ANL-SSD/HP--86-102

DE88 000197

Distribution Category
Remedial Action and
Decommissioning Program
(UC-70A)

ANL-SSD/HP-86-102

ARGONNE NATIONAL LABORATORY
9700 South Cass Avenue
Argonne, Illinois 60439

RADIOLOGICAL ASSESSMENT
AND REMEDIAL ACTION REPORT
FOR THE
"SON OF LANSLOWNE" PROPERTY
186 NORTH LANSLOWNE AVENUE
LANSLOWNE, PENNSYLVANIA

April-October 1986

Prepared by

W. H. Smith Senior Health Physicist
R. A. Wynveen Associate Department Manager, OHS

Radiological Survey Group
Health Physics Section
Support Services Division

DISCLAIMER

This report was prepared as an account of work sponsored by an agency of the United States Government. Neither the United States Government nor any agency thereof, nor any of their employees, makes any warranty, express or implied, or assumes any legal liability or responsibility for the accuracy, completeness, or usefulness of any information, apparatus, product, or process disclosed, or represents that its use would not infringe privately owned rights. Reference herein to any specific commercial product, process, or service by trade name, trademark, manufacturer, or otherwise does not necessarily constitute or imply its endorsement, recommendation, or favoring by the United States Government or any agency thereof. The views and opinions of authors expressed herein do not necessarily state or reflect those of the United States Government or any agency thereof.

MASTER

August 1987

80
DISTRIBUTION OF THIS DOCUMENT IS UNLIMITED

TABLE OF CONTENTS

	<u>Page</u>
Abstract and Executive Summary.	ii
List of Figures	vi
List of Tables.	viii
Glossary of Terms	ix
Introduction.	1
Radiological Assessment	2
General	2
Instrumentation	3
Smear Surveys	4
Air Samples	5
Sewer Samples	6
Soil Corings.	6
Remedial Action	8
Radiological Survey and Remedial Action Results	9
Miscellaneous Items-Basement.	10
Basement.	11
First Floor	
General	13
Living Room	14
Foyer	14
Dining Room	14
Breakfast Room.	14
Kitchen	15
Cooking Room.	15
Pantry.	15
Bathroom.	16
Storeroom	16
Examination Room.	16
East-West Transverse Corridor	17
North-South Transverse Corridor	17
Reception Room.	17
Doctor's Office	17
Second Floor	
General	19
Main Stairwell, 1st to 2nd Floor.	20
Main Bedroom.	20
Glass Closet.	21
Sewing Room	21
Sewing Room Hall.	21

	<u>Page</u>
Second Floor - (cont'd.)	
Bathroom, 2nd Floor, N.W	21
Sewing Room Hall Closet	22
T.V. Room	22
Pink Bedroom.	22
Bathroom, 2nd Floor, S.E	23
Closet, 2nd Floor Landing	23
Third Floor	
General	23
Main Stairwell, 2nd to 3rd Floor.	23
East Bedroom.	24
Bathroom, 3rd Floor	24
West Bedroom.	24
Walk-in Closet.	24
Garage.	25
Effluent Samples.	25
Exterior Survey	26
Dose and Potential Hazard Evaluation	
External Exposure	28
Internal Exposure	29
Conclusions	31
APPENDIX 1 Instrumentation	92
APPENDIX 2 Conversion Factors.	97
APPENDIX 3 Airborne Radionuclide Concentration Calculations.	101
APPENDIX 4 Sample Preparation and Analysis, Generic Protocol	113
APPENDIX 5 Calculation of Uranium Specific Activity.	117
APPENDIX 6 Pertinent Radiological Regulations, Standards, and Guidelines.	119
APPENDIX 7 Evaluation of Radiation Exposures	136
APPENDIX 8 Calibration and Analysis Procedures for Soil.	147

