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**URANIUM MILL TAILINGS
REMEDIAL ACTION PROGRAM**

**RADIOLOGICAL SURVEY OF
SHIPROCK VICINITY PROPERTY SH03
SHIPROCK, NEW MEXICO**

July – November 1982

MASTER

**OCCUPATIONAL HEALTH AND SAFETY DIVISION
Health Physics Section
ARGONNE NATIONAL LABORATORY, ARGONNE, ILLINOIS**

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9700 South Cass Avenue
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July - November 1982

Prepared by

K. F. Flynn	W. H. Smith
A. L. Justus	R. A. Wynveen
C. M. Sholeen	

Radiological Survey Group
Health Physics Section
Occupational Health and Safety Division

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Reports of Argonne National Laboratory Radiological Surveys
at Shiprock, New Mexico, Vicinity Property Sites

<u>Title</u>	<u>Report No.</u>
Radiological Survey of Shiprock Vicinity Property SH01, Shiprock, New Mexico	DOE/NE-SH01 ANL-OHS/HP-84-SH01
Radiological Survey of Shiprock Vicinity Property SH02, Shiprock, New Mexico	DOE/NE-SH02 ANL-OHS/HP-84-SH02
Radiological Survey of Shiprock Vicinity Property SH03, Shiprock, New Mexico	DOE/NE-SH03 ANL-OHS/HP-84-SH03
Radiological Survey of Shiprock Vicinity Property SH04, Shiprock, New Mexico	DOE/NE-SH04 ANL-OHS/HP-84-SH04
Radiological Survey of Shiprock Vicinity Property SH05, Shiprock, New Mexico	DOE/NE-SH05 ANL-OHS/HP-84-SH05
Radiological Survey of Shiprock Vicinity Property SH06, Shiprock, New Mexico	DOE/NE-SH06 ANL-OHS/HP-84-SH06
Radiological Survey of Shiprock Vicinity Property SH07, Shiprock, New Mexico	DOE/NE-SH07 ANL-OHS/HP-84-SH07
Radiological Survey of Shiprock Vicinity Property SH08, Shiprock, New Mexico	DOE/NE-SH08 ANL-OHS/HP-84-SH08
Radiological Survey of Shiprock Vicinity Property SH09, Shiprock, New Mexico	DOE/NE-SH09 ANL-OHS/HP-84-SH09
Radiological Survey of Shiprock Vicinity Property SH10, Shiprock, New Mexico	DOE/NE-SH10 ANL-OHS/HP-84-SH10
Radiological Survey of Shiprock Vicinity Property SH11, Shiprock, New Mexico	DOE/NE-SH11 ANL-OHS/HP-84-SH11
Radiological Survey of Shiprock Vicinity Property SH12, Shiprock, New Mexico	DOE/NE-SH12 ANL-OHS/HP-84-SH12
Radiological Survey of Shiprock Vicinity Property SH13, Shiprock, New Mexico	DOE/NE-SH13 ANL-OHS/HP-84-SH13
Radiological Survey of Shiprock Vicinity Property SH14, Shiprock, New Mexico	DOE/NE-SH14 ANL-OHS/HP-84-SH14
Radiological Survey of Shiprock Vicinity Property SH15, Shiprock, New Mexico	DOE/NE-SH15 ANL-OHS/HP-84-SH15
Radiological Survey of Shiprock Vicinity Property SH16, Shiprock, New Mexico	DOE/NE-SH16 ANL-OHS/HP-84-SH16
Radiological Survey of Shiprock Vicinity Property SH17, Shiprock, New Mexico	DOE/NE-SH17 ANL-OHS/HP-84-SH17

PREFACE AND EXECUTIVE SUMMARY

Much of the uranium ore mined in the United States from the early 1940s through 1970 was processed for the Federal Government by private companies. Millions of tons of uranium mill tailings and other wastes were created by this processing. At the time, the potential health hazards of these wastes were not recognized, and little effort was made to control their dispersal by nature or by man. Because of their sandy composition, mill tailings proved attractive for use in construction and soil conditioning and as fill material. As a result, some radioactive tailings were removed from old tailings piles for use in or around buildings or in other areas frequented by humans. As awareness of the potential health hazards of radioactive mill tailings grew, efforts were undertaken by the Federal Government to assess the extent of the problem relative to abandoned uranium tailings piles. A program was initiated in 1972 to perform initial evaluations of inactive uranium mill tailings sites to determine their radiological status and potential health effects on the public. This effort eventually led to the designation by Congress of 25 inactive uranium processing sites and/or associated vicinity properties for remedial action under the Uranium Mill Tailings Radiation Control Act of 1978. The inactive uranium processing site (and associated vicinity properties) at Shiprock, New Mexico, is one of the processing sites thus designated.

At the request of the Department of Energy (DOE), a detailed radiological assessment of the vicinity properties at Shiprock was conducted by the Radiological Survey Group (RSG) of the Occupational Health and Safety Division, Health Physics Section (OHS/HP) of Argonne National Laboratory (ANL). As part of that assessment, a comprehensive survey of the vicinity property designated as "SH03" was conducted on an intermittent basis from July 26 to November 11, 1982. At the time of the survey, three structures were located on the property--a residential trailer, the main structure (a wooden building housing a thrift shop), and an old gas pump housing. The lands surrounding the structures were either sparsely covered with arid vegetation or paved.

The assessment activities included determination of indoor and outdoor surface radiation levels, for both fixed and removable contamination, through direct instrument and smear (indoor only) surveys; measurement of ambient external penetrating radiation levels at 1-meter heights; and analyses of air, soil, and other material samples.

No evidence of radioactive contamination was found inside the trailer. However, the results of the radiological assessment did indicate the occurrence of elevated levels of gamma, surface alpha, and radon daughter radioactivity within the main structure. The short-term radon daughter measurements exceeded the limit of 0.02 Working Level for average annual concentration including background, as specified in the EPA Standard 40 CFR 192. The elevated radiation levels are believed to be caused by the presence of material containing radium-226 underneath (or directly adjacent to) the concrete foundation, encompassing generally the southern half of the structure (about 1900 ft² of area).

The assessment also indicated elevated levels of radioactivity in the outdoor environs, encompassing about 32,000 ft² (3000 m²) of the grounds adjacent to and surrounding the main structure on the east, south, and west sides. The contamination appeared to be due to the presence of unprocessed uranium ore. Analysis of surface soil samples collected from the environs indicated radium concentrations in excess of the limit of 5 pCi/g above background specified in the EPA Standard. Subsurface soil sampling was not conducted, and thus the vertical extent of the radiological contamination is not known. Since the surface soil contamination levels exceeded the limits specified in the EPA Standard, remedial action for this vicinity site should be considered.

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URANIUM MILL TAILINGS REMEDIAL ACTION PROGRAM
RADIOLOGICAL SURVEY OF SHIPROCK VICINITY PROPERTY SH03
SHIPROCK, NEW MEXICO

INTRODUCTION

Much of the uranium ore mined within the United States from the early 1940s through 1970 was processed by private companies for the Federal Government's Manhattan Engineer District (MED) and the Atomic Energy Commission (AEC). Millions of tons of uranium mill tailings and other radioactive wastes were created as a result of this processing. Most of the mills used during the 1940s through 1970 are now dormant, but their tailings piles remain. At most of the sites, some tailings have been dispersed from the piles by natural forces (e.g., wind and water erosion). Additionally, some tailings have been removed by man for use in or around buildings or other areas because tailings, a sand-like material, are attractive for use in construction and soil conditioning and as a fill material.

During this earlier period of the uranium milling industry, people generally were not aware of the potential public health hazards from exposure to the radioactive mill tailings, and the general scientific consensus at the time was that the effects of such exposure on the public were minimal. Since then, however, radiation exposure guidelines have become more stringent as research on the effects of low-level radiation exposure has revealed the potential dangers involved. As a result, a program was initiated in 1972 to perform initial evaluations of inactive uranium mill tailings sites to determine their radiological status and potential health effects on the public. Since 1972, several efforts have been directed towards identifying sites, conducting radiological and engineering assessments at many of the sites, and developing legislation to initiate remedial action at inactive uranium mill tailings site.¹

These efforts eventually led to the designation by Congress of 24 inactive uranium processing sites and associated vicinity properties, and of the vicinity properties at an inactive uranium mill in South Dakota, for

remedial action under the Uranium Mill Tailings Radiation Control Act of 1978.² The Act authorizes the Department of Energy (DOE), in cooperation with the interested states, Indian tribes, and persons who own or control inactive uranium mill tailings sites, to establish assessment and remedial action programs at such sites in order to stabilize and control such tailings and minimize or eliminate health hazards to the public. It further requires that DOE will meet radiation standards promulgated by the Environmental Protection Agency (EPA).

