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POST-REMEDIAL-ACTION
RADIOLOGICAL SURVEY OF
THE WESTINGHOUSE ADVANCED REACTORS DIVISION
PLUTONIUM FUEL LABORATORIES,
CHESWICK, PENNSYLVANIA

October 1-8, 1981

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EXECUTIVE SUMMARY

At the request of the Engineering Support Division of the U.S. Department of Energy, Chicago Operations Office (DOE-CH), and with the concurrence and sponsorship of DOE-Headquarters Environmental and Safety Engineering Division, a comprehensive post-remedial-action radiological assessment was conducted at the Westinghouse Advanced Reactors Division Plutonium Fuel Laboratories in Cheswick, Pennsylvania, to determine if any radioactive* material contamination remained following the Westinghouse decontamination and decommissioning activities. The assessment was conducted by the ANL Radiological Survey Group from October 1 to October 8, 1981.

During the late 1960s through late 1970s, the Westinghouse Advanced Reactors Division (W-ARD) operated in two laboratories at the Cheswick site, the Plutonium Laboratory (in Building 7) and the Advanced Fuels Laboratory (in Building 8). Mixed uranium-plutonium carbide fuel materials and fuel elements were fabricated within the Plutonium Laboratory in Building 7. Uranium-plutonium oxide and carbide fuel assemblies were fabricated within the Advanced Fuels Laboratory in Building 8, as were five blanket rod assemblies.

The radiological assessment conducted in 1981 included determinations of surface contamination levels, both fixed and removable, through direct instrument and smear surveys; measurements of ambient external penetrating radiation at 1-meter heights; and analyses of air, soil, and other material samples from the areas involved.

Six remaining areas of radioactive contamination at Building 7 and three areas at Building 8 were detected through the direct instrument and smear surveys. The radiation readings obtained at the contaminated areas were compared with standards and guidelines in the American National Standard Institute (ANSI) Draft Standard N13.12, "Control of Radioactive Surface Contamination on Materials, Equipment, and Facilities to be Released for Uncontrolled Use," and in the Nuclear Regulatory Commission's "Guidelines for Decontamination of Facilities and Equipment Prior to Release for Unrestricted Use or Termination of

*The various types and sources of radiation mentioned in this report are discussed in more detail in Appendix 7.

Licenses for By-Product, Source, or Special Nuclear Material." The limits for plutonium, uranium, ^{60}Co , or unknown contaminants were used as the bases for comparison, depending upon the results of radiochemical analyses conducted on samples taken from contaminated areas. Further decontamination was conducted at four of the nine areas; radiation levels following the additional decontamination were below the appropriate surface contamination limit. Since even prior to the survey, elevated levels of radioactivity were known to exist at two of the areas at Building 8--the contaminated ductwork and the north wall of the Advanced Fuels Laboratory--exception was taken and they were not considered for unrestricted-use release. Contamination at the last three remaining areas, involving contaminated soil, gravel, or drain lines, remained.

Measurement of the ambient external penetrating radiation field with a pressurized ionization chamber at 1-meter heights indicated background exposure rates ranging from 8.5 to 8.7 $\mu\text{R/h}$ at the locations sampled in Building 8. The background exposure rates in Building 7 generally ranged from 9.4 to 10.1 $\mu\text{R/h}$. One elevated reading (12.1 $\mu\text{R/h}$) was observed toward the east side of Building 7. This measurement was influenced by its proximity to ^{60}Co -contaminated soil located east of Building 7.

The radon daughter concentrations measured in air samples collected at selected locations in the buildings, including some areas where contamination was found, ranged from 0.15 to 1.2 milli-Working Level (mWL) in Building 7 and was 0.41 mWL in the Advanced Fuels Laboratory in Building 8. These values are well below the limit of 10 mWL above background as given in the Surgeon General's Guidelines. Concentrations of thoron daughters measured in the air samples were well below the concentration guide of 0.6 pCi/ ℓ for ThB (^{212}Pb) as given in DOE Order 5480.1 "Requirements for Radiation Protection." Calculated radon and thoron concentrations, based on the daughter determinations, were below the concentration guides for ^{222}Rn and ^{220}Rn in uncontrolled areas (3 pCi/ ℓ and 10 pCi/ ℓ , respectively). No long-lived radionuclides were detected in any air sample.

Four dirt/sludge or water samples were collected from the Building 7 sanitary drain lines. Radiochemical analyses of those samples disclosed uranium, plutonium, and americium contaminants, indicating a contaminated drain line system for Building 7. Although a monitor (suspect waste) drain line once

served the Advanced Fuels Laboratory within Building 8, no sanitary drain line had served that laboratory.

Ten soil corings and a sand and gravel sample from a storm sewer outfall were collected about the grounds of Buildings 7 and 8 to test for the presence of any radionuclides that could have been spilled or released outside the buildings. A several-square-meter area of contamination was found east of Building 7; ^{60}Co concentrations there ranged up to 279 pCi/g. One coring west of the Advanced Fuels Laboratory (Building 8) indicated 6.4 pCi/g of enriched uranium, 315 fCi/g of plutonium, and 160 fCi/g of americium, indicating release or spillage. The extent of this release or spillage is unknown. All other radionuclide concentrations measured in the soil corings and storm sewer outfall samples were within the range of normally expected background concentrations.

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INTRODUCTION

At the request of the Engineering Support Division of the U.S. Department of Energy, Chicago Operations Office (DOE-CH), and with the concurrence and sponsorship of the DOE-Headquarters Environmental and Safety Engineering Division, the Argonne National Laboratory (ANL) Radiological Survey Group conducted a radiological assessment at the Westinghouse Advanced Reactors Division (W-ARD, or ARD) Plutonium Fuel Laboratories in Cheswick, Pennsylvania. The post-remedial-action assessment was conducted in portions of Buildings 7 and 8 from October 1 to October 8, 1981, to determine if any radioactive contamination remained following decontamination and decommissioning (D&D) of the facilities by Westinghouse.

The site is located west of Cheswick, approximately 3/4 mile north of the Allegheny River in Harman Township, Allegheny County (see Fig. 1). The 113-acre site is bounded by the Cheswick and Harmar Railroad to the north and west, and by Low Grade Road to the east and the borough of Acmetonia to the south. During the late 1960s through the late 1970s, W-ARD operated in two laboratories at the Cheswick site, the Plutonium Laboratory in Building 7 and the Advanced Fuels Laboratory in Building 8 (see Fig. 2). Mixed uranium-plutonium carbide fuel materials and fuel elements were fabricated within the Plutonium Laboratory in Building 7. Uranium-plutonium oxide and carbide fuel assemblies were fabricated in the Advanced Fuels Laboratory in Building 8, as were five blanket rod assemblies. Both buildings were shared with the Westinghouse Nuclear Fuel Division (NFD), as were health physics, security, and other services. Aside from the ARD Advanced Fuels Laboratory, Building 8, which was designated as the Plutonium Fuels Development Laboratory (PFDL), housed predominantly NFD programs involving the development of mixed uranium-plutonium oxide fuel for use in pressurized light water reactors. NFD also operated an Uranium Oxide Laboratory in Building 7, which housed predominantly W-ARD's Plutonium Laboratory and related facilities. The NFD activities were licensed under the Nuclear Regulatory Commission. The areas that those programs occupied were not included in the scope of the radiological assessment addressed in this report.

SURVEY, SAMPLING, AND ANALYTICAL TECHNIQUES

General

The post-remedial-action assessment conducted by the Argonne National Laboratory Radiological Survey Group for the U.S. Department of Energy (DOE) included only parts of Buildings 7 and 8. The areas involved at Building 7 included the Plutonium Laboratory and surrounding area (essentially all of Building 7 except office areas and the NFD Uranium Oxide Laboratory) and the outside environs within or near the fenceline of Building 7 (see Figs. 3 and 4). The areas involved in the survey at Building 8 included the Advanced Fuels Laboratory (ARD), those adjoining areas from each exit to a few meters beyond the exit, and general areas around locations where environmental soil samples were taken (see Fig. 5).

The assessment activities included determination of surface contamination levels, both fixed and removable, through direct instrument and smear surveys; measurement of ambient external penetrating radiation at 1-meter heights throughout the involved areas; measurement of the concentrations of radon, thoron, and actinon daughters and longer-lived radionuclides within air samples; and determination of concentrations of uranium, plutonium, americium, cobalt-60, cesium-137, the thorium-232 decay chain, and the radium-226 decay chain in soil and other material samples from the involved areas. The direct instrument and smear surveys were performed on all accessible floor, wall, and ceiling surfaces, except in the Low-Bay, High-Bay, and Corridor of Building 7, where only accessible floors and walls to a height of about 2 m (7 ft) were surveyed. These areas were adjacent to, not part of, the affected areas. Nonetheless, it was conceivable that radioactive materials could have been spilled or otherwise tracked into these adjacent areas. In some areas, building surfaces might have been retiled, painted, or otherwise covered since the beginning of use of radioactive materials; however, the instruments utilized for the direct survey had some capability to detect beta-gamma activity on the underlying surfaces.

The locations of accessible areas surveyed are listed in Table 1 and shown in Figures 3 through 5.

Direct Instrument Surveys

Four types of portable survey instruments were used to conduct the direct radiological surveys. Gas-flow proportional detectors with detection areas of 51 cm², 330 cm², or 470 cm², and utilizing Eberline PAC-4G-3 electronics were used to monitor for direct alpha and/or beta-gamma surface contamination. The larger area probes were used in Eberline floor monitors (FM-4G), whereas the smaller hand-held probe (Eberline AC-21) was used to survey the walls, overheads, and other areas inaccessible with the floor monitor. NaI(Tl)-crystal detectors, 2-in (5-cm) diameter by 2-mm thick (Eberline PG-2 with Eberline PRM-5-3 electronics), were used to monitor for low energy x and gamma radiation. An Eberline Model 530 Geiger-Mueller (GM) detector with an Eberline HP-190 end-window probe was used to obtain a contact exposure rate reading (in mR/h) of all contaminated areas. NaI(Tl)-crystal detectors, 1-in (2.5-cm) diameter by 1-in thick (Eberline PRM-7 μ R meter) and calibrated with a ²²⁶Ra standard source, were used to measure the ambient external penetrating radiation field in units of μ R/h. These instruments and associated calibration procedures are detailed in Appendices 1 and 2.

Although ²³⁹Pu and ⁹⁰Sr-⁹⁰Y standards were used to calibrate the gas-flow instruments, it should be noted that the numerous isotopes that could be encountered exhibit emission energies differing from those of the standards used in the calibration. When detecting known isotopes that emit alpha and beta energies differing from those of the standards, such as normal uranium*, a conversion factor for those particular radionuclides was developed to determine the appropriate yield. The methods used to determine the conversion factors are described in Appendix 2. All readings of disintegrations per minute per 100 cm²

*The term "normal uranium" refers to uranium which has been separated from its radioactive decay products and other impurities, and which has the normal isotopic percent abundances as found in nature. The normal percent abundances are 0.0054% ²³⁴U, 0.720% ²³⁵U, and 99.2746% ²³⁸U (Ref. 1). The less precise definition of normal uranium as 0.7% ²³⁵U, 99.3% ²³⁸U, and a trace of ²³⁴U is sometimes used for brevity in discussions. The term "natural uranium" denotes uranium and all decay products as found in its natural state in the earth, and is sometimes incorrectly referred to as normal uranium. Appendix 5 contains the detailed calculation of the specific activity of normal uranium.

(dis/min-100 cm²), as reported in Table 1, are equated to ²³⁹Pu and ⁹⁰Sr-⁹⁰Y, unless otherwise stated. It should also be noted that since calibrations are to infinitely-thin flat-plate standards, all readings as reported should be regarded as minimal values; no corrections were made for absorption by surface media.

When possible, the contaminant radionuclides were identified at the time of the survey by performing gamma-spectral analysis on the contaminated item or on a sample of material taken from the contaminated area. These analyses were performed with a NaI(Tl) crystal or hyperpure germanium (HPGe) detector coupled to the appropriate electronics and a multichannel analyzer.** This instrumentation (also described in Appendix 1), along with all other survey and sampling devices, was housed in a mobile laboratory--a specially designed, converted motor home.

Smear Surveys

Dry smears were taken with 4.25-cm-diameter filter papers (Whatman #1) at representative locations throughout each building to assess removable surface contamination levels. A standard smear sample is obtained by applying moderate pressure with the tips of the first two fingers to the back of the filter paper and wiping the surface over an area of approximately 100 cm². Smears were taken on accessible structures and components such as walls, floors, drain pipes, and vents.

To expedite the counting of the hundreds of smear samples collected, two counting techniques were employed with two types of counters. A large-area, 10-wire gas-flow proportional counter, sensitive to alpha and/or beta-gamma radiation, was used to make an initial count on groups of ten smears. Additionally, at least one smear from each group was selected at random and counted in the more sensitive Nuclear Measurements Corporation, Model PC-3A or 5, gas-flow proportional counter (PC counter) using an aluminized Mylar window (Mylar spun top) over the smear. All smears from areas or objects with elevated direct instrument readings were individually counted in the PC counter. Smears

**Such analysis was performed on six samples collected during this survey.

from any group of 10 indicating a reading statistically above the instrument background levels in the 10-wire assembly were counted individually in the PC counter. Smears were counted in each detector for both alpha and beta-gamma activity.

A more detailed description of the counters used is presented in Appendix 1. The factors used to convert instrument counts to disintegrations of a particular isotope for all the smears are given in Appendix 2. Unless otherwise indicated, all contamination on the smears reported in Table 1 is equated to ^{239}Pu and ^{90}Sr - ^{90}Y , as described in Appendix 2.

Ambient Penetrating Radiation Measurements

The areas being surveyed at Buildings 7 and 8 were monitored for ambient external penetrating radiation levels (in $\mu\text{R}/\text{h}$) at 1-meter heights in selected locations. Integrated measurements of the ambient penetrating radiation field (in μR) were taken with a Reuter-Stokes RSS-111 pressurized ionization chamber (PIC), calibrated with an NBS-traceable gamma-ray source (see Figs. 3 and 5). Integration periods were minimally six hours. This instrument and associated calibration procedures are detailed in Appendix 1.

Air Samples

Air samples were collected with a commercial vacuum cleaner modified at ANL for use as a particulate air-sampling device. A total volume of about 30 m^3 of air was sampled at a flow rate of $40\text{ m}^3/\text{h}$ ($670\text{ l}/\text{m}$). A 10% portion, 5 cm in diameter, was removed from the filter medium after collection and counted for both alpha and beta-gamma activity in the proportional counter, using a Mylar spun top. Concentrations of radon (^{222}Rn) daughters, thoron (^{220}Rn) daughters, and any long-lived airborne radionuclides were determined based on the results of several counts of each sample at specified intervals.

Air-particulate samples were also collected on Millipore membrane filter media using a positive-displacement pump at a flow rate of about $1\text{ m}^3/\text{h}$ ($17\text{ l}/\text{m}$). Sampling periods were minimally 60 minutes. A portion of each filter media was used to determine the actinon (^{219}Rn) daughter concentration through alpha spectral analysis.

Details of the equipment used are given in Appendix 1. The assumptions used and details of the air-sampling techniques and associated calculations are given in Appendix 3.

Soil and Material Samples

Five environmental soil corings (16-S-3 through 16-S-7) were collected outside Building 7 to detect the presence of any radioactive material that might have been spilled or released due to W-ARD activities. The sampling locations selected are shown in Figure 4. Five soil corings (16-S-8 through 16-S-12) were also collected around Building 8 (see Fig. 5). One additional coring (16-S-13) was taken at the southern end of the Westinghouse site, about 500 ft south of Building 8, to determine background levels of radionuclides in the soil from the immediate area (see Fig. 2).

The corings were collected with a 10-cm-diameter, 30-cm-long right-circular-cylinder cutting tool, commonly used to cut golf-green holes. Each soil core was 30 cm (12 in) long and was divided into four segments for analysis. Starting from the surface, three separate 5 cm (2 in) segments were cut, bagged, and marked A, B, and C, respectively; the final segment of 15 cm (6 in) was marked D (see Fig. 6). The segmented coring technique was used to determine if any contaminant migration had occurred, to reduce the dilution of upper-level soil with the lower-level segments with respect to the surface deposition of the contaminants (or vice versa), and to reveal if any overburden or backfill material had been added over the years.

The soil corings were prepared at Argonne National Laboratory (ANL). The soil-sample preparation procedures, consisting generally of drying, milling, and sieving, are described in detail in Appendix 4. At no point in the preparation were rocks and solid material ground or pulverized, since this material would act as a diluent and, hence, lower the reported concentration in soil of deposited radioactive material. The rocks/dross and the sieved material were segregated, bagged, and weighed separately (weights are given in Table 5).

All soil samples were analyzed by the Analytical Chemistry Laboratory at ANL. A uranium-fluorometric technique was used to determine total uranium concentration (in $\mu\text{g/g}$), and high-resolution gamma-spectral analysis was used to determine the concentrations of the ^{226}Ra decay chain, the ^{232}Th decay chain, and other gamma-emitting radionuclides in the soil (in pCi/g). Analysis details

are included in Appendix 4. One surface soil segment from Building 7 environs (16-S-6A), two from Building 8 environs (16-S-9A and -10B), and one from the background coring (16-S-13A) also were analyzed by radiochemical separation followed by alpha-spectral analyses to quantify plutonium and americium isotopic concentrations (in fCi/g). One soil segment from Building 8 environs (16-S-10B) was subjected to uranium mass-spectral analysis to quantify the relative isotopic abundances of ^{234}U , ^{235}U , and ^{238}U (in atom %) because of a large discrepancy between the gamma-spectral ^{226}Ra result and the total uranium concentration as determined by uranium-fluorometric analysis. When the ^{226}Ra concentration, as determined by gamma-spectral analysis, appears much less than about half the uranium concentration, as determined by the uranium-fluorometric analysis, this is indicative that normal uranium (i.e., uranium that has been separated from its daughters) rather than natural uranium (i.e., uranium in equilibrium with its daughters) is present. When the reverse of this is found, it is indicative of radium enhancement similar to that found in mill tailings.