LIST OF FIGURES

<u>Figure</u>		<u>Page</u>
1	Lansdowne and Philadelphia Area.	33
2	105-107 E. Stratford Ave., Lansdowne, PA	34
3	Locations-186 N. Lansdowne and 105-107 E. Stratford.	35
4	186 Lansdowne Ave., Lansdowne, PA.	36
5	Background Soil Sample Locations	37
6	Site Plan-186 Lansdowne Ave.	38
7	Contamination Locations-Exterior	39
8	West Dump Area	40
9	East Dump Area	41
10	Air Sample Locations-Exterior.	42
11	Contamination Locations-Basement	43
12	Contamination Locations-First Floor.	44
13	Contamination Locations-Second Floor	45
14	Contamination Locations-Third Floor.	46
15	Air Sample and Gamma Measurement Locations-Basement.	47
16	Air Sample and Gamma Measurement Locations- First Floor.	48
17	Air Sample and Gamma Measurement Locations- Second Floor	49
18	Air Sample and Gamma Measurement Locations- Third Floor.	50
19	Smear Locations-Basement	51
20	Smear Locations-First Floor, East Side	52
21	Smear Locations-First Floor, West Side	53

List of Figures
(cont'd.)

<u>Figure</u>		<u>Page</u>
22	Smear Locations-Second Floor	54
23	Smear Locations-Third Floor.	55
24	Soil Sample Processing	56
25	Gas Proportional Counters	57
26	High Purity Germanium Detector and Shield	58
27	Alpha Spectrometer and Multichannel Analyzer.	59
28	Weighting and Loading Area.	60
29	Backyard After Decontamination and Backfill	61
30	Driveway Prior to Decontamination	62
31	Driveway Decontamination.	63
32	Vein of Natural Material.	64
33	Driveway After Gravel Backfill.	65
34	Contaminated Area Under Borough Sidewalk.	66
35	Radioactive Material Bins (M-3)	67
36	Contaminated Ceiling Area, Foyer.	68
37	Oil-Fired Furnace	69
38	Patio Surface Under Doctor's Office	70
39	Garage (North Side)	71

List of Tables

<u>Table</u>		<u>Page</u>
1	Miscellaneous Contaminated Items.	72
2	Gamma and Alpha Spectral and Uranium Fluorometric Analyses of Selected Smear Samples.	73
3	Air Sample Results for ^{219}Rn , ^{220}Rn , ^{222}Rn and Long-Lived Determinations	74
4	Air Sample Results, Radon Gas Monitors.	75
5	Air Samples, Operational.	76
6	Soil Samples.	80
7	Identification of Miscellaneous Samples	84
8	Ambient Penetrating Radiation Measurements.	85
9	Gamma Spectral and Uranium Fluorometric Analyses of Sewer Samples.	86
10	Specifically Identified Contamination Areas	87
11	Smear Results	89
12	Radiochemical Analyses of Selected Soil Samples for Thorium	90

GLOSSARY OF TERMS

BIN (M-III Standard)	72-3/8"x50-3/8"x58-3/4" (approximately 120 ft ³) steel bin used to ship and store LSA radioactive material.
BIN (M-III Short)	40-3/8"x50-3/8"x58-3/4" (approximately 67 ft ³) steel bin used to ship and store LSA radioactive material, primarily heavy soil and concrete rubble.
CLEAN	To use solvents, solutions, and/or detergents to clean a surface area.
DRUM (55-gallon)	34.5" high x 22.5" diameter (approximately 7.5 ft ³) steel drum used to ship and store LSA radioactive material, primarily small objects.
EXCISE	To cut, saw or otherwise remove in its entirety.
JACK HAMMER	To remove in large pieces and sections.
LSA	Low Specific Activity - radioactive waste.
SCABBLE	To remove a surface layer by chisel chipping or power scabbler.
SCRUB	This generally involves the use of a power scrubber with a wire brush or a hand wire brush with Turco, WO ₂ , Muriatic Acid or other commercial detergents.
SHAVE	To use a scraper, chisel or power planer in conjunction with a filtered vacuum to remove wood surfaces.
SRW	Solid Radioactive Waste.
STRIPPING	Removing paint or similar type coatings with solutions, heat guns, etc.

RADIOLOGICAL ASSESSMENT AND REMEDIAL ACTION REPORT
FOR THE
"SON OF LANSDOWNE" PROPERTY
186 NORTH LANSDOWNE AVENUE
LANSDOWNE, PENNSYLVANIA

ABSTRACT AND EXECUTIVE SUMMARY

This document reports the results of a radiological assessment and remedial action program conducted by Argonne National Laboratory personnel* at a radioactively contaminated private residence in Lansdowne, Pennsylvania. The program was conducted on the residence at 186 Lansdowne Avenue at the request of the U.S. Environmental Protection Agency, Region III.