The inactive uranium processing site (including associated vicinity properties) at Shiprock, New Mexico, is one of the processing sites designated for remedial action under the Act. Upon advice from the EPA, the DOE has established the site as a high-priority site in regards to the performance of remedial action. Shiprock is located on the Navajo Indian Reservation, approximately 30 miles west of Farmington, New Mexico.

The ore processing mill at Shiprock was constructed by Kerr-McGee Oil Industries, Inc., on land leased from the Navajo Nation. The mill was operated by Kerr-McGee from late 1954 until 1963, when it was purchased by Vanadium Corporation of America (VCA). From 1963 to mid-1968, the mill was operated by VCA and its successor, Foote Mineral Company.³

During the operating lifetime of the mill, uranium ore assaying at about 0.25% uranium as uranium oxide (U_3O_8) and 1% vanadium oxide (V_2O_5) was mined, hauled to the mill in 14-ton tandem trucks (generally over about 100 rugged miles), and processed to produce uranium concentrate which was purchased by the AEC. The uranium-vanadium ore was mostly sandstone, containing carnotite as the principal ore mineral. The processing involved the crushing and grinding of the ore to minus-18 (1 mm) mesh, followed by two stages of leaching, then washing, and finally ion-exchange or solvent extraction of the uranium.⁴ Estimated uranium extraction efficiency for the process was 97%. The mill processed about 1.5 million tons of ore and produced a total of 3700 tons of uranium concentrate (about 79% uranium as U_3O_8). Vanadium concentrate was also produced in 1955 and again during the period 1960 to 1968 and sold on the commercial market.

The mill ceased operations in 1968 and has since been dismantled, although some of the former buildings remain. On expiration of the lease of the site in 1973, control of the land reverted to the Navajo Nation. Two

large tailings piles created during operation of the mill still exist at the site. These tailings piles, covering a total of 72 acres, have been stabilized to some extent with a cover of soil and/or river cobble.

The inactive uranium processing site at Shiprock has been the focus of several radiological assessments over the past several years. In the early 1970s, a mobile gamma-ray scan of the Shiprock area performed by AEC for the EPA identified nine anomalies among the 558 structures scanned. Ten locations were subsequently investigated during preliminary property surveys, indicating the presence of tailings or other wastes from mill operations.³ Radiological and engineering assessments of the millsite proper were conducted in 1974 and 1976.^{3,5,6} More recently, at the request of DOE an aerial radiological survey of the Shiprock area was performed in December 1980 by EG&G, Inc. That survey revealed four areas, in addition to the tailings piles, exhibiting gamma radiation above background levels.⁷ As part of the next phase of DOE's activities in the Shiprock area, a mobile gamma-ray scan was performed in April 1982 by Oak Ridge National Laboratory (ORNL). Based on the results of that scan, 14 properties in the Shiprock vicinity were recommended for future comprehensive onsite surveys.⁸ To satisfy this recommendation, DOE requested that the Radiological Survey Group (RSG) of the Occupational Health and Safety Division, Health Physics Section (OHS/HP) of Argonne National Laboratory (ANL) conduct a detailed investigation of these vicinity properties to delineate the radiological characteristics of any contamination. Subsequent to the mobile gamma-ray scan, three additional properties were identified and added to the list, making a total of 17 vicinity properties investigated by the ANL group. To protect the privacy of owners, these properties have been designated as SH01 to SH17. Survey results for each of the 17 sites are provided in separate reports. A complete list of the reports in this series is found at the front of this document.

The results of these detailed investigations will form the basis for informed decisions regarding remedial action at the vicinity properties. Based on the history of the Shiprock site, any contamination found is expected to consist of mill tailings (predominantly ^{226}Ra plus daughters), uranium ore, or uranium concentrate (i.e., yellowcake). Various combinations of these three contaminants could also occur.

VICINITY SITE DESCRIPTION

A comprehensive radiological survey was conducted of vicinity property SH03 on an intermittent basis from July 26 to November 11, 1982. The location of SH03 relative to the Shiprock area as a whole is shown in Figure 1. The layout of the property, delineating the property boundaries as provided by the site owner, is shown in Figure 2. The property is approximately a right-triangle of 400-foot sides.

Before the Shiprock mill began operations, a concrete slab at this location was used as an ore transfer station.^{3,9} During World War II, several small loads of uranium ore were delivered to this station from the many small mines in the area. At the station, the loads of ore were deposited on the concrete slab, then reloaded onto larger trucks for hauling to mills located off the Navajo Reservation. The last time ore was stored at the transfer site was in late 1950. Since then, the station has been partially decontaminated and buildings have been constructed on the lot.

At the time of the survey, three structures were located on the property. The main structure (see Fig. 3) was a single-story wooden building approximately 30 feet wide and 134 feet long. It formerly was used as a general store, with a market space, a walk-in cooler and freezer, and a garage. At the time of this survey, the building was used as a thrift store. Occupancy at the time of the survey was low, consisting of several part-time employees of the thrift store. The second structure, located due west of the garage, was an old gas pump housing with a concrete foundation. This "structure" had no occupancy, and for the purposes of this report, is considered in the open lands category. The third structure, a 9.5 x 43-foot residential trailer (or mobile home), was located approximately 100 feet east of the main structure. Occupancy at the time of the survey was occasional, consisting of perhaps two adults.

The "open lands" that surround the structures were either sparsely covered with arid vegetation or paved. Asphalt pavement covered the land west of the main structure.

SURVEY, SAMPLING, AND ANALYTICAL TECHNIQUES

General

The assessment activities included determination of indoor and outdoor surface radiation (radioactive material) levels, both fixed and removable, through direct instrument and smear (indoor only) surveys; measurement of ambient external penetrating radiation levels at 1-meter heights throughout the involved areas; measurement of the concentrations of radon, thoron, and actinon daughters and longer-lived radionuclides in air samples; and determination of concentrations of the radium-226 decay chain, the thorium-232 decay chain, and uranium in soil and other material samples from the involved areas. The direct instrument and smear surveys were performed on all accessible indoor floors and walls to a height of about 2 m. In some areas, building surfaces might have been retiled, painted, or otherwise covered since the introduction of radioactive materials; however, the instruments utilized for the direct survey had some capability to detect beta-gamma activity on the underlying surfaces. The direct instrument surveys were additionally performed on all accessible outdoor environs.

The locations of accessible areas surveyed are listed in Table 1 and shown in Figures 2 and 3.

Direct Instrument Surveys

Four types of portable survey instruments were used to conduct the direct radiological surveys. NaI(Tl)-crystal detectors, 1-in diameter by 1-in thick (Eberline PRM-7 μ R meter) and calibrated with a ^{226}Ra standard source, were used to measure the ambient external penetrating radiation field in units of $\mu\text{R/h}$. NaI(Tl)-crystal detectors, 2-in 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. Gas-flow proportional detectors with detection areas of 51 cm^2 or 330 cm^2 , and utilizing Eberline PAC-4G-3 electronics, were used to monitor for direct alpha and/or beta-gamma surface contamination. The larger-area probe was used in Eberline floor monitors (FM-4G), and the smaller, hand-held probe (Eberline AC-21)

was used to survey the walls, overheads, and other areas that could not be surveyed with the floor monitor. 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. All accessible areas, both indoors and out, were surveyed with the above instruments. These instruments and associated calibration procedures are detailed in Appendices 1 and 2.