In addition to the 11 environmental soil corings, 11 other material samples were taken during the course of the survey. Four were taken from the Building 7 sanitary drain lines (16-SS-1 and -14, 16-W-15 and -16). Although a monitor (suspect waste) drain line once served the Advanced Fuels Laboratory within Building 8, no sanitary drain line had served that laboratory. Hence, no drain line samples were obtained there. Another 6 of the 11 samples were of material taken from or near contaminated areas found by direct instrument survey (16-PAINT-2, 16-FLOOR-17, -20, and -21, 16-C-18, and 16-GRAVEL-19). The last sample (16-GRAVEL-22) was a sand and gravel sample from the Building 8 storm drain outfall, approximately 300 ft west of Building 8 (see Fig. 2). The preparation of samples 16-SS-1 and -14 and 16-GRAVEL-22 was identical to that for the soil coring segments, consisting of drying, milling, and sieving. The preparation of the others was sample-specific, consisting of ashing, drying, and/or grinding. All 11 samples were analyzed by uranium-fluorometric and gamma-spectral analysis. In addition, samples 16-SS-1 and -14, 16-PAINT-2, 16-W-15 and -16, and 16-GRAVEL-22 were analyzed by radiochemical separation/alpha-spectral analyses for plutonium and americium isotopic concentrations. Samples 16-SS-1 and -14 were also analyzed by mass-spectral analysis for relative isotopic abundances of the uranium isotopes.

SURVEY AND SAMPLING RESULTS

Direct Instrument and Smear Surveys

The results of the direct instrument and smear surveys are given in Table 1. The PAC-4G-3 instrument readings and smear results have been normalized to units of dis/min-100 cm² using the factors derived in Appendix 2 and are equated to ²³⁹Pu and ⁹⁰Sr-⁹⁰Y, unless otherwise stated. The PAC-4G-3 readings and smear data are reported in net count rates, i.e., the background count rates have been subtracted from the gross count rates prior to conversion to dis/min-100 cm². Any alpha contributions have been subtracted from the readings taken in the beta mode so that the corrected values reflect only the beta-gamma readings. The low-energy x and gamma readings (in cts/min), measured with the PG-2 detector, the end-window GM response (in mR/h), and the PRM-7 readings (in μ R/h) are reported as net rates above the appropriate background.

Depending upon the specific instrument, probe, and calibration, background levels varied somewhat from area to area, due in part to differences in and/or proximity to construction materials and soils. The background readings for all modes of operation of the instruments used are given in Appendix 1.

Building 7

Elevated levels of radioactivity, as indicated by measurements above the background levels, were found at 11 areas at Building 7 through the direct instrument surveys. Six of these measurements were due to radioactive contamination; the others were attributable to glazed tiles, "shine" from one of the contaminated areas, and an airfiltration unit (currently in use). Contaminated areas were found in the Shower Room, Clean Locker Room, Low-Bay, High-Bay, and at the environs east of Building 7, about midway between Buildings 7 and 9. No areas of contamination were detected through the smear surveys. The maximum instrument readings at each of the contaminated areas (designated as contaminated areas #1 through #6) are given in Table 1. A brief description of each contaminated area follows.

- Contaminated areas #1 and #2, both in the Low-Bay, were found on the epoxy-covered floor. A sample (16-PAINT-2) of contaminated epoxy was obtained

from area #1. The maximum PG-2 response at the area was 1×10^2 cts/min above the background. The maximum PAC beta-gamma contamination level was 6.4×10^3 dis/min-100 cm², equated to normal uranium based upon the results of analysis of sample 16-PAINT-2 (see section on "Soil and Material Samples").

Contaminated area #3 was discovered in a High-Bay floor drain. A sample of sludge and dirt (16-SS-1) was collected from the drain. The maximum PG-2 response was 5×10^2 cts/min above the background. The maximum PAC beta-gamma and alpha contamination levels were 5.3×10^2 and 3.4×10^2 dis/min-100 cm², respectively, equated to normal uranium based upon results of analysis of sample 16-SS-1.

Contaminated area #4 was beneath the Shower Room floor, where upon the removal of a sample of clay floor tile (16-FLOOR-17), the direct instrument readings increased. The maximum PAC beta-gamma contamination level observed was 3.9×10^3 dis/min-100 cm². A sample of the concrete floor slab (16-C-18) directly beneath the clay tile was collected, as was a portion of the gravel (16-GRAVEL-19) from beneath the concrete slab. The direct instrument readings increased with progressive depths. Gamma-spectral analysis performed during the survey on sample 16-GRAVEL-19 indicated that the contaminant was predominantly ⁶⁰Co.

Contaminated area #5 was on the asphalt-tiled floor in the Clean Locker Room. The maximum PAC beta-gamma contamination level was 5.9×10^2 dis/min-100 cm². Gamma-spectral analysis performed during the survey on a sample of the contaminated floor tile (16-FLOOR-21) failed to indicate the contaminant. This could be due to the poor resolution of NaI(Tl), the limited counting time employed, or the presence of other than higher energy x or gamma emitting contaminants.

Contaminated area #6 was found in the soil in the environs just east of Building 7, between Buildings 7 and 9. An environmental coring sample (16-S-6A through D) was collected at the location of maximum instrument readings. Several square meters of land were involved. The maximum PG-2 response at the area was 4×10^4 cts/min; the maximum PAC beta-gamma con-

tamination level was 3.0×10^4 dis/min-100 cm²; the maximum contact exposure rate was 0.3 mR/h. Gamma-spectral analysis performed during the survey on the coring sample indicated ⁶⁰Co as the predominant contaminant in each of the segments. The ⁶⁰Co contamination apparently was related to activities conducted within Building 9, the Pump Repair Building, where pumps from Navy nuclear submarines had been refurbished. The contamination beneath the Shower Room floor was apparently related to those activities as well.

Building 8

Elevated levels of radioactivity were found at three areas in the Advanced Fuels Laboratory through the direct instrument and smear surveys. All were due to radioactive contamination. The areas are described below:

- Contaminated area #7 was on the laboratory's concrete floor. No sample was collected. The maximum PAC alpha contamination level was 9.8×10^2 dis/min-100 cm²; the maximum PAC beta-gamma contamination level was 4.7×10^2 dis/min-100 cm²; the maximum PG-2 response was 9.3×10^3 cts/min.
- Contamination was detected in the interior of the exhaust duct, located at the ceiling near the center of the room. The maximum PAC alpha contamination level was 1.4×10^4 dis/min-100 cm²; the maximum PAC beta-gamma contamination level was 2.9×10^3 dis/min-100 cm²; the maximum removable alpha contamination level was 10 dis/min-100 cm². Because the ductwork was known to be contaminated prior to the survey, exception was taken and the ductwork was not considered for unrestricted-use release. W-ARD personnel intended to dismantle and properly dispose of the ductwork.
- Elevated levels of radioactivity were measured at the laboratory's north wall, with PG-2 responses of up to 4×10^4 cts/min and PRM-7 responses of up to 1×10^2 μR/h. The elevated readings were caused by the presence of glove boxes, source vaults, and drums of radioactive materials beyond the north wall in the Analytical Chemistry Laboratory and the Instrument Analysis ("Spec") Laboratory, neither of which was included in this survey. In an attempt to reduce the interference from these sources at the north

wall, the source vaults and drums of radioactive materials were transferred to the Storage Addition, leaving only glove boxes beyond the north wall. The maximum remaining PG-2 response was 2.6×10^4 cts/min; the maximum PRM-7 response was 8 μ R/h above the background; the maximum removable alpha contamination level was 9 dis/min-100 cm^2 . Since elevated readings were known to exist at the north wall prior to the survey, exception was taken and the north wall was not considered for unrestricted-use release. Radiological surveys for low-levels of contamination could not be conducted due to the "overwhelming" interferences.

The direct instrument survey data and the smear results from both buildings were compared to the American National Standards Institute (ANSI) Draft Standard N13.12, "Control of Radioactive Surface Contamination on Materials, Equipment, and Facilities to be Released for Uncontrolled Use," and to the Nuclear Regulatory Commission (NRC) "Guidelines for Decontamination of Facilities and Equipment Prior to Release for Unrestricted Use or Termination of Licenses for By-Product, Source, or Special Nuclear Material" (see Appendix 6). At the time of the survey, only gamma-spectral analysis was immediately available for purposes of specific identification, and this technique did identify ^{60}Co as a predominant contaminant in two instances. Nevertheless, most of the contaminants were not immediately identified. It was known, however, that isotopes of plutonium and uranium had been used in the Plutonium Laboratory (Building 7) and Advanced Fuels Laboratory (Building 8). The allowable limits in the ANSI Draft Standard for plutonium isotopes or when the contaminant cannot be identified is 20 dis/min-100 cm^2 removable, and the limits are such that the total (fixed plus removable) activity must be nondetectable using instruments calibrated to measure at least 100 pCi of the contaminant uniformly spread over 100 cm^2 . The NRC Guidelines for plutonium isotopes are stated as follows: "The average (total activity) is 100 dis/min-100 cm^2 and the removable is 20 dis/min-100 cm^2 ." The allowable limit in the ANSI Draft Standard and the NRC Guidelines for ^{60}Co or uranium activity is 5000 dis/min-100 cm^2 total, of which only 1000 dis/min-100 cm^2 can be removable. In both the ANSI and NRC criteria, all levels for total activity may be averaged over one square meter provided the maximum activity in any area of 100 cm^2 is less than three times the limit value.

Five of the seven contaminated areas within Buildings 7 and 8 exceeded the acceptable surface contamination limits for plutonium or unknown contaminants

and thus required further decontamination. The other two contaminated areas (#4 and #6), both contaminated with ^{60}Co , either met the acceptable surface contamination limits for ^{60}Co or were considered as beyond the scope of surface contamination limits, being contaminated soil and gravel. Contaminated areas #1, #2, #5, and #7, were decontaminated further by W-ARD personnel; the results of subsequent direct instrument and smear surveys following the additional decontamination are presented in Table 2. Contaminated area #5, on the Clean Locker Room floor, and contaminated area #7, on the Advanced Fuels Laboratory floor, were both at background levels, following removal and disposal of contaminated material. Contaminated areas #1 and #2, on the epoxy-covered floor in the Low-Bay and just outside the NFD Uranium Oxide Laboratory, were decontaminated further through the use of an industrial-strength paint remover. Analysis of sample 16-PAINT-2, collected at this time, ultimately indicated that uranium was the contaminant. Because of the proximity of the areas to the Uranium Oxide Laboratory and because of the apparent efforts to decontaminate to as low as reasonably achievable levels, the levels following the additional decontamination were deemed by the survey team as acceptable, based on the surface contamination limits for uranium. The soil and gravel, at areas #6 and #4, respectively, as well as the drain, at area #3, remained contaminated.

Ambient Penetrating Radiation Measurements

The results of the ambient external penetrating radiation measurements with the RSS-111 pressurized ionization chamber are presented in Table 3. Prior to each measurement, all locations chosen were surveyed with the PRM-7 μR meter. These chosen locations gave measurements believed to be representative of the area background, except for the measurement in the Clean Locker Room of Building 7, which was influenced by its proximity to the ^{60}Co -contaminated soil at area #6. Exposure rates at the locations sampled in Building 7, excluding the Clean Locker Room, ranged from 9.4 to 10.1 $\mu\text{R}/\text{h}$. The exposure rate at the location sampled in the Clean Locker Room was 12.1 $\mu\text{R}/\text{h}$. Exposure rates at the locations sampled in the Advanced Fuels Laboratory in Building 8 ranged from 8.5 to 8.7 $\mu\text{R}/\text{h}$. These locations were distant enough from the north wall to be essentially unaffected by the elevated levels of radioactivity measured there, primarily due to interferences located beyond the wall in NFD laboratories.

Air Samples

Results of the analyses of air samples collected at selected locations in Building 7 and at the Advanced Fuels Laboratory in Building 8 are presented in Table 4. Techniques detailed in Appendix 3 were used to determine the radon (^{222}Rn) daughter concentration (in milli-Working Level, mWL) and thoron (^{220}Rn) daughter concentration (in picoCurie/liter, pCi/l) at each location.

The radon daughter concentration ranged from 0.15 to 1.2 mWL in Building 7 and was 0.41 mWL in the Advanced Fuels Laboratory in Building 8. These values are well below both the limit of 0.02 WL (or 20 mWL) including background for average annual concentration as specified in the Environmental Protection Agency Standard (40 CFR 192), and less than 0.01 WL (or 10 mWL) above background, for which the U.S. Surgeon General's Guidelines in 10 CFR 712 do not indicate a need for remedial action (see Appendix 6). If an equilibrium fraction* of 0.5 is assumed, radon concentration, as determined from the radon daughter concentrations, ranged from 0.03 to 0.26 pCi/l in Building 7 and was 0.08 pCi/l in the Advanced Fuels Laboratory. These are well below the concentration guide of 3 pCi/l for an uncontrolled area, as given in the Department of Energy (DOE) Order 5480.1 "Requirements for Radiation Protection" (see Appendix 6).

The thoron daughter concentration (ThB and ThC) ranged from 6.4×10^{-4} to 8.6×10^{-4} pCi/l in Building 7 and was 9.7×10^{-4} pCi/l in the Advanced Fuels Laboratory. If equilibrium between thoron and its daughters is assumed for the air sampled (a conservative assumption), then thoron concentrations were identical to those listed for thoron daughters. These are far below the concentration guides for thoron (^{220}Rn) and ThB (^{212}Pb) of 10 pCi/l and 0.6 pCi/l, respectively, for an uncontrolled area, as given in the DOE "Requirements for Radiation Protection."

All measured concentrations of radon and thoron daughters were within the range of values normally expected for background concentrations. No actinon (^{219}Rn) daughters or long-lived radionuclides were detected in any air sample.

*The equilibrium fraction is defined as 100 times the radon daughter concentration (in WL) divided by the concentration of radon (in pCi/l). This fraction typically varies from about 0.3 to 0.7, with an average of about 0.5.

Soil and Material Samples

Results of the gamma-spectral, uranium-fluorometric, and other radiochemical analyses performed on the environmental soil corings and other material samples (surface and structural material, Building 8 storm drain outfall, drain lines of Building 7) are listed in Tables 6 through 8. Table 6 includes the results of the gamma-spectral and uranium-fluorometric analyses of samples, Table 7 the results of uranium mass-spectral analyses of selected samples, and Table 8 the results of plutonium and americium analyses of selected samples.

Environmental Soil Corings - The gamma-spectral analysis of the five soil corings (16-S-3 through 16-S-7) collected about Building 7 indicated ^{60}Co concentrations ranging from 0.13 ± 0.02 to 279 ± 28 pCi/g*, ^{137}Cs concentrations ranging from < 0.03 to 1.34 ± 0.08 pCi/g, thorium decay chain concentrations ranging from 0.44 ± 0.07 to 1.71 ± 0.12 pCi/g, and radium decay chain concentrations ranging from 0.59 ± 0.04 to 2.34 ± 0.17 pCi/g. Uranium-fluorometric analyses indicated uranium concentrations ranging from 0.82 ± 0.08 to 3.5 ± 0.35 pCi/g. Plutonium and americium analyses of segment 16-S-6A indicated $\leq 13 \pm 6$ fCi/g of any single isotope.

The gamma-spectral analyses of the five soil corings (16-S-8 through 16-S-12) collected about Building 8 indicated ^{137}Cs concentrations ranging from < 0.03 to 1.23 ± 0.08 pCi/g, thorium decay chain concentrations ranging from 0.50 ± 0.08 to 1.41 ± 0.10 pCi/g, and radium decay chain concentrations ranging from 0.93 ± 0.06 to 2.00 ± 0.14 pCi/g. A ^{60}Co concentration of 0.17 ± 0.03 pCi/g* was detected in segment 16-S-9A. Uranium-fluorometric analyses indicated uranium concentrations ranging from 1.3 ± 0.13 to 6.4 ± 0.64 pCi/g. Uranium mass-spectral analysis of the segment (16-S-10B) with 6.4 pCi/g (8.1 $\mu\text{g/g}$) of uranium indicated an enriched uranium (0.96% ^{235}U). Plutonium and americium analyses of that segment indicated 215 ± 20 fCi/g of $^{239,240}\text{Pu}$, 100 ± 20 fCi/g of ^{238}Pu , and 160 ± 30 fCi/g of ^{241}Am . Plutonium and americium analyses of segment 16-S-9A indicated $\leq 7 \pm 4$ fCi/g of any single isotope.

*Concentrations of ^{60}Co (with a 5.27-year half-life) are reported as of March 1982, the time of the analyses.

The gamma-spectral analysis of coring 16-S-13, collected toward the southern end of the Westinghouse site, about 500 ft south of Building 8, indicated ^{137}Cs concentrations ranging from < 0.03 to 0.08 ± 0.03 pCi/g, thorium decay chain concentrations ranging from 0.92 ± 0.07 to 1.28 ± 0.09 pCi/g, and radium decay chain concentrations ranging from 1.05 ± 0.07 to 1.40 ± 0.10 pCi/g. Uranium-fluorometric analyses indicated uranium concentrations of 1.2 ± 0.12 to 1.4 ± 0.14 pCi/g. Plutonium and americium analyses indicated 5 ± 5 fCi/g of each isotope.