At one time, the residence was occupied by the son of a University of Pennsylvania physics professor who, during the early part of the century, had conducted operations with radioactive materials at another residence (105 East Stratford) in the same Philadelphia suburb. Contamination was detected at the Lansdowne residence during a cursory survey conducted in conjunction with a detailed radiological assessment of the Stratford property. At one time it was thought that the source of contamination in the Lansdowne Avenue residence had been some items of furniture moved there from the Stratford Avenue house. However, even after those items were removed and at least partial decontamination was conducted by a private contractor, substantial contamination remained in the Lansdowne residence.

In their subsequent radiological assessment and remedial action, the Argonne National Laboratory personnel found that the entire Lansdowne Avenue house, as well as portions of the backyard and the subsurface of the driveway, was contaminated to some extent. The operations revealed that the contamination encountered could not have come solely from the contaminated furniture. It was apparent that some form of radium solutions of unknown origin had been involved. A portion of these solutions had been disposed of in the backyard; in the house, some of the solutions had dripped from upper floors through the flooring, subflooring, and to the ceilings below.

The survey conducted by the ANL personnel* indicated that several dozen areas or spots of contamination were present on all floors and the basement of the three-story house. Contamination was found on furniture, carpeting, walls, floors, woodwork, and ceilings. Remedial action undertaken to remove the contamination ranged from scrubbing, to scraping, to shaving of wood, to removal and disposal of items and material that could not be adequately decontaminated. Outdoors, contaminated soil was removed from the backyard, and the driveway was dug up so the contaminated subsurface material could be removed.

The remedial action generated quantities of radioactive waste, including four 55-gallon drums and one M-III bin (120 ft³) containing floor tile, concrete, personal items, furniture, floor scrapings, vermiculite absorbed scrub water, and other items. In addition, there were 24 M-III bins containing approximately 112 tons of contaminated soil and rock from the two contaminated areas in the backyard and from the contaminated subsurface of the driveway.

Following the remedial actions at the Lansdowne Avenue residence and subsequent assessment of current conditions, it was concluded that continuous occupancy of the entire house and garage and use of the backyard (including growing a vegetable garden any any other types of vegetation) should present no radiological hazards.

*Radiological assessment, certification, and direction of remedial action was performed by the following Health Physics personnel of the Support Services Division, Health Physics Section, Argonne National Laboratory, Argonne, Ill.: W. H. Smith, J. D. Thereon, C. L. Gaines, C. A. Hunckler, G. G. Ketchmark and G. E. Kinsella. Remedial action was conducted by ANL Waste Management Operations personnel C. A. Finch, G. F. Fassnacht, T. R. Corbett, W. D. Ray, E. E. Armand, and W. E. Beavers, assisted by EPA contractor personnel.

RADIOLOGICAL ASSESSMENT AND REMEDIAL ACTION REPORT
FOR THE
"SON OF LANSDOWNE" PROPERTY
186 NORTH LANSDOWNE AVENUE
LANSDOWNE, PENNSYLVANIA

INTRODUCTION

A University of Pennsylvania physics professor engaged in the commercial production of radium sources during the early part of this century conducted a major part of his activities in his home at 105 East Stratford Avenue in Lansdowne, Pennsylvania, a suburb of Philadelphia (Figure 1). The professor's residence comprised the western half of a duplex structure located in the approximate center of a 155-ft by 155-ft lot (Figure 2). As a result of the professor's radium-separation activities, reportedly accomplished by fractional crystallization, the residence and the surrounding land area became contaminated. Additionally, the adjoining residence at 107 East Stratford became contaminated, albeit to a lesser extent.

During the intervening years, the son of the professor, a physician, obtained a single-family residence at 186 Lansdowne Avenue, in Lansdowne, (Figures 3-6). The son moved several items of furniture, namely two tables and three file cabinets, from the Stratford Avenue residence to the Lansdowne Avenue residence. Subsequently, the residence at 186 Lansdowne was purchased by another physician and his family. The physician used part of the first floor area in his practice.