Although ^{239}Pu and ^{90}Sr - ^{90}Y 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 ^{226}Ra plus daughters, or 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 (dis/min-100 cm²), as reported in Table 1, are equated to ^{226}Ra plus daughters, 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 to a multichannel analyzer. This instrumentation (also described in Appendix 1), along with

*The term "normal uranium" refers to uranium that has been separated from its radioactive decay products and other impurities, and that has the normal isotopic percent abundances as found in nature. The normal percent abundances are 0.0054% ^{234}U , 0.720% ^{235}U , and 99.2746% ^{238}U .¹⁰ The less precise definition of normal uranium as 0.7% ^{235}U , 99.3% ^{238}U , and a trace of ^{234}U is sometimes used for brevity. 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.

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 a 4.25-cm-diameter filter paper (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 walls and floors.

To expedite the counting of the 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 from any group of ten 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 ²²⁶Ra plus daughters, as described in Appendix 2.

Ambient Penetrating Radiation Measurements

The areas being surveyed were additionally monitored for ambient external penetrating radiation levels (in $\mu\text{R/h}$) 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 Fig. 3). Integration periods were minimally five 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 l/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.

A microprocessor-based Environmental Working Level Monitor (EWLM) developed at ANL was used to automatically perform series of airborne ^{222}Rn daughter concentration and Working Level (WL) measurements at increments of one or three hours. For each measurement, air was drawn for three minutes through a Gelman membrane filter at a flow rate of 38 l/m ($2.3 \text{ m}^3/\text{h}$). Subsequent counts of alpha spectral and beta-gamma activity, using diffused junction and plastic scintillator detectors, respectively, were analyzed by the programmed microprocessor and the results printed.

Air-particulate samples were also collected on Millipore membrane filter medium using a positive-displacement pump at a flow rate of about $1 \text{ m}^3/\text{h}$ (17 l/m). Sampling periods were minimally 90 minutes. A portion of each filter medium was used to determine the actinon (^{219}Rn) daughter concentration through alpha spectral analysis using a surface barrier detector.

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 Rock Samples

Three rock samples (18A-R-1 through 3), one soil coring sample (18A-S-4A through C), and two surface soil samples (18A-S-5 and 6) were collected from the lands about the main structure (see Fig. 2). Each sample was collected from a localized area exhibiting elevated levels of radioactivity (i.e., "hot spots") as determined by direct instrument survey. Two surface soil samples (18BKGD-SB-1 and 2) were taken at additional locations in the Shiprock area to determine background levels of radionuclides in the soils of the area. It should be noted that subsurface soil sampling was not performed.

The surface soil samples were taken to about a 2-in depth with a small hand trowel and bagged. The rock samples were collected by hand and bagged. The coring sample was collected with a 10-cm-diameter, 30-cm-long right-circular-cylinder cutting tool commonly used to cut golf-green holes. The soil core was 15 cm long and was divided into three segments for analysis. Starting from the surface, three separate 5-cm segments were cut, bagged, and marked A, B, and C, respectively. 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 samples were prepared at Argonne National Laboratory (ANL). The preparation procedures for soil, consisting generally of drying, milling, and sieving (see Fig. 4), are described in detail in Appendix 4. At no point in the preparation of soil samples 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). The rock-sample-preparation procedures consisted of crushing and pulverizing. In addition to the three rock samples (18A-R-1 through 3), the rock portion of sample 18A-S-4A was also individually processed in this manner.

All 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 or rock sample (in pCi/g). Analysis details are included in Appendix 4.

SURVEY AND SAMPLING RESULTS

Direct Instrument and Smear Surveys

The results of the direct instrument and smear surveys are given in Table 1, and areas with readings above background are indicated in Figures 2 and 3. 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 $\mu\text{R/h}$) are reported as net rates above the appropriate background. The PAC-4G-3 instrument readings and smear results have been normalized to units of dis/min-100 cm^2 using the factors derived in Appendix 2 and are equated to ^{226}Ra plus daughters, unless otherwise stated. The PAC-4G-3 readings and smear data are reported in net disintegration rates, i.e., the background count rates have been subtracted from the gross count rates prior to conversion to dis/min-100 cm^2 . 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.

Depending on 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 the footnotes to Table 1.

- Inside Structures - Elevated levels of radioactivity, as indicated by direct measurements considerably above the background levels, were found at 14 discrete spots or localized areas (i.e., "hot spots") within the main structure. In addition, the entire southern half of the building, encompassing about 1700 ft^2 of area, generally exhibited levels above those of the ambient background (see Table 1 and Fig. 3). The localized spots were found in the main room, the office, and two

other south rooms (including the cooler). Two southern rooms, encompassing about 200 ft² of area, were inaccessible for survey and presumed to be included in the involved areas. Within the office, the PRM-7 readings indicated up to 20 μ R/h above background at about a height of 1 m.

Radioactive contamination was detected on one of the smears from the main room wall, indicating the presence of removable contamination. The results, included in Table 1, are 30 ± 14 dis/min-100 cm² beta-gamma and background alpha, normalized to ²²⁶Ra plus daughters.

The results of the direct instrument surveys in the residential trailer revealed only background radiation levels. The smear survey in the trailer revealed no removable contamination.

- Outside Environs - Elevated levels of radioactivity, indicated by direct measurements considerably above the background, were found at 21 discrete hot spots or localized areas in the environs. Additionally, the grounds adjacent to and surrounding the main structure on the east, south, and west sides exhibited levels of radioactivity above those of the ambient background (see Table 1 and Fig. 2). From the main structure, this general area of contamination extended about 50 ft east, and over 150 ft and 60 ft to the south and west, respectively, involving about 32,000 ft² of land area.

The samples collected from six of the discrete hot spots were found by direct instrument measurements to contain the source of the anomalous radiation levels initially detected. It was further determined that the source of the radiation was one or more rocks or stones. Gamma-spectral analyses performed on the samples at the time of the survey indicated the presence of natural uranium ore. This finding was substantiated not only by the vicinity site history,^{3,9} but also by the owner and others, who recounted the day when an overloaded ore truck dropped its excess on the property. The land was later leveled, followed by the construction of the main structure.

Ambient Penetrating Radiation Measurements

The results of the ambient external penetrating radiation measurements with the RSS-111 pressurized ionization chamber are presented in Table 2. Prior to each measurement, each location chosen was surveyed with the PRM-7 μR meter. The location in the trailer gave a measurement (11.4 $\mu\text{R}/\text{h}$) believed to be representative of the area background. The locations chosen within the main room of the main structure yielded exposure rates of 15.0 and 20.1 $\mu\text{R}/\text{h}$. The location chosen within the office, at the point of maximum exposure rate 1 m above the localized hot spot therein, yielded 27.6 $\mu\text{R}/\text{h}$, or 16.2 $\mu\text{R}/\text{h}$ above the area background (11.4 $\mu\text{R}/\text{h}$). This is less than the 20 $\mu\text{R}/\text{h}$ above background limit, averaged over a limited area, as specified in the EPA Health and Environmental Protection Standards for Uranium Mill Tailings, Section 192.12 (b)(2) and 192.20 (b)(1) (see Appendix 6).

Air Samples

Results of the analyses of air samples collected at selected locations within the main structure and trailer, and under varying conditions or states of ventilation, are presented in Tables 3 and 4.

The 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 presented in Table 3. The radon daughter concentrations, as reported there, ranged from 2.30 to 25.6 mWL in the main structure and was 0.823 mWL in the residential trailer. The higher values were measured in a sampling period following a night-long closeup of the structure. The lower values correspond to sampling in a "ventilated" condition. The highest value was above 0.02 WL (or 20 mWL), the limit for average annual concentration including background as specified in the EPA Standard, Section 192.12 (b)(1). If an equilibrium factor* of 0.5 is assumed, radon concentration, as

*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 0.5.

determined from the radon daughter concentrations, ranged from 0.46 to 5.12 pCi/l in the main structure and was 0.16 pCi/l in the trailer. The highest value was above the concentration guide of 3 pCi/l for an uncontrolled area, as given in the DOE Order 5480.1 "Requirements for Radiation Protection" (see Appendix 6).

The thoron daughter concentration (ThB and ThC) was 6.9×10^{-3} pCi/l in the main structure and 2.1×10^{-3} pCi/l in the trailer. 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." No actinon (^{219}Rn) daughter or long-lived radionuclides were detected in any air sample.

