour measured inside "background" bunker	250 microRoentgens per hour above natural background for 40 hours per week and 50 weeks per year for an individual in the general public. This is equivalent to 0.5 Roentgen per year	2500 microRoentgens per hour for 40 hours per week and 50 weeks per year. This is equivalent to 5 Roentgens per year	Average gamma radiation levels one meter above the floor of bunkers ranged from 10 to 17 microRoentgens per hour; average levels outside bunkers ranged from 10 to 14 microRoentgens per hour

[a]The picocurie is a unit which was defined for expressing the amount of radioactivity present in a substance.

[b]The working level is a unit which was defined for radiation protection purposes for uranium miners. It presents a specific level of energy emitted by the short-lived daughters of radon.

[c]The Roentgen is a unit which was defined for radiation protection purposes for people exposed to penetrating gamma radiation. A microRoentgen is one millionth of a Roentgen.

TABLE V-2

Uranium-238 decay series

Parent	Half-life	Decay products	Daughter
uranium-238	4.5 billion years	alpha	thorium-234
thorium-234	24 days	beta, gamma	protactinium-234
protactinium-234	1.2 minutes	beta, gamma	uranium-234
uranium-234	250 thousand years	alpha	thorium-230
thorium-230	80 thousand years	alpha	radium-226
radium-226	1600 years	alpha	radon-222
radon-222	3.8 days	alpha	polonium-218
polonium-218*	3 minutes	alpha	lead-214
lead-214*	27 minutes	beta, gamma	bismuth-214
bismuth-214*	20 minutes	beta, gamma	polonium-214
polonium-214*	$\frac{2}{10,000}$ second	alpha	lead-210
lead-210	22 years	beta	bismuth-210
bismuth-210	5 days	beta	polonium-210
polonium-210	140 days	alpha	lead-206
lead-206	stable	none	none

*Short-lived radon daughters.