As a result of an investigation of the Stratford Avenue site, the EPA, Region III, conducted a cursory survey of the Lansdowne Avenue site and found the three cabinets and two tables to be highly contaminated. A private contractor was hired in April 1985 to dispose of the contaminated items, conduct a survey of the site and effect decontamination measures. The work was not entirely completed because of time constraints.

The EPA subsequently requested that the Argonne National Laboratory (ANL) Support Services Division (SSD), Health Physics Section (HP), perform a radiological assessment and remedial action program for the Lansdowne Avenue site. The ANL-SSD/HP Radiological Survey Group (RSG), along with ANL Waste Management Operations (WMO) personnel conducted the program between April-October 1986.

Investigation and remedial action operations revealed that the contamination present could not have been solely from the contaminated file cabinets and tables. The entire house was found to be contaminated to some extent. It was apparent that some form of radium solutions were involved, a portion of which had been disposed of in the backyard area. The subsurface of the driveway was also found to be contaminated by what appeared to be radioactive residue (Figure 7). The following sections describe the methods and instruments used in the radiological assessment and remedial action operations conducted at the Lansdowne Avenue residence and discuss the results of those operations. Additional details are provided in the illustrations, tables, and appendices that follow the main text of this report.

RADIOLOGICAL ASSESSMENT

General

The radiological assessment of the Lansdowne Avenue site included conducting interior and exterior surveys and collecting and analyzing air, soil, and sewer system samples. Direct surveys, using portable instruments (described below), were made of all floors, walls up to 7 ft off the floor and randomly selected overhead areas. Smear surveys were performed at randomly selected locations on all interior surfaces and from selected areas and items where contamination was found by direct surveys. Air samples were collected on each level of the residence to determine concen-

trations of radon, thoron, and actinon daughters, as well as long-lived radioactive particulates. Additionally, radon concentrations were monitored at several sampling locations for a 24-h period. During remedial action operations, air samples were run in the immediate vicinity and downwind both interior and exterior. Ambient penetrating radiation fields on each level of the structure were monitored with a pressurized ion chamber for a 24-h period.

Soil samples were collected from contaminated areas, from areas where contaminated soil was removed to determine criteria compliance, and from waste disposal bins to determine concentrations of radioactivity in those bins. Environmental soil corings were taken from each quadrant of the property at the periphery, and two off-site samples were collected at a park (Figure 5) to determine background concentrations in the Lansdowne area. Water and sludge samples were taken from a sewer line near the out-fall from the Lansdowne Avenue residence and from a sump in the basement of the residence. Details of these procedures and the instruments used are given below and in Appendix 1. The appendices include generic information not only on instruments and procedures that were required for this particular operation, but also on other instruments and procedures that were available, if needed.

Instrumentation

Three types of portable survey instruments were used to conduct the direct radiological surveys: (1) gas-flow (propane) proportional detectors with window areas of 100 cm^2 and 325 cm^2 (0.85 mg/cm^2), utilizing Eberline PAC-4G-3 electronics, were used to survey for alpha and/or beta-gamma radiation; (2) NaI(Tl) crystal detectors, 2 inches in diameter by 2 mm thick with an 6.9 mg/cm^2 aluminum window, Eberline PG-2 with Eberline PRM-5-3 electronics were used to survey for low-energy x-ray and

gamma radiation; and (3) NaI(Tl) crystal detectors, 1 inch in diameter by 1 inch thick, Eberline PRM-7 μ R meter, were used to measure the ambient external penetrating radiation field (in units of μ R/h) at 3 ft above grade. The first two instruments were used to survey the floors and walls to 7 ft which were surveyed in their entirety and selected areas of overheads. A general survey of the entire facility was performed with the third instrument to establish the general radiation fields. All three types of portable instruments were operated utilizing earphones for audio detection. The ambient penetrating radiation field was monitored continuously for at least a 24-h period on each level of the residence using a Reuter-Stokes (RSS-111) pressurized ionization chamber calibrated with an NBS-Traceable ^{60}Co source. These instruments and associated calibration procedures are detailed in Appendices 1 and 2.