Aside from the ^{60}Co contamination in the soil samples from about Building 7 and the enriched uranium, plutonium, and americium contamination in sample 16-S-10B from near Building 8, all concentrations of ^{137}Cs , thorium decay chain, radium decay chain, uranium, plutonium, and americium measured in the soil corings were within the range of normally expected background concentrations. The enriched uranium, plutonium, and americium in sample 16-S-10B indicated contamination due to release or spillage. The ^{60}Co contamination in the soil samples from the Building 7 environs also indicated contamination; presumably due to the activities conducted within Building 9, the Pump Repair Building.

Surface and Structural Material - Results of analyses of sample 16-PAINT-2 from the Building 7 Low-Bay indicated uranium concentrations of 294 ± 29 $\mu\text{g/g}$ (200 ± 20 pCi/g as normal uranium). This sample was collected at the time of removal of the contaminated epoxy floor covering from contaminated area #1. Analyses indicated uranium was the only contaminant.

Samples 16-FLOOR-17, 16-C-18, and 16-GRAVEL-19 were collected at progressive depths within the Building 7 Shower Room floor at contaminated area #4. Results of analyses of sample 16-FLOOR-17, consisting of clay floor tile from the contaminated area, indicated no contaminant, as did the results for a sample of clay floor tile (16-FLOOR-20) collected about 2 ft west of sample 16-FLOOR-17. This later sample had been collected to provide a measurement of normal background concentrations of radionuclides within the clay tile. Results of analyses of sample 16-C-18, from the concrete floor slab, and sample 16-GRAVEL-19, from directly beneath the concrete slab, indicated ^{60}Co concentrations of 0.1 ± 0.02 and 1.0 ± 0.1 pCi/g, respectively. Analyses indicated ^{60}Co was the only contaminant.

Results of analyses of sample 16-FLOOR-21, consisting of asphalt floor tile from the Building 7 Clean Locker Room, did not identify the contaminant involved at contaminated area #5. As mentioned previously, this could be due to the presence of other than higher energy x- or gamma-emitting contaminants. Additionally, concentrations of these or uranium could have remained in the archived or unused portions of the sample. This sample was collected at the time of removal of the contaminated area.

Storm Drain Outfall - While the survey in the Building 8 Advanced Fuels Laboratory was being conducted, the survey team noticed that a drinking fountain within the lab drained into a 6-in-diameter storm drain pipe leading down from the roof. This pipe passed through the room near the south wall, connecting the roof drain system to the underground vitrified clay pipe (VCP) of the storm drain system. The storm drain outfall from this system's 18-in-diameter VCP was located about 300 ft west of Building 8. Results of analyses of the sand and gravel sample (16-GRAVEL-22) collected from the outfall indicated normal background concentrations only.

Drain Lines - Results of analyses of sample 16-SS-1, a dirt/sludge sample from the Building 7 High-Bay floor drain at contaminated area #3, indicated concentrations of 62.3 ± 6.2 pCi/g for enriched uranium (0.95% ^{235}U), 175 ± 30 fCi/g for $^{239,240}\text{Pu}$, 40 ± 20 fCi/g for ^{238}Pu , and 110 ± 40 fCi/g for ^{241}Am . Results of analyses of sample 16-SS-14, a dirt/sludge sample from the Building 7 Low-Bay floor drain, indicated 46.0 ± 4.6 pCi/g for enriched uranium (3.33% ^{235}U), 145 ± 20 fCi/g for $^{239,240}\text{Pu}$, 20 ± 10 fCi/g for ^{238}Pu , and 63 ± 10 fCi/g for ^{241}Am . Results of analyses of sample 16-W-15, a drain water sample collected from a Sodium (Na) Laboratory drain pipe in Building 7, indicated concentrations of 4000 ± 400 $\mu\text{g}/\ell$ for uranium (2700 ± 270 pCi/ ℓ as normal uranium), 48 ± 4 pCi/ ℓ for $^{239,240}\text{Pu}$, and 3 ± 1 pCi/ ℓ for ^{238}Pu . Results of analyses of sample 16-W-16, a drain water sample from the Building 7 Shower Room drain, indicated concentrations of 4000 ± 400 $\mu\text{g}/\ell$ for uranium (2700 ± 270 pCi/ ℓ as normal uranium), 880 ± 70 pCi/ ℓ for $^{239,240}\text{Pu}$, and 30 ± 10 pCi/ ℓ for ^{238}Pu . All the reported concentrations of uranium, plutonium, and americium in the Building 7 drain line samples are far above normally expected background concentrations in water and sludge, and indicated that the drain lines are contaminated.

CONCLUSIONS

The post-remedial-action radiological assessment conducted by the ANL Radiological Survey Group in October 1981, following decommissioning and decontamination efforts by Westinghouse personnel, indicated that except for the Advanced Fuels Laboratory exhaust ductwork and north wall, the interior surfaces of the Plutonium Laboratory and associated areas within Building 7 and the Advanced Fuels Laboratory within Building 8 were below both the ANSI Draft Standard N13.12 and NRC Guideline criteria for acceptable surface contamination levels. Hence, with the exceptions noted above, the interior surfaces of those areas within Buildings 7 and 8 that were included in the assessment are suitable for unrestricted use. No inferences are intended regarding the radiological conditions in those areas not surveyed. Westinghouse personnel intended to dismantle the exhaust ductwork and dispose of it as solid radioactive waste. Upon completion of the decommissioning and decontamination being performed beyond the north wall in the Analytical Chemistry Laboratory and Instrument Analysis Laboratory, the north wall will require a resurvey.

Air samples collected at the involved areas within Buildings 7 and 8 indicated that the radon, thoron, and progeny concentrations within the air were well below the limits prescribed by the U.S. Surgeon General, the Environmental Protection Agency, and the Department of Energy. No actinon progeny or long-lived radionuclides were detected on any air sample.

The Building 7 drain lines are contaminated with uranium, plutonium, and americium. The NRC guidelines for decontamination of facilities and equipment state that radioactivity on the interior surfaces of drain lines shall be determined by making measurements at all traps and appropriate access points (see Appendix 6). Radiochemical analysis of water and dirt/sludge samples collected from accessible Low-Bay, High-Bay, Shower Room, and Sodium Laboratory drains revealed uranium, plutonium, and americium contaminants. The Building 7 drain lines hence are unsuitable for release for unrestricted use in their present condition.

Low levels of enriched uranium, plutonium, and americium were detected in an environmental soil coring near Building 8, indicating release or spillage due to Advanced Reactors Division activities or Nuclear Fuel Division activities under NRC licensure. The extent of the release or spillage is unknown. ⁶⁰Co contamination was detected within the Building 7 Shower Room and in soil corings

from the environs of Building 7. This contamination apparently was related to activities conducted within Building 9, which is located to the east of Building 7, and was unrelated to Advanced Reactors Division activities. All other radionuclide concentrations measured in soil corings and the storm sewer outfall sample collected from the environs about Buildings 7 and 8 were within the range of normally expected background concentrations.

REFERENCE

1. Holden, N.E. 1977. "Isotopic Composition of the Elements and Their Variation in Nature: A Preliminary Report." BNL-NCS-50605. Brookhaven National Laboratory.

Figure 1 Site Location

Figure 2 Overall Site Plan

Figure 3 Building 7 Survey and Sampling Locations.
ANL-HP Dwg, No. 83-75

Figure 4 Building 7 Environs. ANL-HP Dwg.
No. 83-74

Figure 5 Building 8 Survey and Sampling Locations.
ANL-HP Dwg. No. 83-73

Figure 6 Environmental Soil Sampling Processing.
ANL-HP Dwg. No. 78-2a.

Table 1

DATA SHEET OF AREA SURVEYS

Room or Area No.	Percent of Area Accessible for Survey			PAC 4G-3 Direct Readings ^a (dis/min-100 cm ²)		Contact Exposure Rate (mR/h)	PRM-7 (μ R/h) 1 meter	PG-2 Low Energy α & γ (cts/min)	Smear Results (dis/min-100 cm ²)	Comments
	Floor	Wall	Over-head	Beta	Alpha					
<u>Building 7</u>										
Air Lock Entrance to Plutonium Lab	100	100	100	BKGD ^b	BKGD	NRR ^c	BKGD	BKGD	BKGD	Smears 317-334
Plutonium Laboratory	100	100	100	BKGD	BKGD	NRR	4	BKGD	NST ^d	Near temporary Cambridge absolute filters
				BKGD	BKGD	NRR	BKGD	BKGD	BKGD	Rest of survey was BKGD; smears 50-139
Crawl Space over Vault, Hot Dress Room, Entrance Room	80	80	80							Accessible from, and open to, the Plutonium Lab.
				4x10 ²	BKGD	BKGD	4	2x10 ³	BKGD	Location 278, along east wall, due to shine from Building 9 ⁶⁰ Co.
				BKGD	BKGD	NRR	BKGD	BKGD	BKGD	Rest of survey was BKGD; smears 279-300
Entrance Room	100	100	100	BKGD	BKGD	NRR	NRR	BKGD	BKGD	Smears 48, 140-151

Table 1

DATA SHEET OF AREA SURVEYS

Room or Area No.	Percent of Area Accessible for Survey			PAC 4G-3 Direct Readings ^a (dis/min-100 cm ²)		Contact Exposure Rate (mR/h)	PRM-7 (μ R/h) 1 meter	PG-2 Low Energy α & γ (cts/min)	Smear Results (dis/min-100 cm ²)	Comments
	Floor	Wall	Over-head	Beta	Alpha					
Vault	100	100	100	BKGD	BKGD	NRR	6	BKGD	BKGD	Locations 161-162 near emergency exit along east wall, due to shine from Building 9 ⁶⁰ Co.
				BKGD	BKGD	NRR	BKGD	BKGD	BKGD	Rest of survey was BKGD; smears 152-160; 163-173
Hot Dress Room	100	100	100	BKGD	BKGD	NRR	NRR	5x10 ²	BKGD	Interpreted as BKGD with glazed tile walls; smears 174-185
Shower Room	100	100	100	850	BKGD	NRR	NRR	2x10 ³	BKGD	Smear 192, contaminated area (#4) beneath east floor.
				NRR	NRR	NRR	NRR	3.5x10 ³	NST	Same area after removal of clay baseboard at east wall
				3.9x10 ³	BKGD	NRR	NRR	5.5x10 ³	NST	Same area after removal of clay floor tiles (see 16-FLOOR-17).
				NRR	NRR	0.08	NRR	8.5x10 ³	BKGD	Same area after removal of concrete floor slab, smear 335 (see 16-C-18 and 16-GRAVEL-19).

TABLE 1

DATA SHEET OF AREA SURVEYS

Room or Area No.	Percent of Area Accessible for Survey			PAC 4G-3 Direct Readings ^a (dis/min-100 cm ²)		Contact Exposure Rate (mR/h)	PRM-7 (pR/h) 1 meter	PG-2 Low Energy α & γ (cts/min)	Smear Results (dis/min-100 cm ²)	Comments
	Floor	Wall	Over head	Beta	Alpha					
Shower Room (cont'd.)				BKGD	BKGD	NRR	NRR	1x10 ³	BKGD	Rest of survey interpreted as BKGD with clay tile (see 16-FLOOR-20 and 16-W-16) Smears 186-191, 193
Slop Sink Room	90	70	100	BKGD	BKGD	NRR	NRR	BKGD	BKGD	
Clean Locker Room	90	90	100	5.9x10 ²	BKGD	NRR	NRR	BKGD	BKGD	
				BKGD	BKGD	NRR	NRR	BKGD	BKGD	Smear 336, contaminated area (#5) on asphalt tile floor (see 16-FLOOR-21).
				BKGD	BKGD	NRR	NRR	BKGD	BKGD	Rest of survey was BKGD; smears 200-226
Dark Room	100	100	100	BKGD	BKGD	NRR	BKGD	BKGD	BKGD	Smears 1-40
Low-Bay	100	100	-	6.4x10 ³	BKGD	0.03	BKGD	1x10 ²	BKGD	Contaminated area (#1) on epoxied floor; equated to normal U; smear 41 (see 16-PAINT-2)
				3.2x10 ³	BKGD	BKGD	BKGD	BKGD	BKGD	Contaminated area (#2) on epoxied floor; equated to normal U; smear 42.
				BKGD	BKGD	NRR	BKGD	BKGD	NST	Rest of survey was BKGD (see 16-SS-14).

Table 1

DATA SHEET OF AREA SURVEYS

Room or Area No.	Percent of Area Accessible for Survey			PAC 4G-3 Direct Readings ^a (dis/min-100 cm ²)		Contact Exposure Rate (mR/h)	PRM-7 (μR/h) 1 meter	PG-2 Low Energy x & γ (cts/min)	Smear Results (dis/min-100 cm ²)	Comments
	Floor	Wall	Over-head	Beta	Alpha					
Sodium (Na) Laboratory	100	100	100	BKGD	BKGD	NRR	NRR	BKGD	BKGD	Smears 227-265, 301-316.
				BKGD	BKGD	NRR	NRR	BKGD	BKGD	Smear 47 from drain line (see 16-W-15)
Corridor	100	100	-	BKGD	BKGD	NRR	NRR	BKGD	BKGD	Smears 266-277
High-Bay	50	70	-	5.3x10 ²	3.4x10 ²	BKGD	2	5x10 ²	BKGD	Contaminated area (#3) in floor drain, equated to normal U, smear 45 (see 16-SS-1).
				BKGD	BKGD	NRR	NRR	BKGD	BKGD	Rest of survey was BKGD; smear 46.
Office Areas and Uranium Oxide Lab				-	-	-	-	-	-	Excluded from survey.
Environs of Bldg. 7	100	-	-	3x10 ⁴	BKGD	0.3	NRR	to 4x10 ⁴	NST	Contaminated area (#6) on soil east of Building 7 (see 16-S-6 & 7).
				BKGD	BKGD	NRR	NRR	BKGD ^b	NST	Rest of survey was BKGD (see 16-S-3 to 5).

Table 1

DATA SHEET OF AREA SURVEYS

Room or Area No.	Percent of Area Accessible for Survey			PAC 4G-3 Direct Readings ^a (dis/min-100 cm ²)		Contact Exposure Rate (mR/h)	PRM-7 (μ R/h) 1 meter	PG-2 Low Energy α & γ (cts/min)	Smear Results (dis/min-100 cm ²)	Comments
	Floor	Wall	Over-head	Beta	Alpha					
<u>Building 8</u>										
Advanced Fuels Laboratory	100	100	100	4.7x10 ²	9.8x10 ²	0.01	NRR	9.3x10 ³	$\alpha=8^e$ $\beta\gamma=BKGD$	Contaminated area (#7) on concrete floor, smear 337
				2.9x10 ³	1.4x10 ⁴	NRR	NRR	BKGD	$\alpha=to 10$ $\beta\gamma=BKGD$	Interior of exhaust duct; smears 401-402, 404, 412 --Exception Taken--
				NRR	NRR	NRR	to 1x10 ²	to 4x10 ⁴	-	(at the) north wall, due to source vaults, drums, and glove boxes beyond the wall in Analytical and Instrument Analysis Laboratories.
				NRR	NRR	NRR	to 8	to 2.6x10 ⁴	BKGD	(at the) north wall, after the removal of source vaults and drums to Storage Addition; smears 403, 405-411, 413-423 -- Exception Taken --
				NRR	NRR	NRR	NRR	8x10 ³	$\alpha=9$ $\beta\gamma=BKGD$	Slop sink drain pipe in the north wall; smear 435
				BKGD	BKGD	NRR	BKGD	BKGD	BKGD	Rest of survey was BKGD; smears 338-400, 424-434
Environs near each soil sample taken	100	-	-	BKGD	BKGD	NRR	NRR	BKGD	NST	16-S-8 to 12

TABLE 2

DATA SHEET OF AREA SURVEYS AFTER FURTHER DECONTAMINATION

Room or Area No.	Percent of Area Accessible for Survey			PAC 4G-3 Direct Readings ^a (dis/min-100 cm ²)		Contact Exposure Rate (mR/h)	PRM-7 (μR/h) 1 meter	PG-2 Low Energy x & γ (cts/min)	Smear Results (dis/min-100 cm ²)	Comments
	Floor	Wall	Over-head	Beta	Alpha					
Building 7										
Low-Bay	100	100	-	BKGD	3.4x10 ²	BKGD	BKGD	BKGD	BKGD	Contaminated area (#1) after further D&D, equated to normal U; smear 43.
				4.2x10 ³	3.4x10 ²	BKGD	BKGD	2.5x10 ²	BKGD	Contaminated area (#2) after further D&D, equated to normal U; smear 44.
High-Bay	50	70	-	5.3x10 ²	3.3x10 ²	BKGD	2	5x10 ²	BKGD	Contaminated area (#3) in drain line, remained (see 16-SS-1)
Shower Room	100	100	100	3.9x10 ³	BKGD	0.08	NRR	8.5x10 ³	BKGD	Contaminated area (#4), ⁶⁰ Co beneath shower room floor, remained (see 16-GRAVEL-19)
Clean Locker Room	90	90	100	BKGD	BKGD	NRR	NRR	BKGD	NST	Contaminated area (#5) was removed.
Environs	100	-	-	3.0x10 ⁴	BKGD	0.3	NRR	to 4x10 ⁴	NST	Contaminated area (#6), ⁶⁰ Co-contaminated soil east of Building 7, remained (see 16-S-6 & 7).