The results of the automated Environmental Working Level Monitor (EWLM) measurements performed within the main structure (south location) are presented in Table 4. For the series of measurements conducted at one-hour increments, the radon daughter concentrations ranged from 13.2 to 66.8 mWL, with an overall average of 26.8 mWL. For the subsequent, longer-termed series conducted at three-hour increments, the radon daughter concentrations ranged from 2.45 to 105.4 mWL, with an overall average of 21.1 mWL. These average values are above the EPA limit of 20 mWL for average annual concentrations including background.

Soil and Rock Samples

The results of the gamma-spectral and uranium-fluorometric analyses performed on the environmental surface soil, soil coring, and rock samples are listed in Table 6. The results of analyses of the two background surface soil samples are listed as well. Due to an urgency for immediate results, the samples for gamma-spectral analysis were counted immediately and not allowed to first sit the 30 days required for ingrowth of the ^{222}Rn activity lost during sample preparation and processing. Recounts of several of the Shiprock vicinity sites samples, following that ingrowth, have yielded an average ingrowth correction factor. The ^{226}Ra decay chain con-

centrations reported in the "30-day corrected" column in Table 6 reflect this ingrowth.

- Soil Samples - The gamma-spectral analysis of the two surface soil samples (18A-S-5 and 6) indicated thorium decay chain concentrations of 0.74 ± 0.07 and 0.71 ± 0.07 pCi/g, respectively, and radium decay chain concentrations of 18 ± 2.3 and 26 ± 2.3 pCi/g, respectively. Uranium fluorometric analysis indicated uranium concentrations of 41 ± 4.1 and 54 ± 5.4 pCi/g, respectively.

Gamma spectral analysis of the soil coring sample segments (18A-S-4A through C) indicated thorium decay chain concentrations of < 0.1 , 0.65 ± 0.07 , and 0.56 ± 0.06 pCi/g, respectively, and radium decay chain concentrations of 281 ± 23 , 10 ± 1 , and 9 ± 1 pCi/g, respectively. Uranium fluorometric analysis indicated 340 ± 34 , 22 ± 2.2 , and 17 ± 1.7 pCi/g, respectively.

As indicated in Table 6, analyses of the background soil samples indicated about 0.84 ± 0.08 pCi/g of the thorium decay chain, 1.50 ± 0.15 to 1.92 ± 0.19 pCi/g of the radium decay chain, and 2.0 ± 0.2 pCi/g of uranium. Hence, all surface soil and soil coring segments collected at the SH03 vicinity property site had radium decay chain and uranium concentrations in excess of background concentrations. The radium decay chain concentrations in the soil samples were, additionally, in excess of the 5 pCi/g above background limit, averaged over the first 15 cm (6 in) of soil below the surface, as specified in the EPA Standard, Section 192.12 (a)(1) (see Appendix 6). The uranium concentrations in three of the soil samples were in excess of a proposed interim soil limit of 40 pCi/g for decommissioning and decontamination projects (Ref. 11 and Appendix 6).

- Rock Samples - Gamma-spectral analysis of the three rock samples (18A-R-1 through 3) and the rock portion of sample 18A-S-4A indicated radium decay chain concentrations of 4511 ± 451 , 1579 ± 158 , 1162 ± 113 , and 1759 ± 176 pCi/g, respectively, and all < 0.1 pCi/g of the thorium

decay chain. Uranium fluorometric analysis indicated uranium concentrations of $12,000 \pm 1200$, 2200 ± 220 , 3100 ± 310 , and 4100 ± 410 pCi/g, respectively. The concentrations of uranium and the radium decay chain in the rock samples were in excess of background and the appropriate limit.

When the radium decay chain concentration, as determined by gamma-spectral analysis, appears to be 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 ore (i.e., uranium in equilibrium with its daughters) is present. When the reverse of this is found, i.e., when the radium decay chain concentration appears much greater than about half the uranium concentration, it is indicative of radium enhancement similar to that found in uranium mill tailings. Since the radium decay chain concentrations in all the soil and rock samples at the SH03 site appeared to be about half the respective uranium concentrations, the contamination apparently is primarily natural uranium in the form of unprocessed uranium ore.

SIGNIFICANCE OF FINDINGS

The radiological assessment conducted at the Shiprock vicinity property SH03 by the ANL Radiological Survey Group indicated elevated levels of radioactivity within the main structure, encompassing basically the entire southern half of the structure (about 1900 ft² of area). Gamma-radiation exposure rates reached about 28 μ R/h, including a background of about 11 μ R/h, or about 17 μ R/h above background, less than the 20 μ R/h above background limit specified in the EPA Standard (40 CFR 192.12[b][2]). Alpha surface contamination levels reached 500 dis/min-100 cm² α , equated to ²²⁶Ra plus daughters. Short-term radon daughter measurements exceeded the 0.02 WL (or 20 mWL) limit for average annual concentration including background as specified in Section 192.12 (b)(1) of the EPA Standard. Long-term radon daughter measurements will be required in the main structure in order to further evaluate the average annual radon decay product concentration

relative to the EPA limit, notwithstanding considerations of cost of remedial action, period of occupancy, and the residual useful lifetime of the building (see Section 192.21[d]). Based on indoor measurements, it is believed that the elevated radon daughter, alpha, and gamma radiation levels inside the main structure are a result of the presence of contaminated ^{226}Ra -bearing material underneath (or directly adjacent to) the concrete foundation and the subsequent diffusion of radon into the structure.

The assessment further indicated elevated levels of radioactivity in the outdoor environs, encompassing about 32,000 ft² (3000 m²) of the grounds adjacent to and surrounding the main structure on the east, south, and west sides. The radiation appeared to be due to the presence of rocks and stones. Radiochemical analysis of these rocks and stones indicated natural uranium ore as the contaminant. Analysis of soil samples collected from the environs indicated from 9 ± 1 to 218 ± 23 pCi/g of radium, all in excess of the limit of 5 pCi/g above background, averaged over the first 15 cm of soil below the surface, as specified in Section 192.12 (a)(1) of the EPA Standard. Subsurface soil sampling of the open lands will be required to determine the concentrations of radium and other radionuclides beneath the first 15 cm of soil; the vertical extent of the radiological contamination is presently unknown. Associated uranium analysis of the soil samples indicated natural uranium as the contaminant. Because of the history of this vicinity site and the analyses of the collected soil and rock samples, the contamination appears to be "residual radioactive material" in the form of unprocessed uranium ore under the provisions of the Uranium Mill Tailings Radiation Control Act of 1978. Since the surface soil contamination levels exceed the limits specified in the EPA Standard, remedial action for this vicinity site should be considered.

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Figure 1. Vicinity Site Location.

ANL-HP DWG.NO. 82-49

Figure 2. Survey and Sampling Locations for SHO3 Environs.

ANL HP DWG. NO. 82-37

Figure 3. Survey and Sampling Locations in Main Structure.

ANL HP DWG. NO. 83-1

Figure 4. Soil Sample Preparation Procedures

ANL- HP DWG.NO 78-2

TABLE 1. RESULTS OF DIRECT INSTRUMENT AND SMEAR SURVEYS

Location	PAC-4G-3 Direct Readings ^a (dis/min-100 cm ²)		GM Reading (mR/h) @ contact	PRM-7 (μR/h) @ 1 meter	PG-2 Low-Energy x & y (cts/min)	Smear Results (dis/min-100 cm ²)		Comments
	Beta-Gamma	Alpha				Beta-Gamma	Alpha	
<u>Main Structure</u>								
Main Room	4.2x10 ² to 1.5x10 ⁴	BKGD ^b to 5.0x10 ²	0.01 to 0.18	5 to 16	1.4x10 ⁴ to 4.9x10 ⁴	BKGD	BKGD	Eleven points of elevated activity (i.e., "hot spots")
	BKGD to 1.7x10 ²	BKGD to 1.7x10 ²	NRR ^c	4 to 13	1x10 ³ to 8.5x10 ³	BKGD to 30±14	BKGD	General area of activity at south end above ambient background.
	BKGD	BKGD	NRR	BKGD	BKGD	BKGD	BKGD	Rest of survey, at north end, was background
North Rooms	BKGD	NRR	NRR	BKGD	BKGD	BKGD	BKGD	Background
Office	9.0x10 ³	NRR	0.03	20	1.9x10 ⁴	BKGD	BKGD	Point of ele- vated activity.
	BKGD to 6.7x10 ²	NRR	NRR	11 to 20	BKGD to 6.5x10 ³	BKGD	BKGD	Rest of survey was a general area of activity above background.