Contaminants were identified in-situ, from samples by gamma and/or alpha spectral analysis onsite or by radiochemical separation followed by gamma or alpha spectral analysis at ANL's Analytical Chemistry Laboratory. Onsite analyses were performed using a sodium iodide (NaI[Tl]) or a hyperpure germanium (HPGe) detector coupled to a multichannel analyzer (Figures 26 and 27). Alpha spectral analyses were performed using surface barrier detectors coupled to the same multichannel analyzer (Figure 27). This instrumentation is also described in Appendix 1.

Smear Surveys

Dry smears were taken at representative locations throughout each room in the residence using 4.25-cm-diameter filter papers (Whatman #1). 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 1 ft². Smears were taken on original structures and components such as walls, floors, pipes and vents. A 100-cm² smear was taken from random areas or objects indicated by a

portable survey instrument to have a radiation level notably above expected backgrounds. A 100-cm^2 smear also was taken if the surface was extremely dusty.

To expedite the processing of the numerous smear samples collected, two counting techniques were employed with two types of counters. A large-area, thin-window, gas-flow proportional counter (sensitive to alpha and/or beta-gamma radiation) was used to make an initial count on groups of smears. For confirmatory counts on individual smears noted to be above the expected background level, a Nuclear Measurement Corp. Model PC-5 or 3A internal gas-flow proportional counter (PC counter) with a thin aluminized Mylar window (referred to as Mylar spun top) was used (see Figure 25).

Initial counts were made with the large-area counter on groups of 10 smears at a time. Smears from any group indicating a reading above the instrument background were then counted individually in the PC counter. In addition, at least two smears randomly selected from each group of 10 were counted in the PC counter. All smears from the areas or objects with noted elevated direct survey readings were counted individually in the PC counter. More detailed descriptions of the counters and the counting and calibration techniques are presented in Appendix 1.

Air Samples

Air-particulate samples were collected using a commercial vacuum cleaner modified by ANL to pull air through a filter medium (Hollingsworth Vose HV-70 or LB-5211).

A total volume of 26.7 m^3 of air was sampled at a flow rate of $40\text{ m}^3/\text{h}$. A 10% portion (5 cm in diameter) of the filter medium was removed after collection and counted for both alpha and beta-gamma activity in the PC counter. Concentrations of radon (^{222}Rn) daughters, thoron (^{220}Rn) daughters, and the presence of any long-lived airborne radionu-

clides were determined based on the results of several counts of each sample at specified intervals.

Air-particulate samples were also collected concurrently on Millipore membrane filter medium for 90 minutes at a flow rate of approximately $1 \text{ m}^3/\text{h}$. A portion of each filter sample was used for alpha spectral analysis to determine the actinon (^{219}Rn) daughter concentration. Additionally, the radon concentration was monitored for at least a 24-h period at each of 10 sampling locations. Eberline Radon Gas Monitors (RGM-1 and RGM-2) were used to ascertain the variability of these quantities.

Details of air-sampling techniques and associated calculations are given in Appendix 3.

Sewer Samples

The residence sanitary sewer system was sampled at an access point near the eastern boundary of the site. A sample was also taken from a sump in the southwest corner of the basement. Water samples extracted from each location were sent to the Argonne Analytical Chemistry Laboratory for analysis. The suspended solids in the water samples were filtered and dried and the filtrate was evaporated to ascertain the dissolved solids content.

Each fraction of the water samples was analyzed for uranium (uranium fluorometric), ^{226}Ra , and ^{232}Th decay chains (gamma spectrometric). Each sample was assigned three-part identification numbers; (1) the site number--20, (2) the sample type--SW for sewer water and (3) a consecutive number.

Soil Corings

Four environmental coring samples were taken from the site and compared to two background corings that were previously taken from

selected locations in the Lansdowne Area during 1984 (see Figure 5). These samples (4-inch-diameter by 12-inch-deep corings) were collected using a 4-inch-diameter, 6-inch-long right-circular-cylinder cutting tool, commonly used to cut cup holes on golf course greens. Each soil core was taken in four segments for analysis. Starting from the surface, three 2-inch segments were cut, bagged and marked A, B and C, respectively; the final 6-inch segment was marked D. The segmented coring technique was used to determine if contaminant migration might have occurred, to reduce the dilution of lower-level soil with the upper-level segments with respect to the surface deposition of the contaminants (or vice versa), and to reveal if any overburden or backfill had been added. The background samples were collected in order to establish the expected background concentrations for the contaminant radionuclides in this area. The four environmental corings from the site were identified as 20-S-1 through 20-S-4. The background corings were identified as 19-SB21 and 19-SB22, taken from the same location and the same analyses as 20-SB-5 and 20-SB-6.