TABLE 2

DATA SHEET OF AREA SURVEYS AFTER FURTHER DECONTAMINATION

Room or Area No.	Percent of Area Accessible for Survey			PAC 4G-3 Direct Readings ^a (dis/min-100 cm ²)		Contact Exposure Rate (mR/h)	PRM-7 (μ R/h) 1 meter	PG-2 Low Energy x & γ (cts/min)	Smear Results (dis/min- 100 cm ²)	Comments
	Floor	Wall	Over- head	Beta	Alpha					
<u>Building 8</u>										
Advanced Fuels Laboratory	100	100	100	BKGD	BKGD	NRR	BKGD	BKGD	NST	Contaminated area (#7), on concrete floor, was removed.
				2.9x10 ³	1.4x10 ⁴	NRR	NRR	BKGD	α =to 10 $\beta\gamma$ =BKGD	Contaminated interior of exhaust duct remained -- Exception Taken --
				NRR	NRR	NRR	to 8	to 2.6x10 ⁴	α =to 9 $\beta\gamma$ =BKGD	Elevated readings at the north wall -- Exception Taken --

FOOTNOTES FOR TABLES 1 AND 2

^aThe beta mode direct readings and alpha mode direct readings are taken with PAC-4G-3 instruments (see Appendix 1). The beta mode detects both electromagnetic and particulate radiation. If an area indicated an instrument reading higher than background, a beta mode reading was obtained. The instrument was then switched to the alpha mode, and a reading of the alpha contamination was obtained. In the alpha mode, the instrument only responds to particles with high specific ionization, such as alpha particles. The beta mode readings are compensated for any alpha contribution by subtracting the alpha mode reading from the beta mode reading.

^bBKGD = Background. The following are the instrument background readings:

<u>Instrument</u>	<u>Beta Mode</u>	<u>Alpha Mode</u>
PAC-4G-3 with 51 cm ² probe	150-350 cts/min-51 cm ²	0-50 cts/min-51 cm ²
PAC-4G-3 with 330 cm ² probe	350-400 cts/min-330 cm ²	0-50 cts/min-330 cm ²
PAC-4G-3 with 470 cm ² probe	1.5 k - 2 k cts/min-470 cm ²	0-50 cts/min-470 cm ²
PC-5 or 3A	43 ± 3 cts/min*	0.2 ± 0.2 cts/min*
10-Wire	464 ± 14 cts/min*	1.9 ± 0.6 cts/min*
GM End Window	0.01-0.02 mR/h	
PRM-7	5-8 µR/h	
PG-2 with PRM-5-3	500-1.5 k cts/min, indoors 1.5 k-2 k cts/min, outdoors	

^cNRR = No Reading Recorded.

^dNST = No Smear Taken.

^e_α = Alpha

_{βγ} = Beta-gamma (The beta-gamma readings are compensated for any alpha contribution by subtracting the alpha reading from the beta-gamma reading.)

* ± 2σ due to counting statistics alone.

TABLE 3

AMBIENT PENETRATING RADIATION MEASUREMENTS

Location	RSS-111 Integrated Exposure (μR) ^a	Period of Integration (hr)	Exposure Rate ($\mu\text{R/h}$) ^a
<u>Building 7</u>			
Dark Room	66	6.55	10.1
Plutonium Laboratory	408	41.6	9.8
Sodium (Na) Laboratory	218	23.12	9.4
Low-Bay	97	10.02	9.7
Clean Locker Room	166	13.7	12.1
<u>Building 8</u>			
Advanced Fuels Labora- tory-West	111	12.77	8.7
Advanced Fuels Labora- tory-East	96	11.33	8.5

^aOne meter above ground.

TABLE 4

RADON DAUGHTER DETERMINATIONS

Location	Figure	^{222}Rn (Radon) Daughter Concentration ($\times 10^{-3}$ WL ^a)	^{220}Rn (Thoron) Daughter Concentration (pCi/l)	^{219}Rn (Actinon) Daughter Concentration (pCi/l)
<u>Building 7</u>				
Plutonium Laboratory	3	0.36	6.4×10^{-4}	BDL ^b
Dark Room	3	1.2	-	NS ^c
Sodium (Na) Laboratory	3	0.15	8.6×10^{-4}	NS
<u>Building 8</u>				
Advanced Fuels Laboratory	5	0.41	9.7×10^{-4}	BDL

^aWL, a Working Level (WL) is defined as any combination of short-lived radon-decay products in 1 liter of air that will result in the ultimate emission of 1.3×10^5 MeV of potential alpha energy. The numerical value of the WL is derived from the alpha energy released by the total decay through RaC' of the short-lived radon-daughter products, RaA, RaB, and RaC at radioactive equilibrium with 100 pCi of ^{222}Rn per liter of air.

^bBDL = Below Detection Limit.

^cNS = Not Sampled.

TABLE 5

SOIL AND MATERIAL SAMPLE WEIGHTS
(grams)

Sample Number	Wet Weight	Dry Weight	Sieved Weight	Rocks and Dross
16-SS-1	77	58	38	17
16-PAINT-2	-	7 (ashed)	-	-
16-S-3A	480	379	328	46
16-S-3B	662	554	505	41
16-S-3C	921	797	743	50
16-S-3D	3016	2532	1508	898
16-S-4A	744	698	439	255
16-S-4B	794	737	336	396
16-S-4C	1095	999	364	627
16-S-4D	4889	4504	1106	3385
16-S-5A	587	416	251	149
16-S-5B	786	633	421	202
16-S-5C	798	652	458	185
16-S-5D	2428	1973	1501	461
16-S-6A	667	589	256	228
16-S-6B	630	505	417	81
16-S-6C	746	625	543	75
16-S-6D	2704	2359	1349	1005
16-S-7A	685	510	377	126
16-S-7B	594	485	457	23
16-S-7C	735	618	570	39
16-S-7D	3626	3160	1581	1568
16-S-8A	526	418	357	56
16-S-8B	744	630	600	24
16-S-8C	976	853	661	186
16-S-8D	3576	3247	1300	1939
16-S-9A	627	504	347	144
16-S-9B	755	647	429	217
16-S-9C	908	794	419	372
16-S-9D	3951	3552	1587	1867

TABLE 5
(cont'd.)

Sample Number	Wet Weight	Dry Weight	Sieved Weight	Rocks and Dross
16-S-10A	969	887	273	615
16-S-10B	711	644	317	325
16-S-10C	1265	1186	316	866
16-S-10D	4031	3785	654	3126
16-S-11A	282	138	78	54
16-S-11B	756	605	366	236
16-S-11C	733	615	318	292
16-S-11D	3305	2742	1149	1569
16-S-12A	1033	946	252	653
16-S-12B	1562	1399	412	981
16-S-12C	1889	1695	851	826
16-S-12D	3889	3396	1595	1781
16-S-13A	760	610	450	156
16-S-13B	801	691	366	317
16-S-13C	861	769	453	305
16-S-13D	3174	2820	1591	1180
16-SS-14	321	210	90	110
16-W-15	125 ml	18 (sediment)	-	-
16-W-16	125 ml	17 (sediment)	-	-
16-FLOOR-17	762 (ground up)	-	-	-
16-C-18	696 (ground up)	-	-	-
16-GRAVEL-19	1196	1140 (ground up)	-	-
16-FLOOR-20	763 (ground up)	-	-	-
16-FLOOR-21	113 (ground up)	-	-	-
16-GRAVEL-22	1285	952	137	812

TABLE 6

GAMMA-SPECTRAL AND URANIUM-FLUOROMETRIC ANALYSIS OF SAMPLES

Sample Number	Gamma Spectra, pCi/g $\pm \sigma^a$				Uranium Fluorometric ^b	
	¹³⁷ Cs	⁶⁰ Co ^c	²³² Th	²²⁶ Ra	$\mu\text{g/g} \pm 10\%$	pCi/g $\pm 10\%$
			Decay Chain	Decay Chain		
ENVIRONMENTAL SOIL CORINGS						
16-S-3A	0.49 $\pm$ 0.04	0.14 $\pm$ 0.02	1.08 $\pm$ 0.07	1.15 $\pm$ 0.08	2.8 $\pm$ 0.28	1.9 $\pm$ 0.19
16-S-3B	0.34 $\pm$ 0.03	0.13 $\pm$ 0.02	1.29 $\pm$ 0.08	1.22 $\pm$ 0.08	2.5 $\pm$ 0.25	1.7 $\pm$ 0.17
16-S-3C	<0.03	BDL ^d	0.81 $\pm$ 0.06	0.84 $\pm$ 0.06	2.2 $\pm$ 0.22	1.5 $\pm$ 0.15
16-S-3D	<0.03	BDL	0.92 $\pm$ 0.06	1.12 $\pm$ 0.08	2.1 $\pm$ 0.21	1.4 $\pm$ 0.14
16-S-4A	0.03 $\pm$ 0.02	BDL	0.44 $\pm$ 0.07	0.59 $\pm$ 0.04	1.2 $\pm$ 0.12	0.82 $\pm$ 0.08
16-S-4B	0.10 $\pm$ 0.03	BDL	0.91 $\pm$ 0.06	1.29 $\pm$ 0.09	2.3 $\pm$ 0.23	1.6 $\pm$ 0.16
16-S-4C	0.05 $\pm$ 0.02	BDL	1.37 $\pm$ 0.10	2.30 $\pm$ 0.16	4.4 $\pm$ 0.44	3.0 $\pm$ 0.30
16-S-4D	<0.03	BDL	1.32 $\pm$ 0.10	2.34 $\pm$ 0.17	5.2 $\pm$ 0.52	3.5 $\pm$ 0.35
16-S-5A	0.76 $\pm$ 0.05	0.37 $\pm$ 0.04	1.27 $\pm$ 0.09	1.34 $\pm$ 0.09	3.0 $\pm$ 0.30	2.0 $\pm$ 0.20
16-S-5B	0.37 $\pm$ 0.04	0.14 $\pm$ 0.02	1.37 $\pm$ 0.10	1.56 $\pm$ 0.11	2.4 $\pm$ 0.24	1.6 $\pm$ 0.16
16-S-5C	0.46 $\pm$ 0.04	BDL	1.25 $\pm$ 0.08	1.63 $\pm$ 0.11	2.3 $\pm$ 0.23	1.6 $\pm$ 0.16
16-S-5D	0.15 $\pm$ 0.03	0.49 $\pm$ 0.05	1.32 $\pm$ 0.10	1.59 $\pm$ 0.11	2.1 $\pm$ 0.21	1.4 $\pm$ 0.14
16-S-6A	1.34 $\pm$ 0.08	279 $\pm$ 28	BDL	BDL	2.5 $\pm$ 0.25	1.7 $\pm$ 0.17
16-S-6B	0.68 $\pm$ 0.05	207 $\pm$ 21	BDL	1.60 $\pm$ 0.11	2.3 $\pm$ 0.23	1.6 $\pm$ 0.16
16-S-6C	0.24 $\pm$ 0.03	87 $\pm$ 9	BDL	1.08 $\pm$ 0.07	2.3 $\pm$ 0.23	1.6 $\pm$ 0.16
16-S-6D	0.11 $\pm$ 0.03	15 $\pm$ 2	1.15 $\pm$ 0.08	1.15 $\pm$ 0.08	2.0 $\pm$ 0.20	1.4 $\pm$ 0.14
16-S-7A	0.68 $\pm$ 0.05	4.33 $\pm$ 0.4	1.71 $\pm$ 0.12	1.64 $\pm$ 0.11	2.7 $\pm$ 0.27	1.8 $\pm$ 0.18
16-S-7B	0.40 $\pm$ 0.04	1.44 $\pm$ 0.1	1.10 $\pm$ 0.08	2.02 $\pm$ 0.14	2.4 $\pm$ 0.24	1.6 $\pm$ 0.16
16-S-7C	0.12 $\pm$ 0.04	0.56 $\pm$ 0.06	1.21 $\pm$ 0.08	1.58 $\pm$ 0.11	2.2 $\pm$ 0.22	1.5 $\pm$ 0.15
16-S-7D	0.05 $\pm$ 0.02	BDL	1.43 $\pm$ 0.10	1.45 $\pm$ 0.10	2.1 $\pm$ 0.21	1.4 $\pm$ 0.14

Table 6
(cont'd.)

Sample Number	Gamma Spectra, pCi/g $\pm \sigma^a$				Uranium Fluorometric	
	^{137}Cs	$^{60}\text{Co}^c$	^{232}Th	^{226}Ra	$\mu\text{g/g} \pm 10\%$	pCi/g $\pm 10\%^b$
			Decay Chain	Decay Chain		
ENVIRONMENTAL SOIL CORINGS - (cont'd.)						
16-S-8A	0.31 $\pm$ 0.03	BDL	1.25 $\pm$ 0.09	1.96 $\pm$ 0.14	2.3 $\pm$ 0.23	1.6 $\pm$ 0.16
16-S-8B	0.14 $\pm$ 0.02	BDL	1.08 $\pm$ 0.07	1.67 $\pm$ 0.12	2.1 $\pm$ 0.21	1.4 $\pm$ 0.14
16-S-8C	<0.03	BDL	1.26 $\pm$ 0.09	1.49 $\pm$ 0.11	1.9 $\pm$ 0.19	1.3 $\pm$ 0.13
16-S-8D	<0.03	BDL	1.21 $\pm$ 0.08	1.46 $\pm$ 0.10	1.9 $\pm$ 0.19	1.3 $\pm$ 0.13
16-S-9A	0.30 $\pm$ 0.02	0.17 $\pm$ 0.03	0.91 $\pm$ 0.06	1.31 $\pm$ 0.09	2.7 $\pm$ 0.27	1.8 $\pm$ 0.18
16-S-9B	0.12 $\pm$ 0.04	BDL	1.04 $\pm$ 0.07	1.20 $\pm$ 0.08	3.0 $\pm$ 0.30	2.0 $\pm$ 0.20
16-S-9C	<0.03	BDL	1.01 $\pm$ 0.07	1.25 $\pm$ 0.08	2.1 $\pm$ 0.21	1.4 $\pm$ 0.14
16-S-9D	0.04 $\pm$ 0.02	BDL	0.92 $\pm$ 0.06	0.93 $\pm$ 0.06	2.0 $\pm$ 0.20	1.4 $\pm$ 0.14
16-S-10A	0.56 $\pm$ 0.06	BDL	0.88 $\pm$ 0.06	2.00 $\pm$ 0.14	5.2 $\pm$ 0.52	3.5 $\pm$ 0.35 ^b
16-S-10B	0.10 $\pm$ 0.03	BDL	0.87 $\pm$ 0.06	1.38 $\pm$ 0.10	8.1 $\pm$ 0.81	6.4 $\pm$ 0.64 ^b
16-S-10C	0.07 $\pm$ 0.03	BDL	0.66 $\pm$ 0.07	1.13 $\pm$ 0.08	3.5 $\pm$ 0.35	2.4 $\pm$ 0.24
16-S-10D	0.10 $\pm$ 0.03	BDL	0.96 $\pm$ 0.07	1.27 $\pm$ 0.09	5.2 $\pm$ 0.52	3.5 $\pm$ 0.35
16-S-11A	1.23 $\pm$ 0.08	BDL	0.50 $\pm$ 0.08	1.51 $\pm$ 0.11	2.4 $\pm$ 0.24	1.6 $\pm$ 0.16
16-S-11B	0.27 $\pm$ 0.03	BDL	1.15 $\pm$ 0.08	1.62 $\pm$ 0.11	2.0 $\pm$ 0.20	1.4 $\pm$ 0.14
16-S-11C	0.05 $\pm$ 0.02	BDL	1.26 $\pm$ 0.09	1.52 $\pm$ 0.11	1.9 $\pm$ 0.19	1.3 $\pm$ 0.13
16-S-11D	<0.03	BDL	1.41 $\pm$ 0.10	1.46 $\pm$ 0.10	2.2 $\pm$ 0.22	1.5 $\pm$ 0.15
16-S-12A	0.21 $\pm$ 0.04	BDL	0.68 $\pm$ 0.07	1.62 $\pm$ 0.11	5.4 $\pm$ 0.54	3.7 $\pm$ 0.37
16-S-12B	0.07 $\pm$ 0.03	BDL	0.69 $\pm$ 0.07	1.41 $\pm$ 0.10	3.4 $\pm$ 0.34	2.3 $\pm$ 0.23
16-S-12C	0.06 $\pm$ 0.03	BDL	0.95 $\pm$ 0.07	1.07 $\pm$ 0.07	2.1 $\pm$ 0.21	1.4 $\pm$ 0.14
16-S-12D	0.03 $\pm$ 0.02	BDL	1.33 $\pm$ 0.09	1.09 $\pm$ 0.08	1.9 $\pm$ 0.19	1.3 $\pm$ 0.13

TABLE 6
(cont'd.)