TABLE 1 (cont'd.)

Location	PAC-4G-3		GM Reading (mR/h) @ contact	PRM-7 (μR/h) @ 1 meter	PG-2 Low-Energy x & y (cts/min)	Smear Results		Comments
	Direct Readings ^a (dis/min-100 cm ²)					(dis/min-100 cm ²)		
	Beta-Gamma	Alpha				Beta-Gamma	Alpha	
Other south rooms	1.1x10 ⁴ to 1.4x10 ⁴	BKGD to 1.7x10 ²	0.03 to 0.08	11 to 13	1.4x10 ⁴ to 4.4x10 ⁴	BKGD	BKGD	Two points of elevated activity.
	BKGD	NRR	NRR	3 to 11	BKGD to 2.5x10 ³	BKGD	BKGD	General area of activity above ambient back-
	BKGD	NRR	NRR	BKGD to 5	BKGD	NS ^d	NS	Rest of survey was background.
Garage	NRR	NRR	NRR	5 to 10	1.0x10 ³ to 6.0x10 ³	NS	NS	General area of activity above ambient background.
<u>Trailer</u>	BKGD	NRR	NRR	BKGD	BKGD	BKGD	BKGD	Survey was background.
<u>Outside Environs</u>	4.0x10 ³ to 6.2x10 ⁴	BKGD to 1.6x10 ³	BKGD to 0.7	2 to 40	8.0x10 ³ to 9.8x10 ⁴	NS	NS	Twenty-one points of elevated ac- tivity (i.e., "hot spots")
	BKGD to 9.0x10 ³	BKGD	BKGD to 0.1	BKGD to 70	BKGD to 3.8x10 ⁴	NS	NS	General area of activity above ambient background.

TABLE 1 (cont'd.)

Location	PAC-4G-3		GM Reading (mR/h) @ contact	PRM-7 (μR/h) @ 1 meter	PG-2		Smear Result (dis/min-100 cm ²) Beta-Gamma Alpha	Comments
	Direct Readings ^a (dis/min-100 cm ²)				Low-Energy x & y (cts/min)			
	Beta-Gamma	Alpha						
<u>Outside</u> <u>Environs</u> (cont'd.)	BKGD	NRR	NRR	BKGD	BKGD	NS	NS	Rest of survey was background.

^aThe beta mode direct readings and alpha mode direct readings were 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, in which 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:

Instrument	Beta Mode	Alpha Mode
PAC-4G-3 with 51 cm ² probe	250 - 400 cts/min-51 cm ²	0 - 50 cts/min-51 cm ²
PAC-4G-3 with 330 cm ² probe	5 k cts/min-330 cm ²	0 - 50 cts/min-330 cm ²
PC-5 or 3A	48 $\pm$ 3 cts/min*	0.6 $\pm$ 0.3 cts/min*
10-wire	464 $\pm$ 14 cts/min*	1.9 $\pm$ 0.6 cts/min*
GM End Window	0.01 - 0.02 mR/h	
PRM-7	8 - 12 μ R/h	
PG-2 with PRM-5-3	1.5 k - 2 k cts/min, indoors	
	2 k - 2.5 k cts/min, outdoors	

^cNRR = No Reading Recorded

^dNS = No Smear Taken

* $\pm$ 2 σ due to counting statistics.

TABLE 2. AMBIENT PENETRATING RADIATION MEASUREMENTS

Location	RSS-111 Integrated Exposure (μ R) ^a	Period of Integration (hr)	Exposure Rate (μ R/h) ^a
<u>Main Structure</u>			
Main Room- south	342	17.02	20.1
Main Room- north	75	5.00	15.0
Office	138	5.00	27.6
<u>Trailer</u>	269	23.67	11.4

^aOne meter above ground.

TABLE 3. RADON DAUGHTER DETERMINATIONS

Location	Figure Showing Location	^{222}Rn (Radon) Daughter Concentration ($\times 10^{-3}$ WL ^a)	^{220}Rn (Thoron) Daughter Concentration (pCi/l)	^{219}Rn (Actinon) Daughter Concentration (pCi/l)	Comments ^d
<u>Main Structure</u>					
Main Room-near entrance	3	25.6	6.9×10^{-3}	BDL ^b	7/27/82, 10:00, U
Main Room-north	3	9.53 3.18	- -	NS ^c	7/29/82, 10:35, U 7/30/82, 13:40, V
Main Room-south	3	12.0 2.30	- -	NS	7/29/82, 10:33, U 7/30/82, 13:55, V
<u>Trailer</u>	-	0.823	2.1×10^{-3}	BDL	7/28/82, 10:51, U

^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

^dU = Denotes an air sample collected during or immediately following a generally unventilated condition; V = Denotes an air sample collected during or immediately following a generally ventilated condition.

TABLE 4. ENVIRONMENTAL WORKING LEVEL MONITOR MEASUREMENTS OF RADON DAUGHTER
CONCENTRATIONS IN THE MAIN ROOM-SOUTH
(July 27 to August 2, 1982)

Date	Time	mWL ^a (±%)	Condition of Ventilation ^b	Date	Time	mWL (±%)	Condition of Ventilation
1 hr increments				3 hr increments (cont'd.)			
7/29/82	14:09	50.4 (3.7)	U	7/31/82	00:59	2.45 (37)	U
	15:09	57.6 (3.4)	U		03:59	9.64 (11)	U
	16:09	66.8 (3.2)	U		06:59	10.7 (9.7)	U
	17:09	44.1 (4.1)	U		09:59	11.2 (10)	V
	18:09	40.4 (4.1)	U		12:59	34.2 (4.8)	V
	19:09	31.2 (5.0)	U		15:59	84.0 (2.8)	U
	20:09	26.3 (5.6)	U		18:59	105.4 (2.8)	U
	21:09	15.4 (7.8)	U		21:59	63.7 (3.2)	U
	22:09	15.4 (3.0)	U	8/1/82	00:59	16.5 (7.6)	U
	23:09	13.2 (9.2)	U		03:59	8.47 (12)	U
7/30/82	00:09	15.7 (8.0)	U		06:59	7.84 (13)	U
	01:09	15.8 (7.8)	U		09:59	5.77 (16)	U
	02:09	17.5 (7.1)	U		12:59	18.4 (7.0)	U
	03:09	18.1 (7.3)	U		15:59	43.0 (4.0)	U
	04:09	16.8 (7.4)	U		18:59	17.4 (7.5)	U
	05:09	14.0 (8.5)	U		21:59	8.87 (12)	U
	06:09	16.9 (7.5)	U	8/2/82	00:59	5.00 (20)	U
	07:09	15.6 (8.0)	U		03:59	12.4 (9.3)	U
	08:09	17.4 (7.4)	U		06:59	18.0 (7.1)	U
		<26.8>			09:59	5.31 (17)	V
						<21.1>	
3 hr increments							
7/30/82	12:59	5.99 (16)	V ^c				
(cont'd.)	15:59	2.48 (37)	V				
	18:59	5.34 (19)	U				
	21:59	3.58 (26)	U				

^amWL = milli (or $\times 10^{-3}$) Working Level

^bU = Denotes an air sample collected during or immediately following a generally unventilated condition; V = Denotes an air sample collected during or immediately following a generally ventilated condition.