In preparation for analysis, each soil sample was weighed in its "as collected" state, dried for approximately 48 h at 80°C, and then reweighed to determine dry weight. Each sample was then put into a mill jar (8.7 liters) and milled for up to two hours. At no time were any rocks in these samples crushed, ground, or pulverized, since this would act to dilute, and hence lower the reported concentrations of, deposited radioactive material. After sufficient milling, the sample material was sieved. Each fraction (rocks and dross vs. fines) was bagged and weighed separately. Additional details of sample processing are given in Appendix 4.

The soil samples were analyzed at ANL. Weighed aliquots of the milled material from the soil samples were loaded into screwtop plastic containers; aliquots of 100 g, if available, were prepared for gamma-spectral analysis, and aliquots of 5 g were used for radiochemical (fluorometric) analysis. Every effort was made during sample preparation to prevent cross-contamination. Soil samples suspected of containing elevated levels of radioactivity were processed in equipment separate from

soil samples thought to contain background or near background levels. All processing equipment was scrubbed and air dried before introduction of the next sample. The processing of soil samples is shown schematically in Figure 24, and the sample weighing and loading area is shown in Figure 28.

REMEDIAL ACTION

Remedial action was initiated in the basement of the facility, where the major portion of the contamination was reportedly located. Prior to decontamination operations, several hundred miscellaneous items, such as books, chairs, grill, etc., had to be surveyed. Thirty-one separate items were found to be contaminated above criteria (Table 1). The basement was decontaminated by steel brush scrubbing with phosphoric acid solutions and detergents and/or excising. Floortile had to be removed in the entire basement area since contamination was found in the concrete beneath the tile.

The remaining portion of the residence was found to be contaminated in varying degrees under and on the various floor coverings. This included tile, tile underlayment, carpeting, and padding. During the remedial action phase of the operations, it was determined that the contamination was not solely from tracking, but also from radioactive solutions. This was evident in the second floor sun porch, where the entire floor had to be removed due to extensive contamination. It was found that solutions had leaked between the floor boards onto the ceiling below. The ceiling had to be excised. Contamination found in the garage was probably cross-contamination from the highly contaminated table transferred there from the basement.

The contamination in the residence and the garage was detected primarily (90 to 95%) with the PAC-4G-3 (100-cm² detector) in the beta mode. All areas of contamination were cleaned to instrument background levels or excised. Wash water was solidified in vermiculite and, along with the excised material, disposed of as solid radioactive waste.

Two heavily contaminated areas were discovered in the backyard and subsurface material under the driveway was radioactive (see Figures 7, 8 and 9). The backyard contamination was from grade level to approximately 2.5 ft and appeared (from the glassware and debris uncovered) to be two radioactive dump areas. The contamination percolated to levels of 1 to 2.5 ft, where a layer of clay served as a barrier to further percolation. However, there was considerable lateral migration to the north and to the south along this clay layer and above. The PRM-5-3 with PG-2 detector was used to locate the migrant radioactive material from the two dump sites and the material and under the driveway. Soil criteria levels were certified by gamma spectral analysis and quantification utilizing a High Purity Germanium (HPGe) detector coupled to a multichannel analyzer (see Appendix 8).

The remedial action operations detailed below resulted in the generation of radioactive waste consisting of four 55-gallon drums and one M-III bin (Figure 35) of waste that contained floor tile, concrete, personal items, furniture, floor scrappings, vermiculite absorbed scrub water, etc. In addition, there were 24 M-III bins containing approximately 112 tons of contaminated soil and rock from two contaminated dump areas in the backyard and from the contaminated subsurface of the driveway. Operations were completed on October 22, 1986.

RADIOLOGICAL SURVEY AND REMEDIAL ACTION RESULTS

The detailed results of the radiological survey and remedial operations are discussed in the following subsections. The discussions are keyed to tables and figures presented at the end of the main text.