Sample Number	Gamma Spectra, pCi/g $\pm \sigma^a$				Uranium Fluorometric	
	^{137}Cs	$^{60}\text{Co}^c$	^{232}Th Decay Chain	^{226}Ra Decay Chain	$\mu\text{g/g} \pm 10\%$	pCi/g $\pm 10\%^b$
BACKGROUND ENVIRONMENTAL SOIL CORINGS						
16-SB13-A	0.08 $\pm$ 0.03	BDL	1.25 $\pm$ 0.09	1.40 $\pm$ 0.10	2.0 $\pm$ 0.20	1.4 $\pm$ 0.14
16-SB13-B	<0.03	BDL	1.28 $\pm$ 0.09	1.16 $\pm$ 0.08	2.0 $\pm$ 0.20	1.4 $\pm$ 0.14
16-SB13-C	<0.03	BDL	1.02 $\pm$ 0.07	1.24 $\pm$ 0.08	1.8 $\pm$ 0.18	1.2 $\pm$ 0.12
16-SB13-D	0.04 $\pm$ 0.02	BDL	0.92 $\pm$ 0.07	1.05 $\pm$ 0.07	2.0 $\pm$ 0.20	1.4 $\pm$ 0.14
SURFACE AND STRUCTURAL MATERIAL						
16-PAINT-2	<0.03	BDL	0.20 $\pm$ 0.06	0.70 $\pm$ 0.07	294.0 $\pm$ 29.4	200.0 $\pm$ 20.0
16-FLOOR-17	<0.03	BDL	0.44 $\pm$ 0.07	0.72 $\pm$ 0.05	1.9 $\pm$ 0.19	1.3 $\pm$ 0.13
16-C-18	<0.03	0.1 $\pm$ 0.02	0.20 $\pm$ 0.06	0.58 $\pm$ 0.04	0.93 $\pm$ 0.093	0.63 $\pm$ 0.063
16-GRAVEL-19	0.09 $\pm$ 0.04	1.0 $\pm$ 0.1	0.79 $\pm$ 0.06	0.80 $\pm$ 0.06	1.6 $\pm$ 0.16	1.1 $\pm$ 0.11
16-FLOOR-20	<0.03	BDL	1.63 $\pm$ 0.11	1.17 $\pm$ 0.08	2.2 $\pm$ 0.22	1.5 $\pm$ 0.15
16-FLOOR-21	0.08 $\pm$ 0.03	BDL	<0.06	0.31 $\pm$ 0.02	1.3 $\pm$ 0.13	0.88 $\pm$ 0.088
STORM DRAIN OUTFALL						
16-GRAVEL-22	0.37 $\pm$ 0.04	BDL	0.25 $\pm$ 0.07	0.58 $\pm$ 0.04	1.9 $\pm$ 0.19	1.3 $\pm$ 0.13
DRAIN LINES OF BUILDING 7 - SEWER SLUDGE						
16-SS-1	<0.03	2.97 $\pm$ 0.3	2.03 $\pm$ 0.14	2.57 $\pm$ 0.19	85.9 $\pm$ 8.59	62.3 $\pm$ 6.23 ^b
16-SS-14	0.12 $\pm$ 0.04	1.27 $\pm$ 0.1	0.74 $\pm$ 0.05	1.55 $\pm$ 0.11	29.2 $\pm$ 2.92	46.0 $\pm$ 4.60 ^b
DRAIN LINES OF BUILDING 7 - SEWER WATER						
			(pCi/l $\pm \sigma^a$)		($\mu\text{g/l} \pm 10\%$)	(pCi/l $\pm 10\%$)
16-W-15	<30	140 $\pm$ 30	<60	190 $\pm$ 30	4000 $\pm$ 400	2700 $\pm$ 270
16-W-16	<30	<30	140 $\pm$ 50	90 $\pm$ 30	4000 $\pm$ 400	2700 $\pm$ 270

TABLE 6
(cont'd.)

^aOne standard deviation due to counting statistics.

^bConversion of μg to pCi per Appendix 5. The conversion factor for 16-S-10B is 0.787 pCi per μg ; for 16-SS-1 is 0.725 pCi per μg ; for 16-SS-14 is 1.576 pCi per μg ; and for all other samples is 0.68 pCi per μg .

^cConcentration of ^{60}Co (with a 5.27-year half-life) are reported as of March 1982, the time of analyses.

^dBDL = Below Detection Limit.

TABLE 7

URANIUM MASS SPECTROMETRIC ANALYSIS
OF SELECTED SAMPLES

Sample Number	U Iostopic Abundances, Atom %				
	233	234	235	236	238
16-SS-1	<0.001	0.006	0.95	0.006	99.04
16-S-10B	<0.001	0.007	0.96	0.006	99.03
16-SS-14	<0.001	0.019	3.33	0.021	96.63

TABLE 8

PLUTONIUM AND AMERICIUM RADIOCHEMICAL ANALYSES
OF SELECTED SOIL AND MATERIAL SAMPLES

Sample Number	$^{239,240}\text{Pu}$ (fCi/g)	^{238}Pu (fCi/g)	^{241}Am (fCi/g)
ENVIRONMENTAL SOIL CORINGS			
16-S-6A	13 ± 6	< 5	< 5
16-S-9A	7 ± 4	< 3	< 5
16-S-10B	215 ± 20	100 ± 20	160 ± 30
16-S-13A	5 ± 5	5 ± 5	5 ± 5
SUBSURFACE OR STRUCTURAL MATERIAL			
16-PAINT-2	≤ 5	BDL ^a	NS ^b
STORM DRAIN OUTFALL			
16-GRAVEL-22	23 ± 5	≤ 3	BDL
DRAIN LINES - SEWER SLUDGE			
16-SS-1	175 ± 30	40 ± 20	110 ± 40
16-SS-14	145 ± 20	20 ± 10	63 ± 10
DRAIN LINES - SEWER WATER			
	(pCi/l)	(pCi/l)	(pCi/l)
16-W-15	48 ± 4	3 ± 1	NS
16-W-16	880 ± 70	30 ± 10	NS

^aBDL = Below Detection Limit.

^bNS = Not Sampled.

APPENDIX 1

INSTRUMENTATION

I. PORTABLE RADIATION SURVEY EQUIPMENT

A. Gas-Flow Proportional Survey Meters

The Eberline PAC-4G-3 was one of the primary instruments used for surveying. This instrument is a gas-flow proportional counter that utilizes a propane gas-proportional detector, 51 cm² (AC-21 hand-held probe), or 330 or 470 cm² (FM-4G) in effective area, with a thin, double-aluminized Mylar window (~ 0.85 mg/cm²).

Since this instrument has multiple high-voltage settings, it can be used to distinguish between alpha and beta-gamma contamination. This instrument was initially used with headphones in the beta mode. In that mode, the detector responds to alpha and beta particles and x- and gamma-rays. When areas indicated a higher count rate than the average instrument background, the beta-mode reading was recorded, and the instrument was then switched to the alpha mode to determine any alpha contribution. In the alpha mode, the instrument responds only to particles with high-specific ionization. This instrument is calibrated in the alpha mode with a flat-plate, infinitely thin, NBS-traceable ²³⁹Pu standard, and in the beta mode with a flat-plate, infinitely thin, NBS-traceable ⁹⁰Sr-⁹⁰Y standard. The PAC-4G-3 instruments are calibrated to an apparent 50% detection efficiency.

B. Beta-Gamma End Window Survey Meter

When an area of contamination was found with a PAC instrument, a reading was taken while using headphones with an Eberline Beta-gamma Geiger-Mueller Counter Model E-530 with a HP-190 probe. This probe has a thin mica end window and is, therefore, sensitive to alpha and beta particles and x- and gamma-rays. A thin piece of aluminum is added to the mica, thus making the window density ~7 mg/cm². At this density, the instrument is not sensitive to alpha particles. A maximum reading is obtained with the probe placed in contact with the area of contamination. In this position, the response (in mR/h) to gamma radiation is generally conservative relative to a determination of mrad/h at 1 cm; however, the response (in mR/h) to beta radiation is nonconservative by a factor of up to about four relative to a determination of mrad/h through 7 mg/cm². This instrument is calibrated in a good geometry configuration in mR/h with a ²²⁶Ra standard source.

C. Low-Energy Gamma Scintillation Survey Meter

An Eberline Pulse Rate Meter Model PRM-5-3 with a PG-2 low energy gamma scintillation detector was used with headphones to detect low-energy x and gamma radiation. The PG-2 detector consists of a thin NaI(Tl) scintillation crystal, 5 cm in diameter by 2 mm thick, with a 0.001-in (0.025-mm) thick aluminum window (~ 7 mg/cm²). This instrument is calibrated with a 25% window on three separate discriminators for three energy regions determined by NBS-traceable ²³⁹Pu (17 keV), ²⁴¹Am (59.5 keV), and ²³⁵U (185.7 keV) sources.

APPENDIX 1
(cont'd.)

The PRM-5-3 can be operated in either a pulse height analysis (PHA) mode or a gross mode of operation. In the PHA mode, it counts only those energies within the 25% energy window. The PRM-5-3 has three energy settings in the PHA mode, HV-1 (centered on 17 keV), HV-2 (centered on 59.5 keV), and HV-3 (centered on 185.7 keV). In the gross mode, the upper-level discriminator is removed, opening the window to all the higher energies. During the radiological survey, the PRM-5-3 was normally set to the HV-1 gross mode. The calibration was checked daily with an NBS-traceable ^{137}Cs - $^{137\text{m}}\text{Ba}$ gamma source.

D. High-Energy Micro-R Scintillation Survey Meter

An Eberline Micro-R meter, model PRM-7, was used to detect high-energy gamma radiation. This instrument contains an internally mounted NaI(Tl) scintillation crystal, 2.5-cm diameter by 2.5 cm thick, and can be used to measure fields of low-level radiation between 10 $\mu\text{R/h}$ and 5000 $\mu\text{R/h}$. This instrument is used with headphones to survey ambient penetrating radiation levels. It is normally held 1 m from the surface during survey. The NaI(Tl) detector is highly energy dependant. This instrument is calibrated with a ^{226}Ra standard source and checked daily with the ^{137}Cs - $^{137\text{m}}\text{Ba}$ gamma source.

E. Pressurized Ionization Chamber

In addition to the PRM-7, a pressurized ionization chamber (PIC), Reuter Stokes Model RSS-111, was used at selected locations to determine the ambient external penetrating radiation field in units of $\mu\text{R/h}$. The RSS-111 has three output modes; (1) instantaneous exposure rate digital display, (2) strip chart exposure rate readout, and (3) integrated exposure display. The chamber is mounted on a tripod, 1 m (~ 3 ft) above the surface and has a uniform energy response from about 0.2 MeV to about 4 MeV. A six-hour period of operation is usually sufficient to obtain integrated exposures (in μR) significant to at least two digits. The PIC is calibrated with an NBS-traceable ^{60}Co gamma source.

II. SMEAR COUNTING INSTRUMENTATION

An ANL-designed large area, 10-wire, gas-flow proportional detector connected to an Eberline Mini Scaler Model MS-2 was used to count multiple smears simultaneously. This detector has a large area (400 cm^2) double-aluminized Mylar window (~ 0.85 mg/cm^2) and uses P-10 (90% argon and 10% methane) as the counting gas. The metal sample holder for this detector has been machined to hold ten smear papers. This particular system consists of two Mini Scalers and two detectors. One is used to count in the alpha mode; the other is used in the beta mode. Up to ten samples can be counted simultaneously in each.

Any smear taken from a contaminated area was counted individually in a Nuclear Measurements Corporation PC-5 or 3A gas-flow proportional counter using a double-aluminized Mylar spun top (~0.85 mg/cm^2 window). This top is placed over non-conducting media (e.g., paper smears) to negate the dielectric effect and hence eliminate spurious counts. This counter also uses P-10 counting gas. Smears are counted in both the alpha and beta modes. This instrument is calibrated using NBS-traceable ^{239}Pu and ^{90}Sr - ^{90}Y sources.

APPENDIX 1 (cont'd.)

III. AIR-SAMPLING DEVICES

Air samples were collected using a commercially available (Filter Queen) vacuum cleaner modified by ANL for use as an air-sampling device. This device draws air through a filter medium at a flow rate of 40 m³/h. The filters consist of 200-cm² sheets of Hollingsworth-Vose HV-70-0.23 mm or LB5211-9 mil filter paper. The collection efficiency at these flow rates for 0.3- μ m particles is about 99.9%.

A separate air sample was taken with a Bell and Gossett positive displacement pump at a flow rate of about 20 liters/min (1 m³/h) through a Millipore membrane (0.5 to 0.8 μ m) filter paper for about one hour. An alpha spectrum can be acquired from a section of this filter paper sample. The ratio of actinon (²¹⁹Rn) daughters (6.62 MeV α , AcC) to radon (²²²Rn) daughters (7.69 MeV α , RaC') can be determined from this spectrum.

IV. GAMMA SPECTRAL INSTRUMENTATION

A Nuclear Data Multichannel Analyzer Model ND-66 with a 7.6-cm-diameter by 7.6-cm-thick NaI(Tl) scintillation crystal and the appropriate electronics, was used for determining gamma spectrum. Samples from contaminated areas were analyzed using this system to identify contaminating radionuclides. This instrument is calibrated with NBS-traceable gamma sources.

A Hyperpure Germanium (HPGe) detector (ORTEC - 17% efficiency right-circular cylinders) was used when gamma-ray analyses of greater resolution were required. This detector is coupled to the appropriate electronics and to a Nuclear Data Multichannel Analyzer (Model ND-60 or ND-66).

V. AVERAGE INSTRUMENT BACKGROUND READINGS

<u>Instrument</u>	<u>Beta Mode</u>	<u>Alpha Mode</u>
Eberline PAC-4G-3		
with 51 cm ² probe	150-350 cts/min-51 cm ²	0-50 cts/min-51 cm ²
with 330 cm ² probe	350-400 cts/min-330 cm ²	0-50 cts/min-330 cm ²
with 470 cm ² probe	1.5 k - 2 k cts/min-470 cm ²	0-50 cts/min-470 cm ²
PC-5 or 3A	43 $\pm$ 3 cts/min*	0.2 $\pm$ 0.2 cts/min*
10-Wire	464 $\pm$ 14 cts/min*	1.9 $\pm$ 0.6 cts/min*
End Window GM	0.01-0.02 mR/h	
PRM-7	5-8 μ R/h	
PG-2 with PRM-5-3	500-1.5 k cts/min, indoors	
	1.5 k-2 k cts/min, outdoors	

* $\pm 2\sigma$ due to counting statistics alone.

APPENDIX 2

CONVERSION FACTORS

I. INSTRUMENTATION

The factors used to convert the various instrument readings into units of disintegrations per minute per 100 cm² (dis/min-100 cm²) and the derivation of those factors are listed below.

A. Conversion Factors

	PAC-4G-3 with Hand Probe (AC-21)		Floor Monitor (FM-4G) (330/470 cm ²)	
	<u>Alpha</u>	<u>Beta</u>	<u>Alpha</u>	<u>Beta</u>
To 100 cm ²	1.96	1.96	0.30/0.21	0.30/0.21
dis/min per cts/min for ²³⁹ Pu	2	-	2	-
dis/min per cts/min for ⁹⁰ Sr- ⁹⁰ Y	-	2	-	2
dis/min per cts/min for normal uranium	3.5	2.7	-	-
dis/min per cts/min for ²²⁶ Ra plus daughters	1.7	1.7	-	-

B. Derivation of Conversion Factors. Floor Monitor (FM-4G)

Window Area: ~ 330 cm²

Conversion to 100 cm² = 0.30 times floor monitor readings

Window Area: ~ 470 cm²

Conversion to 100 cm² = 0.21 times floor monitor readings

. Hand Probe (AC-21)

Window Area: ~ 51 cm²

Conversion to 100 cm² = 1.96 times PAC reading

. 2π Internal Gas-Flow Counter, PC Counter

Geometry with Solid Steel Spun Top - 0.50

APPENDIX 2 (cont'd.)

Geometry with Mylar Spun Top - 0.43

Mylar Spun Top counting {double-aluminized Mylar window ($\sim 0.85 \text{ mg/cm}^2$)} utilizes the well of the PC counter and is a method developed and used by the Argonne National Laboratory Health Physics Section for negating the dielectric effect in counting samples on nonconducting media.

A $1.25 \times 1.25 \times 0.005$ in ($3.2 \times 3.2 \times 0.013$ cm) normal-uranium foil (used as a source of uranium alpha emissions) was counted in the 2π Internal Gas-Flow Counter (PC Counter) with the source leveled to an apparent 2π geometry. As previously stated, this instrument was calibrated using ^{239}Pu NBS-traceable sources. The alpha reading was 2.83×10^4 cts/min, or $2.83 \times 10^4 \div 0.50 = 5.66 \times 10^4$ dis/min alpha with the PC counter.

The same uranium source, when counted in the alpha mode with the PAC-4G-3 instrument (51 cm^2 probe), was found to be 1.62×10^4 cts/min at contact. The conversion factor for cts/min to dis/min for the PAC instrument is $5.66 \times 10^4 \div 1.62 \times 10^4 = 3.5$ dis/min alpha per cts/min alpha.

The same normal uranium source covered with two layers of conducting paper, each 6.31 mg/cm^2 thick to absorb the alpha emissions, was counted for composite beta and gamma emissions in the PC counter; however, no provision was made for backscatter. The composite beta-gamma count was 3.84×10^5 cts/min, or $3.84 \times 10^5 \div 0.50 = 7.68 \times 10^5$ dis/min beta-gamma.

When the covered normal uranium source was counted in the beta mode of the PAC-4G-3, the count rate was 2.85×10^5 cts/min. This indicates a conversion factor of $7.68 \times 10^5 \div 2.85 \times 10^5 = 2.7$ dis/min beta-gamma per cts/min beta-gamma.

A similar method was used to determine the conversion factors for ^{226}Ra plus daughters.

II. SMEAR COUNT

The conversion factors for cts/min- 100 cm^2 to dis/min- 100 cm^2 for smear counts are given below.

A. Conversion Equation (Alpha)

$$\frac{\text{cts/min} - (\text{Bkgd})}{g \times \text{bf} \times \text{sa} \times \text{waf}} = \text{dis/min alpha}$$

A geometry (g) of 0.43 is standard for all flat-plate counting using a Mylar spun top.