TABLE 5. SOIL AND MATERIAL SAMPLE WEIGHTS
(grams)

Sample Number	Wet Weight	Dry Weight	Sieved Weight	Rocks and Dross
18A-R-1	283 (ground up)	-	-	-
18A-R-2	48 (ground up)	-	-	-
18A-R-3	292 (ground up)	-	-	-
18A-S-4A	1012	723	112	608
18A-R-4A	608	-	-	-
(rock portion) (ground up)				
18A-S-4B	993	986	847	129
18A-S-4C	1196	1179	1106	65
18A-S-5	899	890	738	149
18A-S-6	1147	1114	842	239
18BKGD-SB-1	1172	1148	1120	20
18BKGD-SB-2	993	965	597	358

TABLE 6. GAMMA-SPECTRAL AND URANIUM-FLUOROMETRIC ANALYSIS OF SAMPLES

Sample Number	Gamma Spectra, pCi/g $\pm$ σ^a						Uranium Fluorometric			
	^{137}Cs	^{232}Th	^{226}Ra Decay Chain							
		Decay Chain	(as re-ported)		(30-day corrected ^b)		$\mu\text{g/g} \pm 10\%$		pCi/g $\pm 10\%^c$	
18A-R-1	<0.1	<0.1	4000	± 400	4511	± 451	18000	± 1800	12000	± 1200
18A-R-2	<0.1	<0.1	1400	± 140	1579	± 158	3300	± 330	2200	± 220
18A-R-3	<0.1	<0.1	1030	± 100	1162	± 113	4500	± 450	3100	± 310
18A-S-4A	<0.1	<0.1	193	± 20	218	± 23	500	± 50	340	± 34
18A-R-4A (rock portion)	<0.1	<0.1	1560	± 156	1759	± 176	6000	± 600	4100	± 410
18A-S-4B	0.09 $\pm$ 0.05	0.65 $\pm$ 0.07	9	± 1	10	± 1	33	± 3.3	22	± 2.2
18A-S-4C	0.06 $\pm$ 0.03	0.56 $\pm$ 0.06	8	± 1	9	± 1	25	± 2.5	17	± 1.7
18A-S-5	0.03 $\pm$ 0.02	0.74 $\pm$ 0.07	16	± 2	18	± 2.3	61	± 6.1	41	± 4.1
18A-S-6	<0.03	0.71 $\pm$ 0.07	23	± 2	26	± 2.3	80	± 0.8	54	± 5.4
18BKGD-SB-1	0.15 $\pm$ 0.02	0.84 $\pm$ 0.08	1.70 $\pm$	0.17	1.92 $\pm$	0.19	3.0 $\pm$	0.3	2.0 $\pm$	0.2
18BKGD-SB-2	0.05 $\pm$ 0.03	0.84 $\pm$ 0.08	1.33 $\pm$	0.13	1.50 $\pm$	0.15	2.9 $\pm$	0.3	2.0 $\pm$	0.2

^aOne standard deviation due to counting statistics.^bIngrowth correction due to ^{222}Rn lost during sample preparation.^cConversion of μg to pCi per Appendix 5.

APPENDICES

Appendices 1 through 5 contain detailed descriptions of the array of instruments and computational and analytical procedures typically employed by ANL's Radiological Survey Group in its comprehensive radiological assessments. Although the specific instruments and techniques used in a given survey depend on the conditions encountered and the information sought, descriptions of the entire array have been included here for completeness. The exact instruments and methods used in the survey reported in this document are specified in appropriate discussions in the text.

Appendix 6 contains excerpts from numerous regulations, standards, and guidelines relative to radiological conditions and exposure to radiation. Not all these necessarily apply at each site surveyed. Again, however, all have been included for completeness. The pertinent regulations, standards, and guidelines for this survey are cited in the text.

Appendix 7 contains a generic discussion of the nature and sources of radiation, its potential danger to humans, and methods utilized to evaluate radiation exposures.

APPENDIX 1

INSTRUMENTATION

I. PORTABLE RADIATION SURVEY EQUIPMENT

A. Gas-Flow Proportional Survey Meters

The Eberline PAC-4G-3 was one of the instruments used for radiological 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 cm² (AC-22 floor monitor probe) 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. With a 2 mV input discrimination level, the alpha mode voltage is 1600 V. 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 (2 in) 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

APPENDIX 1 (cont'd.)

regions determined by NBS-traceable ^{239}Pu (17 keV), ^{241}Am (59.5 keV), and ^{235}U (185.7 keV) sources.

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 - ^{137m}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-dependent. This instrument is calibrated with a ^{226}Ra standard source and during use is checked daily with the ^{137}Cs - ^{137m}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 five-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 10 samples can be counted simultaneously in each.

APPENDIX 1

(cont'd.)

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/cm² 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 ²³⁹Pu and ⁹⁰Sr-⁹⁰Y sources.

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 drew 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/minute (1 m³/h) through a Millipore membrane (0.5 to 0.8 μ m) filter paper for about one hour or more. An alpha spectrum was acquired from a section of this filter paper sample using a 450 mm² ruggedized silicon surface barrier detector. 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.

Samples were also collected with an Environmental Working Level Monitor (EWLM), developed at ANL. The EWLM is a microprocessor-based instrument for performing automated series of Rn daughter concentration and Working Level (WL) measurements. A series starts with the measurement of the alpha (silicon diffused junction detector) and beta (plastic scintillator) detector backgrounds for three minutes. The EWLM then samples air for three minutes at a flow rate of about 38 l/min, through a section of Gelman Acropor AN1200 membrane (1.2 μ m) filter paper. This filter paper is in the form of a continuous, splice-free, 100-ft roll of 2-in width. The filtered air sample is then advanced by the sample transport (13 sec) to the detector position, where alpha (air inlet side of filter) and beta (exit side) counts are simultaneously measured for three minutes. The system spectroscopically separates the alpha counts from RaA and RaC' and measures the gross beta counts from RaB and RaC. From the above counts and times, the programmed microprocessor calculates the Rn daughter concentrations and errors, the WL and error, and prints the results. No assumptions about Rn-daughter equilibrium are required. Calibration of the WL determination is traceable to the DOE Environmental Measurements Laboratory (EML).

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

APPENDIX 1
(cont'd.)

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).

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

	<u>PAC-4G-3 with Hand Probe (AC-21)</u>		<u>Floor Monitor (FM-4G with AC-22 Probe)</u>	
	<u>Alpha</u>	<u>Beta</u>	<u>Alpha</u>	<u>Beta</u>
To 100 cm ²	1.96	1.96	0.30	0.30
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	3.0	2.5
dis/min per cts/min for ²²⁶ Ra plus daughters	1.7	1.7	1.7	1.8

B. Derivation of Conversion Factors. Floor Monitor (AC-22)

Window Area: ~ 330 cm²

Conversion to 100 cm² = 0.30 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

Geometry with Mylar Spun Top - 0.43

Mylar Spun Top counting {double-aluminized Mylar window (~ 0.85 mg/cm²)} 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.

APPENDIX 2 (cont'd.)

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 in good electrical contact with the chamber, 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.

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.

APPENDIX 2
(cont'd.)

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.

The 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 about 100 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 about 300 minutes following the cessation of sampling. Counting (integration) time was generally two 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:

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

APPENDIX 3
(cont'd.)

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})

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

^a 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 unit 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.)

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 ThA (i.e., $1:C_B'/C_A'$). 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).

Example Calculation:

An air sample was collected of 40 minutes duration at a flow rate of $40 \text{ m}^3/\text{h}$ ($670 \text{ l}/\text{min}$). The flow rate through the 10% portion of the filter medium counted in the proportional counter was $67 \text{ l}/\text{min}$. 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 two minutes duration, beginning 99 minutes after the end of sampling, yielded 1205.4 net counts. A second integral gross alpha count of two minutes duration, beginning 292 minutes after the end of sampling, yielded 27.4 net counts. From Eqs. 1 and 2, the total radon and thoron daughter counts during the interval $t_1 = 99$ minutes to $t_2 = 101$ minutes from the sampling interval $t_0 = 40$ minutes are:

$$\frac{N_1}{\text{EQ}} = 2.603 C_A + 20.79 C_B + 2.826 C_C + 122.1 C_{B'} + 45.41 C_{C'}$$

Similarly, the total counts during the second interval $t_1 = 292$ minutes to $t_2 = 294$ minutes are:

$$\frac{N_2}{\text{EQ}} = 5.6 \times 10^{-2} C_A + 0.202 C_B + 3.2 \times 10^{-3} C_C + 134.2 C_{B'} + 4.994 C_{C'}$$

APPENDIX 3
(cont'd.)