A backscatter factor (bf) of 1.0 was used when determining alpha activity on a filter media.

APPENDIX 2 (cont'd.)

The self-absorption factor (sa) was assumed to be 1, unless otherwise determined.

If the energies of the isotope were known, the appropriate window air factor waf was used; if the energies of the isotopes were unknown, the waf of ^{239}Pu (0.713) was used.

The waf for normal-uranium alphas is 0.54.

The waf for alphas from ^{226}Ra plus daughters is 0.55.

B. Conversion Equation (Beta)

$$\frac{\text{cts/min} - \{\beta \text{ Bkgd (cts/min)} + \alpha \text{ cts/min}\}}{g \times bf \times sa \times waf} = \text{dis/min beta}$$

A geometry (g) of 0.43 is standard for all flat-plate counting using the Mylar spun top.

A backscatter factor (bf) of 1.1 was used when determining beta activity on a filter media.

A self-absorption factor (sa) was assumed to be 1, unless otherwise determined.

If the energies of the isotopes were known, the appropriate window air factor (waf) was used; if the energies of the isotopes were unknown, the waf of ^{90}Sr - ^{90}Y (0.85) was used.

The waf for normal-uranium betas is 0.85.

The waf for betas from ^{226}Ra plus daughters is 0.85.

APPENDIX 3

RADON AND THORON DAUGHTER DETERMINATION CALCULATIONS

The basic assumptions and calculations used to derive the radon (^{222}Rn) daughter and thoron (^{220}Rn) daughter concentrations in air are detailed in this appendix. The air samples were collected with an ANL-designed air sampler using HV-70-0.23 mm or LB 5211-9 mil filter paper. Sampling times were usually 40 minutes at a flow rate of 40 m³/h (670 l/min). Accordingly, the flow rate through the 10% portion of filter medium counted in the proportional counter was usually 67 l/m. The radon-daughter concentrations (in WL) were determined by a generalized Kusnetz-like technique involving a single integral gross alpha count performed no sooner than 60 minutes following the end of sampling. The thoron-daughter concentrations (in pCi/l) were similarly determined by a second integral gross alpha count performed no sooner than 360 minutes following the cessation of sampling. Counting (integration) time was 10 minutes for each count.

The measured counts were related to concentrations through equations that describe the expected counts within any arbitrary time interval after sampling from radon and thoron daughters on a filter sample. There are two general approaches in use to derive those equations. One of the approaches involves the solution of two sets of differential equations (Refs. 1 and 2). The first set describes the growth and decay of the daughters during the sampling time t_0 , whereas the second set describes the growth and decay of the daughters after sampling and during the counting interval t_1 to t_2 . A more recent approach involves the integration of the differential form of the generalized Bateman equation. This method yields one set of generalized equations (Ref. 3) that describe the expected counts during the counting interval t_1 to t_2 due to the build-up of daughters on the filter sample during the sampling time t_0 and their subsequent transformation both during and after that sampling interval. The results of this second approach, presented in detail in Reference 3, are utilized here.

The radon daughters RaA and RaC (RaC') contribute the alpha counts. Taking the half-lives of the radon daughters RaA, RaB, and RaC to be 3.05 min, 26.8 min, and 19.7 min (Ref. 4), respectively, the equation that relates concentration to the integral gross alpha counts during the interval t_1 to t_2 from the sampling of radon daughters during a time t_0 is

$$\begin{aligned} \frac{N}{EQ} = & (43.99 f_A + 1.609 \times 10^3 f_B - 911.4 f_C) C_A \\ & + (1.253 \times 10^4 f_B - 6.769 \times 10^3 f_C) C_B \\ & + 1.793 \times 10^3 f_C C_C, \end{aligned} \quad (1)$$

where

N = the integral gross alpha count (cts)

E = the detector yield

Q = the air sampling flow rate (liters/min)

C_A, C_B, C_C = the concentrations of daughters A, B, C in air (pCi/l)

$f_i = (1 - e^{-\lambda_i t_0})(e^{-\lambda_i t_1} - e^{-\lambda_i t_2}), i = A, B, C$

λ_i = the radioactive decay constant of the i th species (min⁻¹)

APPENDIX 3
(cont'd.)

The thoron daughter ThC (ThC') contributes the alpha counts. Taking the half-lives of the thoron daughters ThB and ThC to be 10.643 hr and 60.60 min (Ref. 4), respectively, the equation that relates concentration to the integral gross alpha counts from thoron daughters during an interval t_1 to t_2 from a sampling interval t_0 is

$$\frac{N'}{EQ} = (2.082 \times 10^6 f_B' - 1.875 \times 10^4 f_C') C_B + 1.697 \times 10^4 f_C' C_C',$$

where the parameters are defined as above, with the "primes" denoting thoron daughters. A similar expression can be obtained for actinon (^{219}Rn) daughters, if needed. The counting interval t_1 to t_2 is referenced to $t = 0$ at the end of sampling. It is assumed that the sampling does not disturb the ambient concentrations of the daughters and that the concentrations in air remain constant over the relatively short sampling interval.

The radon-daughter concentrations, in pCi/l, are related to the Working Level* unit of concentration through the equation

$$WL = 0.001046 C_A + 0.005161 C_B + 0.003793 C_C, \quad (3)$$

derived from the definition of a Working Level and the half-lives, alpha abundances and energies given in Reference 4. Although the numerical value of the WL unit is derived with the assumption of radioactive equilibrium (i.e., 100 pCi/l of each radon daughter), the unit is applicable for any nonequilibrium mixture. Nonequilibrium mixtures of daughter concentrations are specified by three numbers called "air indices," defined for radon daughters as the concentration ratio of RaA, RaB, and RaC to RaA (i.e., $1: C_B/C_A : C_C/C_A$).

The single-integral-gross-alpha-count technique currently utilized by ANL is simpler than multiple-measurement or alpha-spectroscopic techniques. However, an uncertainty is introduced due to the lack of knowledge of the state of disequilibrium among the radon daughters during sampling. The three concentrations C_A , C_B , and C_C in Eq. 1 cannot be determined by a single count. A conversion error, therefore, is introduced when assumed daughter-ratios are substituted into Eq. 1. The air-sampling data collected during the survey were processed for heuristic purposes with assumed daughter ratios of 1:1:1, 1:0.75:0.5, and 1:0.6:0.4. It was found that the daughter ratio 1:1:1 yielded a slightly more conservative WL value and was, therefore, used in the calculation of all reported values. A thoron daughter ratio can be similarly defined as the concentration ratio of ThB and ThC to ThB (i.e., $1: C_C'/C_B'$). A thoron daughter ratio of 1:1 was assumed in Eq. 2, and used in the calculation of all reported values. This assumption is only slightly conservative (Ref. 5).

*A Working Level (WL) is defined as any combination of short-lived radon-decay products in one liter of air that will result in the ultimate emission of 1.3×10^5 MeV of potential alpha energy. The numerical value of the WL is derived from the alpha energy released by the total decay through RaC' of the short-lived radon-daughter products, RaA, RaB, and RaC at radioactive equilibrium with 100 pCi of ^{222}Rn per liter of air.

APPENDIX 3 (cont'd.)

Example Calculation:

An air sample of 40 minutes duration at a flow rate of 40 m³/h (670 l/min) was collected from the Plutonium Laboratory in Building 7. The flow rate through the 10% portion of the filter medium counted in the proportional counter was 67 l/min. The detector yield is the composite of a geometry factor (0.43), backscatter factor (1.0), sample absorption factor (0.77 for RaC'), and window-air factor (0.8 for RaC'). These factors give a detector yield of 0.265. A single integral gross alpha count of 10 minutes duration, beginning 60 minutes after the end of sampling, yielded 186 net counts. A second integral gross alpha count of 10 minutes duration, beginning 402 minutes after the end of sampling, yielded 7 net counts. From Eqs. 1 and 2, the total radon and thoron daughter counts during the interval $t_1 = 60$ minutes to $t_2 = 70$ minutes from the sampling interval $t_0 = 40$ minutes is

$$\frac{N_1}{EQ} = 25.34 C_A + 206.3 C_B + 48.65 C_C + 520.2 C_{B'} + 339.0 C_{C'}$$

Similarly, the total counts during the second interval $t_1 = 402$ minutes to $t_2 = 412$ minutes is

$$\frac{N_2}{EQ} = 7.1 \times 10^{-3} C_A + 5.5 \times 10^{-2} C_B + 2.9 \times 10^{-4} C_C + 609.8 C_{B'} + 6.781 C_{C'}$$

With conservatively assumed radon and thoron daughter ratios of 1:1:1 and 1:1, respectively, these equations yield results of 6.4×10^{-4} pCi/l of ThB and C and 3.6×10^{-2} pCi/l of RaA, B, and C. Equations 3 then yields a WL of 3.6×10^{-4} , or 0.36 mWL (milli-Working Level).

REFERENCES FOR APPENDIX 3

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3. Fu-Chia, Y. and T. Chia-Yong. "A General Formula for the Measurement of Concentrations of Radon and Thoron Daughters in Air." Health Physics 34, 501 (1978).

APPENDIX 3
(cont'd.)

4. Lederer, C.M. and V. S. Shirley. Table of Isotopes, Seventh Edition. John Wiley & Sons, Inc. (1978).
5. Porstendörfer, J., A. Wicke, and A. Schraub. "The Influence of Exhalation, Ventilation and Deposition Processes Upon the Concentration of Radon (^{222}Rn), Thoron (^{220}Rn) and Their Decay Products in Room Air." Health Physics 34, 465 (1978).

APPENDIX 4

SAMPLE PREPARATION AND ANALYSIS PROCEDURES

I. SOIL-SAMPLE PREPARATION

Standard procedures for preparation of soil samples acquired during a radiological survey are described in this section. These samples are bagged and identified at the collection site and returned to ANL. If there is an indication of radioactive contamination, the sample is sealed in a Nalgene jar. At ANL, the soil samples are logged into the soil-sample book, and each sample is weighed (on a tared balance scale) and the weight is marked on the container. This weight is recorded in the soil book as a "net weight."

After all samples are marked, weighed, and recorded, they are dried. Each sample is placed in a pyrex beaker marked with the sample identification number. If more than one beaker is necessary, additional numbers (e.g., 1-3, 2-3, 3-3) are used. The original containers are saved for repackaging the dried samples. The beaker is set in an 80°C oven until the soil is dry (usually about 24 hours). The sample is returned to the original container and reweighed using a tared balance scale. This weight is also marked on the container and in the soil-sample book, where it is referred to as a "dry weight."

After all the samples are returned to their original containers, the milling process is started. Each dried sample is transferred to a 2.3-gallon (8.7 l) ceramic mill jar containing mill balls (1½" x 1½" burundum cylinders). The mill jar number is marked on the original container. The jars are sealed and the samples are milled for two hours or until sufficient material is produced to obtain 100 g and 5 g samples for analyses. The samples are milled six at a time. A second set of six jars is prepared while the milling of the first set is proceeding. After each sample is milled, the mill balls are removed with tongs and placed in a tray. A large plastic bag is inverted over the mill jar. Both are inverted and shaken until all the soil is transferred to the bag. If the soil plates the inside of the mill jar, a small paint brush is used to loosen the soil before the jar is inverted. A separate brush is used for each jar to prevent cross-contamination of the soil samples.

After milling, each sample is sieved through a No. 30 (600 µm) Standard Testing sieve and transferred to a 12 in x 12 in ziplock bag. Rocks and dross are bagged separately. The bags are marked with the sample number, the sieve number and the designation R(rocks) or S(soil). The balance is tared and the weights of the soil (or rocks) are measured and recorded in the soil-sample book. A 100-g sample of the sieved material is transferred to a 4-oz. Nalgene bottle. These samples are analyzed by suitable analytical techniques, including, as a minimum, high resolution gamma spectroscopy (GeLi or HPGe). A 5-g sample of the sieved material is transferred to a 1-oz Nalgene bottle. One gram of this sample is used for the determination of uranium by laser fluorometry and the remainder for radiochemical analysis for Pu, Am, and Th, if these analyses are required. The bottles containing these weighed samples are marked with sample number and date, and this information is recorded in the soil-sample book. The rocks (and dross) and remaining soil are placed in storage.

APPENDIX 4
(cont'd.)

The sieves, mill jars, and burundum milling balls used in this work are classified in two sets. One set is used for background samples exclusively. The other set is used for all samples from suspect areas. Soil samples with elevated levels of radioactivity based on instrument measurements are milled in one-gallon Nalgene bottles using burundum balls from the set used for suspect samples. After use, these balls are either decontaminated (see below) or disposed of as radioactive waste. The Nalgene bottles are always disposed of as radioactive waste. The sieves used for these samples are also from the set used for suspect samples and are decontaminated after use.

II. EQUIPMENT DECONTAMINATION

The care of the milling apparatus is as important as the actual sample preparation. Proper care prevents cross-contamination of successive samples. The beakers used to dry the samples are washed thoroughly by placing a small amount of Haemo-Sol in each beaker and filling with warm water. The beaker is then scrubbed thoroughly on the inside and scoured on the outside with scouring powder. The beakers are rinsed three times with tap water and three times with demineralized water, and finally dried thoroughly before reuse.

The milling apparatus (tongs, brushes, milling jars, lids, and milling balls) are rinsed. The tongs and brushes are washed thoroughly with Haemo-Sol. Eight burundum balls are returned to each milling jar along with about one pint of clean road gravel, one spoon of Haemo-Sol, one spoon of scouring powder with bleach, and one quart of water. The lid is tightened on the jar and the jar is placed on the rolling mill and rolled for approximately two hours or until the balls and the inside of the jar appear to be physically clean. After this time, the mill jar is removed from the rolling mill and its contents are dumped into a screen or basket. The lid and balls are then rinsed thoroughly three times with tap water followed by three times with demineralized water. The inside of the jar is rinsed until it is absolutely clean. The milling apparatus is air-dried with warm air. Room air is drawn through the mill jars with a hose which is attached to a fume hood or specially constructed drying box.

The sieves are rinsed, washed in Haemo-Sol, thoroughly rinsed (three times with tap water, followed by three times with demineralized water) and then air dried as above before reuse.

III. WATER AND SLUDGE

Water samples are collected in 0.1-liter, 0.5-liter and/or 1-liter quantities as deemed appropriate. These samples are forwarded directly to a certified radiochemistry laboratory for preparation and analysis. The customary analysis procedure consists of filtration to obtain the suspended solids followed by evaporation to obtain the dissolved solids. Both suspended and dissolved solids are analyzed by appropriate radiochemical analytical techniques.

Sludge samples are collected in 0.1-liter bottles and are processed as outlined above for water samples.

APPENDIX 4
(cont'd.)

IV. VEGETATION, MATERIAL AND RUBBLE

Samples of potentially contaminated vegetation, material (e.g. tile, piping, ducts, conduit, etc.) and rubble are collected, bagged, and labeled at the site and returned to ANL for analysis.

Vegetation samples are initially weighed and transferred to Marinelli beakers for gamma spectrometric analysis. Then they are ashed, reweighed, and analyzed by appropriate analytical techniques.

Material and rubble samples are forwarded to a certified radiochemistry laboratory for specific processing and analysis as required.

V. TRITIUM FROM SOLID MATERIALS

Samples of solid materials (e.g., concrete) suspected of containing tritium are collected, broken into small pieces, and submitted to a certified radiochemistry laboratory for analysis. The standard analytical procedure consists of transferring a 20-40 g sample to a ceramic boat followed by heating in a tube furnace at 425°C for a period of two hours (~ 40 min to reach temperature and ~ 80 min heating at temperature). Helium is used as a flow gas through the tube during heating, and the tritium is collected in two traps on the downstream side of the furnace. The first trap is immersed in an ordinary ice bath (0°C); the second trap is immersed in a CO₂-Freon bath (-57°C). The collected tritiated water from both traps is combined, made up to a known volume, and an aliquot taken for liquid scintillation counting of the tritium.

VI. ANALYSIS PROCEDURES

A 100-g or less fraction from each soil or other sample is analyzed by high resolution gamma-ray spectroscopy using a germanium crystal detector coupled to the appropriate electronics and a multichannel analyzer. This analysis allows for a quantitative determination of the ²²⁶Ra decay chain (via the 609 keV γ-ray of ²¹⁴Pb) and the ²³²Th decay chain (via the 911 keV γ-ray of ²²⁸Ac), as well as any other gamma-emitting radionuclide (e.g., ¹³⁷Cs) present in the soil.

The total uranium (elemental) present in the sample is determined by an acid leach of the mass of sample followed by laser fluorometry of the leached sample.

Thorium analysis consists of an acid leach of the soil or other sample (using an appropriate Th spike for yield determination) followed by plating a thin source of the radiochemically separated thorium and determining the activity of the thorium isotopes (²²⁸Th and ²³²Th) by alpha spectroscopy.

Plutonium and/or americium analysis consists of an acid leach of the soil or other sample (using an appropriate Pu and/or Am spike for yield determination) followed by plating a thin source of the radiochemically separated plutonium or americium and determining the activity of the plutonium or americium isotopes (²³⁸Pu, ^{239,240}Pu, ²⁴¹Am) by alpha spectroscopy.

APPENDIX 4
(cont'd.)

The results of the above measurements allow for quantitative determination of the relative amounts of plutonium, americium, normal uranium, natural uranium, tailings (i.e., ^{226}Ra decay chain), thorium (^{232}Th), mesothorium (^{228}Ra decay chain), and radiothorium (^{228}Th) decay chain present in the contaminated material.

A mass spectrometric analysis of the uranium or plutonium fraction is conducted when it is necessary to know the relative isotopic abundances (in atom %).

APPENDIX 5

CALCULATION OF URANIUM SPECIFIC ACTIVITIES

The specific activity for uranium of the various isotopic abundances encountered during the survey was obtained by summing the specific activities for the individual contributing isotopes weighted according to their measured abundances. Best values for the specific activities of ^{235}U and ^{238}U were taken from A. H. Jaffey et al., Phys. Rev. C 4 1889 (1971). The specific activity of ^{236}U was taken from K. F. Flynn et al., J. Inorg. Nucl. Chem. 34 1121 (1972). The half-life for each isotope was taken from the "Table of Isotopes," 7th Edition, by C. M. Lederer and V. S. Shirley (1978). The percent abundances of normal uranium were taken from N. E. Holden, BNL-NCS-50605 (1977). Atomic weights were taken from the "Handbook of Chemistry and Physics," 52nd Edition (1971). The specific activity of ^{234}U was calculated from the half-life with Avogadro's number = 6.0225×10^{23} per mole and 5.2595×10^5 min per year.

<u>Isotope</u>	<u>Specific Activity</u> <u>(dis/min-μg)</u>	<u>Half-life</u> <u>(years)</u>	<u>Atomic Weight</u> <u>(grams)</u>
^{234}U	1.386×10^4	2.446×10^5	234.0409
^{235}U	4.798	7.038×10^8	235.0439
^{236}U	1.436×10^2	2.3415×10^7	236.0457
^{238}U	0.746	4.4683×10^9	238.0508

A) Specific activity for normal uranium:

<u>Isotope</u>	<u>Abundance</u> <u>(atom %)</u>	<u>Abundance</u> <u>(wt. %)</u>	<u>Specific Activity</u> <u>of Contribution</u> <u>Isotopes</u>	<u>Activity</u> <u>Contribution</u>
^{234}U	0.0054	0.0053	x 1.386×10^4 dis/min- μg	= 0.736 dis/min- μg
^{235}U	0.720	0.711	x 4.798	= 0.034
^{238}U	99.2746	99.2837	x 0.746	= 0.740
Total				= 1.510 dis/min- μg
				or 0.680 pCi/ μg

where $(\text{wt}\%)_i =$

$$\frac{(\text{atom}\%)_i (\text{atomic weight})_i}{\sum_j (\text{atom}\%)_j (\text{atomic weight})_j} = \frac{(\text{atom}\%)_i (\text{atomic weight})_i}{238.0289 \text{ g}}$$

Note that 2.26% of the total activity is due to ^{235}U and 48.87% each is due to ^{234}U and ^{238}U .

APPENDIX 5
(cont'd.)

B) For sample 16-SS-1:

<u>Isotope</u>	<u>atom %</u>	<u>wt. %</u>	<u>Spec. Act. of Contributing Isotope</u>	<u>Activity Contribution</u>
²³⁴ U	0.006	0.00590 x	1.386×10^4 dis/min- μ g =	0.818 dis/min- μ g
²³⁵ U	0.95	0.9381 x	4.798 =	0.045
²³⁶ U	0.006	0.00595 x	1.436×10^2 =	0.0085
²³⁸ U	99.04	99.050 x	0.746 =	0.739
Total =				1.610 dis/min- μ g
or				0.725 pCi/ μ g

where $(wt\%)_i = (atom\%)_i (atomic\ weight)_i / 238.0266\ g.$

C) For sample 16-S-10B:

<u>Isotope</u>	<u>atom %</u>	<u>wt %</u>	<u>Spec. Act of Contributing Isotope</u>	<u>Activity Contribution</u>
²³⁴ U	0.007	0.00688 x	1.386×10^4 dis/min- μ g =	0.954 dis/min- μ g
²³⁵ U	0.96	0.948 x	4.798 =	0.045
²³⁶ U	0.006	0.00595 x	1.436×10^2 =	0.0085
²³⁸ U	99.03	99.039 x	0.746 =	0.739
Total =				1.747 dis/min- μ g
or				0.787 pCi/ μ g

where $(wt\%)_i = (atom\%)_i (atomic\ weight)_i / 238.0287\ g.$

D) For sample 16-SS-14:

<u>Isotope</u>	<u>atom %</u>	<u>wt. %</u>	<u>Spec. Act of Contributing Isotope</u>	<u>Activity Contribution</u>
²³⁴ U	0.019	0.01869 x	1.386×10^4 dis/min- μ g =	2.590 dis/min- μ g
²³⁵ U	3.33	3.289 x	4.798 =	0.158
²³⁶ U	0.021	0.0208 x	1.436×10^2 =	0.030
²³⁸ U	96.63	96.671 x	0.746 =	0.721
Total =				3.499 dis/min- μ g
or				1.576 pCi/ μ g

where $(wt\%)_i = (atom\%)_i (atomic\ weight)_i / 237.9495\ g.$

APPENDIX 6

PERTINENT RADIOLOGICAL REGULATIONS
STANDARDS, AND GUIDELINES

I.

Excerpts From

DRAFT AMERICAN NATIONAL STANDARD

N13.12

Control of Radioactive Surface Contamination

On Materials, Equipment, and Facilities to be

Released for Uncontrolled Use

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 shall be made the subject of case-by-case evaluation.

Property shall not be released for uncontrolled use unless measurements show the total and removable contamination levels to be no greater than the values in Table 1 or Table 2. (The values in Table 2 are easier to apply when the contaminants cannot be individually identified.)

Coatings used to cover the contamination shall not be considered a solution to the contamination problem. That is, the monitoring techniques shall be sufficient to determine, and such determination shall be made, that the total amount of contamination present on and under any coating does not exceed the Table 1 or Table 2 values before release.

TABLE 1

SURFACE CONTAMINATION LIMITS*

Contaminants			Limit (Activity) (dis/min-100 cm ²) ⁺	
Group	Description	Nuclides (Note 1)	Removable	Total (Fixed plus Removable)
1	Nuclides for which the non-occupational MPC (Note 2) is 2×10^{-13} Ci/m ³ or less or for which the nonoccupational MPC (Note 4) is 2×10^{-7} Ci/m ³ or less	²²⁷ Ac ²⁴¹ , ²⁴² ^m , ²⁴³ Am ²⁴⁹ , ²⁵⁰ , ²⁵¹ , ²⁵² Cf ²⁴³ , ²⁴⁴ , ²⁴⁵ , ²⁴⁶ , ²⁴⁷ , ²⁴⁸ Cm ¹²⁵ , ¹²⁹ I ²³⁷ Np ²³¹ Pa ²¹⁰ Pb ²³⁸ , ²³⁹ , ²⁴⁰ , ²⁴² , ²⁴⁴ Pu ²²⁶ , ²²⁸ Ra ²²⁸ , ²³⁰ Th	20	Nondetectable (Note 3)
2	Those nuclides not in Group 1 for which the nonoccupational MPC (Note 2) is 1×10^{-12} Ci/m ³ or less or for which the nonoccupational MPC (Note 4) is 1×10^{-6} Ci/m ³ or less	²⁵⁴ Es ²⁵⁶ Fm ¹²⁶ , ¹³¹ , ¹³³ I ²¹⁰ Po ²²³ Ra ⁹⁰ Sr ²³² Th ²³² U	200	2000 α Nondetectable β , γ (Note 5)
3	Those nuclides not in Group 1 or Group 2		1000	5000

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(cont'd.)

SURFACE CONTAMINATION LIMITS*

*The levels may be averaged over one square meter provided the maximum activity in any area of 100 cm² is less than three times the limit value. For purposes of averaging with regard to isolated spots of activity, any square meter of surface shall be considered to be contaminated above the limit L, applicable to 100 cm², if (1) from measurements of a representative number n of sections it is determined that $1/n \sum S_i \geq L$, where S_i is the dis/min-100 cm² determined from measurement of section i; or (2) it is determined that the activity of all isolated spots or particles in any area less than 100 cm² exceeds 3 L.

⁺ Disintegrations per minute per square decimeter.

NOTES:

- (1) Values presented here are obtained from the Code of Federal Regulations, Title 10, Part 20, April 30, 1975. The most limiting of all given MPC values (for example, soluble versus insoluble) are to be used. In the event of the occurrence of mixtures of radionuclides, the fraction contributed by each constituent of its own limit shall be determined and the sum of the fraction shall be less than 1.
- (2) 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 the National Committee on Radiation Protection and Measurements (NCRP), the International Commission on Radiological Protection (ICRP), or the Nuclear Regulatory Commission (NRC). From the Code of Federal Regulations, Title 10, Part 20, Appendix B, Table 2, Column 1.
- (3) The instrument utilized for this measurement shall be calibrated to measure at least 100 pCi of any Group 1 contaminants uniformly spread over 100 cm².
- (4) Maximum permissible concentration in water applicable to members of the public.
- (5) The instrument utilized for this measurement shall be calibrated to measure at least 1 nCi of any Group 2 beta or gamma contaminants uniformly spread over an area equivalent to the sensitive area of the detector. Direct survey for unconditional release should be performed in areas where the background is ≤ 100 counts per minute. When the survey must be performed in a background exceeding 100 counts per minute, it may be necessary to use the indirect survey method to provide the additional sensitivity required.

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(cont'd.)

ALTERNATE SURFACE CONTAMINATION LIMITS

(All Alpha Emitters, except U_{nat} and Th_{nat} , Considered as a Group)*

Contamination Contingencies	Limit (Activity) (dis/min-100 cm ²) ⁺	
	Removable	Total (Fixed Plus Removable)
If the contaminant cannot be identified; or if alpha emitters other than U_{nat} (Note 1) and Th_{nat} are present; or if the beta emitters comprise ^{227}Ac or ^{228}Ra .	20	Nondetectable (Note 2)
If it is known that all alpha emitters are generated from U_{nat} (Note 1) and Th_{nat} ; and if beta emitters are present that, while not identified, do not include ^{227}Ac , ^{125}I , ^{226}Ra , and ^{228}Ra .	200	2000 α Nondetectable β, γ (Note 3)
If it is known that alpha emitters are generated only from U_{nat} (Note 1) and Th_{nat} in equilibrium with its decay products; and if the beta emitters, while not identified, do not include ^{227}Ac , ^{125}I , ^{129}I , ^{90}Sr , ^{223}Ra , ^{228}Ra , ^{126}I , ^{131}I and ^{133}I .	1000	5000

APPENDIX 6
(cont'd.)

ALTERNATE SURFACE CONTAMINATION LIMITS

*The levels may be averaged over one square meter provided the maximum activity in any area of 100 cm² is less than three times the limit value. For purposes of averaging with regard to isolated spots of activity, any square meter of surface shall be considered to be contaminated above the limit L, applicable to 100 cm², if (1) from measurements of a representative number n of sections it is determined that $1/n \sum_{i=1}^n S_i \geq L$, where S_i is the dis/min-100 cm² determined from measurement of section i; or (2) it is determined that the activity of all isolated spots or particles in any area less than 100 cm² exceeds 3 L.

⁺ Disintegrations per minute per square decimeter.

NOTES:

- (1) U_{nat} and decay products.
- (2) The instrument utilized for this measurement shall be calibrated to measure at least 100 pCi of any Group 1 contaminants uniformly spread over 100 cm².
- (3) The instrument utilized for this measurement shall be calibrated to measure at least 1 nCi of any Group 2 beta or gamma contaminants uniformly spread over an area equivalent to the sensitive area of the detector. Direct survey of unconditional release should be performed in areas where the background is ≤ 100 counts per minute. When the survey must be performed in a background exceeding 100 counts per minute, it may be necessary to use the indirect survey method to provide the additional sensitivity required.

APPENDIX 6
(cont'd.)II. GUIDELINES FOR DECONTAMINATION OF FACILITIES AND
EQUIPMENT PRIOR TO RELEASE FOR UNRESTRICTED
USE OR TERMINATION OF LICENSES FOR BY-PRODUCT
SOURCE, OR SPECIAL NUCLEAR MATERIAL

U.S. Nuclear Regulatory Commission, July 1982

(These have been retyped for
purposes of this report.)

The instructions in this guide, in conjunction with Table 1, specify the radionuclides and radiation exposure rate limits which should be used in decontamination and survey of surfaces or premises and equipment prior to abandonment or release for unrestricted use. The limits in Table 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 1 prior to the application of 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 duct work 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 duct work. 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 of 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.

APPENDIX 6

(cont'd.)

- 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 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 Administrator of the NRC Regional Office 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.

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(cont'd.)

TABLE 1

ACCEPTABLE SURFACE CONTAMINATION LEVELS

NUCLIDES ^a	AVERAGE ^{bcf}	MAXIMUM ^{bdf}	REMOVABLE ^{bef}
U-nat, ²³⁵ U, ²³⁸ U and associated decay products	5,000 dis/min-100 cm ² α	15,000 dis/min-100 cm ² α	1,000 dis/min-100 cm ² α
Transuranics, ²²⁶ Ra, ²²⁸ Ra, ²³⁰ Th, ²²⁸ Th, ²³¹ Pa, ²²⁷ Ac, ¹²⁵ I, ¹²⁹ I	100 dis/min-100 cm ²	300 dis/min-100 cm ²	20 dis/min-100 cm ²
Th-nat, ²³² Th, ⁹⁰ Sr, ²²³ Ra, ²²⁴ Ra, ²³² U, ¹²⁶ I, ¹³¹ I, ¹³³ I	1,000 dis/min-100 cm ²	3,000 dis/min-100 cm ²	200 dis/min-100 cm ²
Beta-gamma emitters (nuclides with decay modes other than alpha emission or spontaneous fission) except ⁹⁰ Sr and others noted above.	5,000 dis/min-100 cm ² βγ	15,000 dis/min-100 cm ² βγ	1,000 dis/min-100 cm ² βγ

APPENDIX 6
(cont'd.)TABLE 1
(Footnotes)

ACCEPTABLE SURFACE CONTAMINATION LEVELS

- ^aWhere surface contamination by both alpha and beta-gamma emitting nuclides exists, the limits established for alpha and beta-gamma emitting nuclides should apply independently.
- ^bAs used in this table, dis/min (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.
- ^cMeasurements 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.
- ^dThe maximum contamination level applies to an area of not more than 100 cm².
- ^eThe amount of removable radioactive material per 100 cm² 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.
- ^fThe average and maximum radiation levels associated with surface contamination resulting from beta-gamma emitters should not exceed 0.2 mrad/h at 1 cm and 1.0 mrad/h at 1 cm, respectively, measured through not more than 7 milligrams per square centimeter of total absorber.

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(cont'd.)

III. 40 CFR 192 - HEALTH AND ENVIRONMENTAL PROTECTION STANDARDS FOR URANIUM
MILL TAILINGS

Authority: Section 275 of the Atomic Energy Act of 1954, 42 U.S.C. 2022, as added by the Uranium Mill Tailings Radiation Control Act of 1978, PL 95-604.

Subpart B -- Standards for Cleanup of Land and Buildings Contaminated with Residual Radioactive Materials from Inactive Uranium Processing Sites

192.10 Applicability

This subpart applies to land and buildings that are part of any processing site designated by the Secretary of Energy under Section 102 of the Act. Section 101 of the Act, states, in part, that "processing site" means -

(a) any site, including the mill, containing residual radioactive materials at which all or substantially of the uranium was produced for sale to any Federal agency prior to January 1, 1971, under a contract with any Federal agency, except in the case of a site at or near Slick Rock, Colorado, unless --

(1) such site was owned or controlled as of January 1, 1978, or is thereafter owned or controlled, by any Federal Agency, or

(2) a license (issued by the {Nuclear Regulatory} Commission or its predecessor agency under the Atomic Energy Act of 1954 or by a State as permitted under Section 274 of such Act) for the production at site of any uranium or thorium product derived from ores is in effect on January 1, 1978, or is issued or renewed after such date; and

(b) any other real property or improvement thereon which --

(1) is in the vicinity of such site, and

(2) is determined by the Secretary, in consultation with the Commission, to be contaminated with residual radioactive materials derived from such site.

192.11 Definitions

(a) Unless otherwise indicated in this subpart, all terms shall have the same meaning as defined in Title I of the Act or in Subpart A.

(b) Land means any surface or subsurface land that is not part of a disposal site and is not covered by an occupiable building.

(c) Working Level (WL) means any combination of short-lived radon decay products in one liter of air that will result in the ultimate emission of alpha particles with a total energy of 130 billion electron volts.

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(cont'd.)

(d) Soil means all unconsolidated materials normally found on or near the surface of the earth including, but not limited to, silts, clays, sands, gravel, and small rocks.

192.12 Standards

Remedial actions shall be conducted so as to provide reasonable assurance that, as a result of residual radioactive materials from any designated processing site:

(a) the concentration of radium-226 in land averaged over any area of 100 square meters shall not exceed the background level by more than --

(1) 5 pCi/g, averaged over the first 15 cm of soil below the surface, and

(2) 15 pCi/g, averaged over 15 cm thick layers of soil more than 15 cm below the surface.

(b) in any occupied or habitable building --

(1) the objective of remedial action shall be, and reasonable effort shall be made to achieve, an annual average (or equivalent) radon decay product concentration (including background) not to exceed 0.02 WL. In any case, the radon decay product concentration (including background) shall not exceed 0.03 WL, and

(2) the level of gamma radiation shall not exceed the background level by more than 20 microroentgens per hour.

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(cont'd.)

IV.

SURGEON GENERAL'S GUIDELINES
as included in 10 CFR Part 712
Grand Junction Remedial Action Criteria

712.1 Purpose

- (a) The regulations in this part establish the criteria determination by DOE of the need for, priority of and selection of appropriate remedial action to limit the exposure of individuals in the area of Grand Junction, Colorado, to radiation emanating from uranium mill tailings which have been used as construction-related material.
- (b) The regulations in this part are issued pursuant to Pub. L. 92-314 (86 Stat. 222) of June 16, 1972.