With conservatively assumed radon and thoron daughter ratios of 1:1:1 and 1:1, respectively, these equations yield results of 6.9×10^{-3} pCi/l of ThB and C and 2.56 pCi/l of RaA, B, and C. Equation 3 then yields a WL of 0.0256, or 25.6 mWL (milli-Working Level).

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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 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 sample book as a "wet 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 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, if possible. 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 sample book. A 100-g or less sample of the sieved material is transferred to a 4-oz. (125 ml) 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 (30 ml) 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

APPENDIX 4 (cont'd.)

sample number and date, and this information is recorded in the sample book. The rocks (and dross) and remaining soil are placed in storage.

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. ROCK SAMPLE PREPARATION

Rock samples are collected, bagged, and identified at the collection site and returned to ANL. The rock samples are then logged into the sample book; each sample is weighed on a tared balance scale and the weight recorded in the sample book.

Rock samples are normally crushed to about minus- $\frac{1}{2}$ in. mesh with a cold chisel and hammer. Samples can then be fed into a motor-driven pulverizer utilizing 6 in. diameter parallel grinding plates. Samples are normally ground to about minus-1/16 in. mesh. Plates are wiped or scrubbed clean, as necessary. Samples of 100 g or less and 5 g are transferred to 4 oz. (125 ml) and 1 oz. (30 ml) Nalgene bottles, respectively, as in soil-sample processing.

III. 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 it 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

APPENDIX 4 (cont'd.)

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 attached to a fume hood or specially constructed drying box.

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

IV. WATER AND SLUDGE

Water samples are collected in 0.125-liter, 0.5-liter and/or 1-liter quantities as deemed appropriate. These samples are logged in the sample book and then 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 0.125-liter bottles and are processed as outlined above for water samples.

V. VEGETATION, MATERIAL AND RUBBLE

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

Vegetation samples are initially weighed, logged in the sample book, 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 initially weighed and logged in the sample book. Processing is sample-specific, consisting of drying, ashing, grinding, milling, and/or sieving. The samples are then forwarded to a certified radiochemistry laboratory for further specific processing and analysis as required.

VI. 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 to 40 g sample to a ceramic boat followed by heating in a tube furnace at 425°C for 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

APPENDIX 4
(cont'd.)

(-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.

VII. ANALYSIS PROCEDURES

A subsample of 100-g or less 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 ^{226}Ra decay chain (via the 609 keV γ -ray of ^{214}Bi) and the ^{232}Th decay chain (via the 911 keV γ -ray of ^{228}Ac), as well as any other gamma-emitting radionuclide (e.g., ^{137}Cs) 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 (^{228}Th , ^{230}Th , and ^{232}Th) 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 (^{238}Pu , $^{239,240}\text{Pu}$, ^{241}Am) by alpha spectroscopy.

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

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

APPENDIX 5

CALCULATION OF URANIUM SPECIFIC ACTIVITY

The specific activity for uranium of the presumed normal isotopic abundance encountered during the survey was obtained by summing the specific activities for the individual contributing isotopes weighted according to their normal 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 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 (dis/min-μg)</u>	<u>Half-life (years)</u>	<u>Atomic Weight (grams)</u>
^{234}U	1.386×10^4	2.446×10^5	234.0409
^{235}U	4.798	7.038×10^8	235.0439
^{238}U	0.746	4.4683×10^9	238.0508

Specific activity for normal uranium:

<u>Isotope</u>	<u>Abundance (atom %)</u>	<u>Abundance (wt. %)</u>	<u>Specific Activity of Contribution Isotopes</u>	<u>Activity 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 6

PERTINENT RADIOLOGICAL REGULATIONS, STANDARDS, AND GUIDELINES

I. 40 CFR Part 192
 EPA HEALTH AND ENVIRONMENTAL PROTECTION STANDARDS
 FOR
 URANIUM MILL TAILINGS

SUBPART A--Standards for the Control of Residual Radioactive Materials from Inactive Uranium Processing Sites

192.00 Applicability

This subpart applies to the control of residual radioactive material at designated processing or depository sites under Section 108 of the Uranium Mill Tailings Radiation Control Act of 1978 (henceforth designated "the Act"), and to restoration of such sites following any use of subsurface minerals under Section 104(h) of the Act.

192.01 Definitions

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

(b) Remedial action means any action performed under Section 108 of the Act.

(c) Control means any remedial action intended to stabilize, inhibit future use of, or reduce emissions or effluents from residual radioactive materials.

(d) Disposal site means the region within the smallest perimeter of residual radioactive material (excluding cover materials) following completion of control activities.

(e) Depository site means a disposal site (other than a processing site) selected under Section 104(b) or 105(b) of the Act.

(f) Curie (Ci) means the amount of radioactive material that produces 3.7×10^{10} nuclear transformation per second. One picocurie (pCi) = 10^{-12} Ci.

192.02 Standards

Control shall be designed* to:

*Because the standard applies to design, monitoring after disposal is not required to demonstrate compliance.

APPENDIX 6
(cont'd.)

(a) be effective for up to one thousand years, to the extent reasonably achievable, and, in any case, for at least 200 years, and,

(b) provide reasonable assurance that releases of radon-222 from residual radioactive material to the atmosphere will not:

(1) exceed an average** release rate of 20 picocuries per square meter per second, or

(2) increase the annual average concentration of radon-222 in air at or above any location outside the disposal site by more than one-half picocurie per liter.

SUBPART B--Standards for Cleanup of Open Lands and Buildings Contaminated with Residual Radioactive Materials from Inactive Uranium Processing Sites

192.10 Applicability

This subpart applies to land and buildings which are part of any processing site designated by the Secretary of Energy under Pub. L. 95-604, Section 102. Section 101 of Pub. L. 95-604, states that "processing site" means--

(a) any site, including the mill, containing residual radioactive materials at which all or substantially all 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 an 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 such 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--

**This average shall apply over the entire surface of the disposal site and over at least a one-year period. Radon will come from both residual radioactive materials and from materials covering them. Radon emissions from the covering materials should be estimated as part of developing a remedial action plan for each site. The standard, however, applies only to emissions from residual radioactive materials to the atmosphere.

APPENDIX 6
(cont'd.)

(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 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.

(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 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.)

SUBPART C--Implementation

192.20 Guidance for Implementation

Section 108 of the Act requires the Secretary of Energy to select and perform remedial actions with the concurrence of the Nuclear Regulatory Commission and the full participation of any State that pays part of the cost, and in consultation, as appropriate, with affected Indian Tribes and the Secretary of the Interior. These parties, in their respective roles under Section 108, are referred to hereafter as "the implementing agencies."

The implementing agencies shall establish methods and procedures to provide "reasonable assurance" that the provisions of Subparts A and B are satisfied. This should be done as appropriate through use of analytic models and site-specific analyses, in the case of Subpart A, and for Subpart B through measurements performed within the accuracy of currently available types of field and laboratory instruments in conjunction with reasonable survey and sampling procedures. These methods and procedures may be varied to suit conditions at specific sites. In particular:

(a) The purpose of Subpart A is to provide for long-term stabilization and isolation in order to inhibit misuse and spreading of residual radioactive materials, control releases of radon to air, and protect water. Subpart A may be implemented through analysis of the physical properties of the site and the control system and projection of the effects of natural processes over time. Events and processes that could significantly affect the average radon release rate from the entire disposal site should be considered. Phenomena that are localized or temporary, such as local cracking or burrowing of rodents, need to be taken into account only if their cumulative effect would be significant in determining compliance with the standard. Computational models, theories, and prevalent expert judgment may be used to decide that a control system design will satisfy the standard. The numerical range provided in the standard for the longevity of control and stabilization methods and their costs. These factors have different levels of predictability and may vary for the different sites.

Protection of water should be considered in the analysis for reasonable assurance of compliance with the provisions of Section 192.02. Protection of water should be considered on a case-specific basis, drawing on hydrological and geochemical surveys and all other relevant data. The hydrologic and geologic assessment to be conducted at each site should include a monitoring program sufficient to establish background groundwater quality through one or more upgradient wells, and identify the presence and movement of plumes associated with the tailings piles.