712.2 Scope

The regulations in this part apply to all structures in the area of Grand Junction, Colorado, 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, Colorado," means Mesa County, Colorado.
- (c) "Background" means radiation arising from cosmic rays and radioactive material other than uranium mill tailings.
- (d) "DOE" means the U. S. Department of Energy 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 six 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.

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(cont'd.)

- (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-214), 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, Colorado.
- (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 milling 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 DOE other than a written interpretation by the General Counsel will be recognized to be binding upon DOE.

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. Department of Energy, 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 recommended the following graded action levels for remedial action in terms of

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(cont'd.)

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/h	Greater than 0.05 WL	Remedial action indicated
From 0.05 to 0.1 mR/h	From 0.01 to 0.05 WL	Remedial action may be suggested.
Less than 0.05 mR/h	Less than 0.01 WL	No remedial action indi- cated.

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 DOE 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 DOE 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/h 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 exceed 0.02 mR/h above background, the indoor radon daughter concentration level equals or exceeds 0.01 WL above background.

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- (B) It should be presumed that if the external gamma radiation level is less than 0.001 mR/h 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/h above background but is less than 0.02 mR/h 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/h 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 of 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 in which the application is received.

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(cont'd.)

- (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/h above background in the case of dwellings and schools and 0.15 mR/h 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. DOE shall select the remedial action technique or combination of techniques, which it determines to be the most appropriate under the circumstances.

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V. EXCERPTS FROM DOE 5480.1 Chg. 6, Chapter XI

"Requirements for Radiation Protection"

Exposure of Individuals and Population Groups in Uncontrolled Areas.

Exposures to members of the public shall be as low as reasonably achievable levels within the standards prescribed below.

Radiation Protection Standards
for Internal and External Exposure
of Members of the Public

Annual Dose Equivalent or Dose Commitment		
Type of Exposure	Based on Dose to Individuals at Points of Maximum Probable Exposure	Based on Average Dose to a Suitable Sample of the Exposed Population
Whole body, gonads, or bone marrow	0.5 rem (or 500 mrem)	0.17 rem (or 170 mrem)
Other organs	1.5 rem (or 1500 mrem)	0.5 rem (or 500 mrem)

CONCENTRATION IN AIR AND WATER ABOVE NATURAL BACKGROUND

Element (Atomic Number)	Isotope Soluble (S) Insoluble (I)	Table I Controlled Area		Table II Uncontrolled Area	
		Column 1	Column 2	Column 1	Column 2
		Air (pCi/l)	Water (pCi/l)	Air (pCi/l)	Water (pCi/l)
Radon (86)	Rn 220 S	300		10	
	Rn 222 S	100		3	
Lead (82)	Pb 212 S	20		0.6	

APPENDIX 7

EVALUATION OF RADIATION EXPOSURESI. INTRODUCTIONA. Types of Radiation

Radiation is the emission or transmission of energy in the form of waves or particles. Examples are acoustic waves (i.e., sound), electromagnetic waves (such as radio, light, x- and gamma-rays), and particulate radiations (such as alpha particles, beta particles, neutrons, protons, and the elementary particles).

The class of radiation of importance to this report is known as ionizing radiation. Ionizing radiations are those, either electromagnetic or particulate, with sufficient energy to ionize matter, i.e., to remove or displace electrons from atoms and molecules. The most common types of ionizing radiation are x- and gamma-rays, alpha particles, beta particles, and neutrons.

X- and gamma-rays are electromagnetic waves of pure energy, having no charge and no mass or existence at rest. Gamma-rays and x-rays are identical except that x-rays originate in the atom and gamma-rays originate in the nucleus of an atom. X- and gamma-rays are highly penetrating and can pass through relatively thick materials before interacting. Upon interaction, some or all of the energy is transferred to electrons, which, in turn, produce additional ionizations while coming to rest.

Alpha particles are positively charged particulates composed of two neutrons and two protons, identical to the nucleus of a helium atom. Due to its comparatively large mass and double charge, an alpha particle interacts readily with matter and penetrates only a very short distance before coming to rest, causing intense ionization along its path.

Beta particles are negatively charged free electrons moving at high speeds. Due to its comparatively small mass and single charge, a beta particle's penetration through matter is intermediate between that of the alpha particle and the gamma-ray, causing fewer ionizations per unit path length than an alpha particle.

B. Sources of Radiation

Ionizing radiations arise from terrestrial radioactive materials (both naturally occurring and man-made), extra-terrestrial (cosmic) sources, and radiation-producing machines. The sources of ionizing radiation important to this report are radioactive materials and cosmic sources.

Most atoms of the elements in our environment remain structurally stable. With time, an atom of potassium, for instance, may change its association with other atoms in chemical reactions and become part of other compounds, but it will always remain a potassium atom. Radioactive atoms, on the other hand, are not stable and will spontaneously emit radiation in order to achieve a more stable state. By spontaneously transforming itself, the ratio of protons and

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(cont'd.)

neutrons in the nucleus is altered toward a more stable condition. Radiation may be emitted from the nucleus as alpha particles, beta particles, neutrons, or gamma-rays, depending uniquely upon each particular radionuclide. Radionuclides decay at characteristic rates dependent upon the degree of stability and characterized by a period of time called the half-life. In one half-life, the number of radioactive atoms and, therefore, the amount of radiation emitted, decrease by one half.

The exposure of man to terrestrial radiation is due to naturally occurring radionuclides and also to "man-made" or technologically enhanced radioactive materials. Several dozen radionuclides occur naturally, some having half-lives of at least the same order of magnitude as the estimated age of the earth. The majority of these naturally occurring radionuclides are isotopes of the heavy elements and belong to three distinct radioactive series headed by uranium-238, uranium-235, and thorium-232. Each of these decays to stable isotopes of lead (Pb) through a sequence of radionuclides of widely varying half-lives. Other naturally occurring radionuclides, which decay directly to a stable nuclide, are potassium-40 and rubidium-87. It should be noted that even though the isotopic abundance of potassium-40 is less than 0.012%, potassium is so widespread that potassium-40 contributes about one-third of the radiation dose received by man from natural background radiation. A major portion of the exposure (dose) of man to external terrestrial radiation is due to the radionuclides in the soil, primarily potassium-40 and the radioactive decay chain products of thorium-232 and uranium-238. The naturally occurring radionuclides deposited internally in man through uptake by inhalation/ingestion of air, food, and drinking water containing the natural radioactive material also contribute significantly to his total dose. Many other radionuclides are referred to as "man made" in the sense that they can be produced in large quantities by such means as nuclear reactors, accelerators, or nuclear weapons tests.

The term "cosmic radiation" refers both to the primary energetic particles of extra-terrestrial origin that are incident on the earth's atmosphere and to the secondary particles that are generated by the interaction of these primary particles with the atmosphere and reach ground level. Primary radiation consists of "galactic" particles, externally incident on the solar system, and "solar" particles emitted by the sun. This radiation is composed primarily of energetic protons and alpha particles. The first generation of secondary particles (secondary cosmic radiation), produced by nuclear interactions of the primary particles with the atmosphere, consists predominantly of neutrons, protons, and pions. Pion decay, in turn, results in the production of electrons, photons, and muons. At the lower elevations, the highly penetrating muons and their associated decay and collision electrons are the dominant components of the cosmic-ray particle flux density. These particles, together with photons from the gamma-emitting, naturally occurring radionuclides in the local environment, form the external penetrating component of the background environmental radiation field which produces a significant portion of the whole-body radiation dose to man.

In addition to the direct cosmic radiation, cosmic sources include cosmic-ray produced radioactivity, i.e., cosmogenic radionuclides. The major production

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(cont'd.)

of cosmogenic radionuclides is through interaction of the cosmic rays with the atmospheric gases through a variety of spallation or neutron-capture reactions. The four cosmogenic radionuclides that contribute a measurable radiation dose to man are carbon-14, sodium-22, beryllium-7, and tritium (hydrogen-3), all produced in the atmosphere.

II. BACKGROUND RADIATION DOSES

Background radiation doses consist of an external component of radiation impinging on man from outside the body and an internal component due to radioactive materials taken into the body by inhalation or ingestion.

Radiation dose may be expressed in units of rads or rems, depending upon whether the reference is to the energy deposited or to the biological effect. A rad is the amount of radiation that deposits a certain amount of energy in each gram of material. It applies to all radiations and to all materials which absorb that radiation.

Since different types of radiation produce ionizations at different rates as they pass through tissue, differences in damage to tissues, and hence the biological effectiveness of different radiations, has been noticed. A rem is defined as the amount of energy absorbed (in rads) from a given type of radiation multiplied by the factor appropriate for the particular type of radiation in order to approximate the biological damage that it causes relative to a rad of x or gamma radiation. The rem permits evaluation of potential effects from radiation exposure without regard to the type of radiation or its source. One rem received from cosmic radiation results in the same biological effects as one rem from medical x-rays or one rem from the radiations emitted by naturally occurring or man-made radioactive materials.

The external penetrating radiation dose to man derives from both terrestrial radioactivity and cosmic radiation. The terrestrial component is due primarily to the gamma dose from potassium-40 and the radioactive decay products of thorium-232 and uranium-238 in soil, as well as from the beta-gamma dose from radon daughters in the atmosphere. Radon is a gaseous member of the uranium-238 chain. The population-weighted external dose to an individual's whole body from terrestrial sources in the United States has been estimated as 15 mrem per year for the Atlantic and Gulf Coastal Plain, 57 mrem per year for an indeterminate area along the Rocky Mountains, and 29 mrem per year for the majority of the rest of the United States. The overall population-weighted external dose for the U.S. population as a whole has been estimated to be 26 mrem per year.

The cosmic radiation dose, due to the charged particles and neutrons from secondary cosmic rays, is typically about 30% to 50% of the total from all external environmental radiation. The cosmic-ray dose to the population is estimated to be 26 mrem per year for those living at sea level, and increases with increasing altitude. Considering the altitude distribution of the U.S. population, the population-weighted external cosmic-ray dose is 28 mrem per year. The population-weighted total external dose from terrestrial plus cosmic sources is thus 54 mrem per year for the U.S. population as a whole.

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(cont'd.)

The internal radiation doses derive from terrestrial and cosmogenic radionuclides deposited within the body through uptake by inhalation/ingestion of air, food, and drinking water. Once deposited in the body, many radioactive materials can be incorporated into tissues because the chemical properties of the radioisotopes are identical or similar to stable isotopes in the tissues. Potassium-40, for instance, is incorporated into tissues in the same manner as stable potassium atoms because the chemical properties are identical; radioactive radium and strontium can be incorporated into tissues in the same manner as calcium because their chemical properties are similar. Once deposited in tissue, these radionuclides emit radiation that results in the internal dose to individual organs and/or the whole body as long as it is in the body.

The internal dose to the lung is due primarily to the inhalation of polonium-218 and -214 (radon daughters), lead-212 and bismuth-212 (thoron daughters) and polonium-210 (one of the longer-lived radon decay products). The dose to the lung is about 100 mrem per year from inhaled natural radioactivity. The internal dose from subsequent incorporation of inhaled or ingested radioactivity is due to a beta-gamma dose from incorporation of potassium-40, rubidium-87, and cosmogenic nuclides, and an alpha dose from incorporation of primarily polonium-210, radium-226 and -228, and uranium-238 and -234. The dose to man from internally incorporated radionuclides is about 28 mrem per year to the gonads, about 25 mrem per year to the bone marrow, lung, and other soft tissues, and about 117 mrem per year to the bone (osteocytes). The bone dose arises primarily from the alpha-emitting members of the naturally occurring series, with polonium-210 being the largest contributor. The gonadal and soft tissue doses arise primarily from the beta and gamma emissions from potassium-40. The total internal dose from inhaled plus incorporated radioactivity is about 28 mrem per year to the gonads (or whole-body dose), about 125 mrem per year to the lung, about 25 mrem per year to the bone marrow, and about 117 mrem per year to the bone (osteocytes).

The total natural background radiation dose is the sum of the external and internal components. The population-weighted dose for the U.S. population as a whole is about 82 mrem per year to the gonads or whole body, about 179 mrem per year to the lung, about 79 mrem per year to the bone marrow, and about 171 mrem per year to the bone (osteocytes) (Ref. 1).

Besides the natural background radiation, background radiation doses include contributions from man-made or technologically enhanced sources of radiation. By far, the most significant are x-ray and radiopharmaceutical medical examinations. These contribute a population-averaged dose estimated to be 70 mrem per year for the U.S. population as a whole. Fallout from nuclear weapons testing through 1970 has contributed 50-year dose commitments estimated as 80 mrem external, and 30, 20, and 45 mrem internal to the gonads, lung, and bone marrow, respectively. Contributions from the use of fossil fuels (natural gas and coal) and nuclear reactors; mining, milling, and tailings piles; television sets, smoke detectors, and watch dials could be responsible for an additional 5 mrem per year, averaged over the U.S. population as a whole. In addition, the use of radiation or radioactivity for scientific, industrial, or medical purposes may cause workers in the industry, and, to a lesser extent, members of the general public to receive some radiation exposure above natural background.

APPENDIX 7
(cont'd.)III. EVALUATION OF RADIATION DOSE AND POTENTIAL HAZARD

Radiation, regardless of its sources, is considered to be a hazard because of its potential for producing adverse effects on human life. Very large amounts of radiation received over a brief period, i.e., hundreds of rem delivered within a few hours, can produce severe injury or death within days or weeks. Distributed over longer intervals, however, these same doses would not cause early illness or fatality. At doses and rates too low to produce these immediate symptoms, chronic or repeated exposure to radiation can bring about biological damage which does not appear until years or decades later. These low-level effects are stochastic in nature; their probability rather than their severity increases with dose. Primary among these latent or delayed effects are somatic effects, where insults such as cancers occur directly to the individual exposed, and genetic defects, where, through damage to the reproductive cells of the exposed individual, disability and disease ranging from subtle to severe are transmitted to the exposed individual's offspring.

Clinical or observed evidence of a relationship between radiation and human cancers arise from several sources. The most important data come from the victims of Hiroshima and Nagasaki, patients exposed during medical therapy, radium dial painters, and uranium miners. Data exist only for relatively large doses; there have been no direct measurements of increased incidence of cancer for low-level radiation exposures. Evaluation of the available data has led to estimates of the risk of radiation-induced cancer; estimated risks for the lower doses have been derived by linear extrapolation from the higher doses. All radiation exposures then, no matter how small, are assumed to be capable of increasing an individual's risk of contracting cancer.

Data on genetic defects resulting from radiation exposure of humans is not available to the extent necessary to allow an estimate of the risk of radiation-induced effects. Data from animals, along with general knowledge of genetics, have been used to derive an estimate of the risks of genetic effects.

Estimates of health effects from radiation doses are usually based on risk factors as provided in reports issued by the International Commission on Radiological Protection (ICRP) (Ref. 2), National Research Council Advisory Committee on the Biological Effects of Ionizing Radiation (BEIR) (Refs. 3 and 4), or, United Nations Scientific Committee on the Effects of Atomic Radiation (UNSCEAR) (Ref. 5). Multiplying the estimated dose by the appropriate risk factor provides an estimate of the risk or probability of induction of health effects to an individual or his descendants as a result of that exposure. The evaluation of these risk factors is presently subject to large uncertainties and, therefore, potential continual revision. The risk factors recommended by the ICRP for cancer mortality and hereditary ill health to the first and second generations are 10^{-4} per rem of whole body dose and 4×10^{-5} per rem of gonadal dose, respectively. As an example, a whole-body dose of 1 rem would be estimated to add a risk of cancer mortality to the exposed individual of 10^{-4} , i.e., 1 chance in 10,000. However, a precise numerical value cannot be assigned with

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(cont'd.)

any certainty to a particular individual's increase in risk attributable to radiation exposure. The reasons for this are numerous and include the following: (1) uncertainties over the influence of the individual's age, state of health, personal habits, family medical history, and previous or concurrent exposure to other cancer-causing agents, (2) the variability in the latent period (time between exposure and physical evidence of disease), and (3) the uncertainty in the risk factor itself.

To be meaningful, an attempt should be made to view such risk estimates in the appropriate context. One useful comparison is with risks encountered in normal life. Another comparison, potentially more useful, is with an estimation of the risks attributable to natural background radiation. Radiation from natural external and internal radioactivity results in the same types of interactions with body tissues as that from "man-made" radioactivity. Hence, the risks from a specified dose are the same regardless of the source. Rather than going through an intermediate step involving risk factors, doses can also be compared directly to natural background radiation doses.

Besides being used as the basis for estimation of risks and comparisons to natural background, doses may be compared to standards and regulations. The appropriate standards, the Department of Energy "Requirements for Radiation Protection," give limits for external and internal exposure for the whole body and specified organs which are expressed as the permissible dose or dose commitment annually in addition to natural background and medical exposures. There are in general two sets of limits, one applicable to occupationally exposed persons and the second applicable to individuals and population groups of the general public. The limits for individuals of the public are one-tenth of those permitted for occupationally exposed individuals. The set of limits important to this report are those applicable to individuals and population groups of the public. The limits for individuals of the public are 500 mrem per year to the whole body, gonads, or bone marrow and 1500 mrem per year to other organs. The limits for population groups of the public are 170 mrem to the whole body, gonads, or bone marrow and 500 mrem per year to other organs, averaged over the group. In either case, exposures are to be limited to the lowest levels reasonably achievable within given limits.

APPENDIX 7
(cont'd.)

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