If contaminants have been released from a tailings pile, an assessment of the location of the contaminants and the rate and direction of movement

APPENDIX 6
(cont'd.)

of contaminated groundwater, as well as its relative contamination, should be made. In addition, the assessment should identify the attenuative capacity of the unsaturated and saturated zone to determine the extent of plume movement. Judgments on the possible need for remedial or protective actions for groundwater aquifers should be guided by relevant considerations described in EPA's hazardous waste management system (47 CFR 32274, July 26, 1982) and by relevant State and Federal Water Quality Criteria for anticipated or existing uses of water over the term of the stabilization. The decision on whether to institute remedial action, what specific action to take, and to what levels an aquifer should be protected or restored should be made on a case-by-case basis taking into account such factors as technical feasibility of improving the aquifer in its hydrogeologic setting, the cost of applicable restorative or protective programs, the present and future value of the aquifer as a water resource, the availability of alternative water supplies, and the degree to which human exposure is likely to occur.

(b) Compliance with Subpart B, to the extent practical, should be demonstrated through radiation surveys. Such surveys may, if appropriate, be restricted to locations likely to contain residual radioactive materials. These surveys should be designed to provide for compliance averaged over limited areas rather than point-by-point compliance with the standards. In most cases, measurement of gamma radiation exposure rates above and below the land surface can be used to show compliance with Section 192.12(a). Protocols for making such measurements should be based on realistic radium distributions near the surface rather than extremes rarely encountered.

In Section 192.12(a), the "background level" refers to native radium concentration in soil. Since this may not be determinable in the presence of contamination by residual radioactive materials, a surrogate "background level" may be established by simple or indirect (e.g., gamma radiation) measurements performed nearby but outside of the contaminated location.

Compliance with Section 192.12(b) may be demonstrated by methods that the Department of Energy has approved for use under PL 92-314 (10 CFR 712), or by other methods that the implementing agencies determine are adequate. Residual radioactive materials should be removed from buildings exceeding 0.03 WL so that future replacement buildings will not pose a hazard [unless removal is not practical--see Section 192.21(c)]. However, sealants, filtration, and ventilation devices may provide reasonable assurance of reductions from 0.03 WL to below 0.02 WL. In unusual cases, indoor radiation may exceed the levels specified in Section 192.12(b) due to sources other than residual radioactive materials. Remedial actions are not required in order to comply with the standard when there is reasonable assurance that residual radioactive materials are not the cause of such an excess.

192.21 Criteria for Applying Supplemental Standards

The implementing agencies may (and in the case of Subsection (f) shall)

APPENDIX 6
(cont'd.)

apply standards under Section 192.22 in lieu of the standards of Subparts A or B if they determine that any of the following circumstances exists:

(a) Remedial actions required to satisfy Subparts A or B would pose a clear and present risk of injury to workers or to members of the public, notwithstanding reasonable measures to avoid or reduce risk.

(b) Remedial actions to satisfy the cleanup standards for land, Section 192.12(a), or the acquisition of minimum materials required for control to satisfy Section 192.02(b), would, notwithstanding reasonable measures to limit damage, directly produce environmental harm that is clearly excessive compared to the health benefits to persons living on or near the site, now or in the future. A clear excess of environmental harm is harm that is long-term, manifest, and grossly disproportionate to health benefits that may reasonably be anticipated.

(c) The estimated cost of remedial action to satisfy Section 192.12(a) at a "vicinity" site [described under Section 101(6)(B) of the Act] is unreasonably high relative to the long-term benefits, and the residual radioactive materials do not pose a clear present or future hazard. The likelihood that buildings will be erected or that people will spend long periods of time at such a vicinity site should be considered in evaluating this hazard. Remedial action will generally not be necessary where residual radioactive materials have been placed semi-permanently in a location where site-specific factors limit their hazard and from which they are costly or difficult to remove, or where only minor quantities of residual radioactive materials are involved. Examples are residual radioactive materials under hard surface public roads and sidewalks, around public sewer lines, or in fence-post foundations. Supplemental standards should not be applied at such sites, however, if individuals are likely to be exposed for long periods of time to radiation from such materials at levels above those that would prevail under Section 192.12(a).

(d) The cost of a remedial action for cleanup of a building under Section 192.12(b) is clearly unreasonably high relative to the benefits. Factors that should be included in this judgment are the anticipated period of occupancy, the incremental radiation level that would be affected by the remedial action, the residual useful lifetime of the building, the potential for future construction at the site, and the applicability of less costly remedial methods than removal of residual radioactive materials.

(e) There is no known remedial action.

(f) Radionuclides other than radium-226 and its decay products are present in sufficient quantity and concentration to constitute a significant radiation hazard from residual radioactive materials.

192.22 Supplemental Standards

Federal agencies implementing Subparts A and B may in lieu thereof

APPENDIX 6
(cont'd.)

proceed pursuant to this section with respect to generic or individual situations meeting the eligibility requirements of Section 192.21.

(a) When one or more of the criteria of Section 192.21(a) through (e) applies, the implementing agencies shall select and perform remedial actions that come as close to meeting the otherwise applicable standard as is reasonable under the circumstances.

(b) When Section 192.21(f) applies, remedial actions shall, in addition to satisfying the standards of Subparts A and B, reduce other residual radioactivity to levels that are as low as is reasonably achievable.

(c) The implementing agencies may make general determinations concerning remedial actions under this Section that will apply to all locations with specified characteristics, or they may make a determination for a specific location. When remedial actions are proposed under this Section for a specific location, the Department of Energy shall inform any private owners and occupants of the affected location and solicit their comments. The Department of Energy shall provide any such comments to the other implementing agencies. The Department of Energy shall also periodically inform the Environmental Protection Agency of both general and individual determinations under the provisions of this section.

192.23 Effective Date

Subparts A, B, and C shall be effective March 7, 1983.

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(cont'd.)

II.

EXCERPTS FROM LA-UR-79-1865-Rev.,

"Interim Soil Limits for D&D Projects"
Table XXIII. Recommended Soil Limits^{a,b} (in pCi/g)

	Inhalation	Ingestion		External Radiation	All Pathways ^c
		Home Gardener	Full Diet		
²³¹ Pa	50 ^d	740	150	250	40 ^d
²²⁷ Ac	200 ^d	4,900	1,000	300	120 ^d
²³² Th	45	670	140	40	20
²²⁸ Th	1,000	37,000	7,800	55	50
²³⁰ Th (No Daught.)	300	4,400	940	36,000	280
²³⁸ U- ²³⁴ U	750	44	8	6,000	40
⁹⁰ Sr	2x10 ⁶	100	19	-	100
¹³⁷ Cs	7x10 ⁶	800	1	90	80

^a Soil limits for ²⁴¹Am and ^{239,240}Pu are available from EPA recommendations, and a soil limit for ²²⁶Ra has been reported by Healy and Rodgers.

^b Limits are to apply to only one nuclide present in the soil. If more than one is present, a weighted average should apply.

^c Based on a diet of a home gardener.

^d Modified from LA-UR-79-1865-Rev. values to correct error.

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(cont'd.)

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

"Requirements for Radiation Protection"

Exposures 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

Type of Exposure	Annual Dose Equivalent or Dose Commitment	
	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 Air (pCi/l)	Column 2 Water (pCi/l)	Column 1 Air (pCi/l)	Column 2 Water (pCi/l)
Radon (86)	Rn 220 S	300		10	
	Rn 222 S	100		3	
Lead (82)	Pb 212 S	20		0.6	

APPENDIX 6
(cont'd.)

IV.

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, 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 , ^{242m} , 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

APPENDIX 6
(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 $1/n \sum_{i=1}^n S_i \geq L$, 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) 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.

APPENDIX 6
(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.

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(cont'd.)

V. 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, 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.

APPENDIX 6
(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

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(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.

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

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(cont'd.)

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. As a result of spontaneous transformation, the ratio of protons and 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 that 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 operating nuclear reactors or accelerators, or conducting 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 subsequently 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

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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 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 hydrogen-3 (tritium), 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 over-

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(cont'd.)

all 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.

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 the properties of 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 the source 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

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(cont'd.)

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 sources 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.

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 lead 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.

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(cont'd.)

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. Instead, 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 the 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 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

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(cont'd.)

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.

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