Table 1 lists miscellaneous contaminated items encountered. Table 10 lists specifically identified contaminated areas and spots, and the locations of those areas and spots are shown in Figure 7 (exterior) and Figures 11 through 14 (interior). Results of smear surveys are shown in

Table 11, and the locations at which the smears were taken inside the house are shown in Figures 19 through 23.

Tables 3 through 5 list results of air sampling analyses and ambient penetrating radiation measurements (Table 8). Locations at which the samples and measurements were taken are shown in Figures 10 and 15 through 18. Table 7 lists gamma spectrum analyses of miscellaneous samples taken during remedial action activities.

Miscellaneous Items - Basement

Radiological survey of several hundred items stored in the basement revealed 31 items to be contaminated above criteria for radium-226 (see Table 1). Surface contamination levels ranged from 500 to 374,000 disintegrations per minute per 100 cm² (0.5 to 374 k dis/min) alpha and 0.9 to 900 k dis/min per 100 cm² beta-gamma.

An alcohol smear (smear No. 10) was taken from a contaminated plastic pad; a dry smear (No. 11) and an alcohol smear (No. 12) were taken from a contaminated wooden seat. All three smears were submitted to ANL's Analytical Chemistry Laboratory for analysis including (1) gamma spectral analysis; (2) uranium fluorometric analysis, and (3) thorium separation and alpha spectral analysis. The results of these analyses are presented in Table 2.

For all three smears, uranium fluorometric analysis indicated an expected amount of uranium, and gamma spectral analysis indicated an expected elevated amount of ²²⁶Ra plus daughter products. The ²²⁸Th and ²²⁷Th levels from smears No. 11 and 12 were not expected. Gamma spectral analysis in this case assumes an equilibrium condition existing in the thorium series. The ²³²Th levels are based on the daughter ²²⁸Ac (mesothorium II) (911 keV), and the ²²⁸Th (radiothorium) levels are based on the daughter ²⁰⁸Tl (583 keV). The thorium separation and alpha spectral analysis revealed the following: smear 10 had a normal

amount of ^{228}Th and ^{232}Th , smear 11 had a detectable amount of ^{228}Th and no ^{232}Th , smear 12 had a detectable amount of ^{227}Th and ^{228}Th and no ^{232}Th .

The absence of ^{232}Th in the alpha spectral analysis of smears 11 and 12 and the presence of ^{228}Ac in the gamma spectral analysis indicated that ^{228}Ra (mesothorium I) was the parent precursor, not ^{232}Th . Thus, $^{228}\text{Ra} \xrightarrow{\beta} ^{228}\text{Ac} \xrightarrow{\beta} ^{228}\text{Th}$ and so on is the series order of decay. The presence of ^{227}Th in smear 12 indicated the presence of ^{227}Ac , the parent. This is in the actinouranium series that could include the radionuclide ^{231}Pa not accounted for.

The analysis results indicate that at some time either in the process operated at the 105-107 East Stratford Avenue site or the feed operations process conducted prior to the Stratford Avenue site operations, radium separation was occurring with thorium ore as well as uranium ore. The presence of ^{227}Ac in smear 12 suggests either incomplete separation or cross-contamination of the feed material.

Except for a cart that was decontaminated, all 31 items (Table 1) found to be contaminated, were disposed of as radioactive waste. The remaining, uncontaminated items were either returned to the basement for storage or remanded to the local landfill for disposal.

Basement

A radiological assessment of the basement area was conducted after the removal of the miscellaneous items and prior to remedial action. For survey purposes, the basement was divided into three areas: the furnace room, the library room, the workshop room. In addition, there was a storage area under the side porch (south) and a crawl space (north) under an addition to the original structure that were accessible only from the furnace room. the results are presented below for each area of the basement.

Furnace Room--Floor contamination was prevalent throughout the furnace room area, with readings up to 17 k dis/min-100 cm² alpha, 45 k dis/min-100 cm² beta-gamma, and 25 k counts per minute (cts/min) PRM-5-3. Spots on the west wall read up to 17 k dis/min-100 cm² alpha and 54 k dis/min-100 cm² beta-gamma; spots on the furnace read up to 19 k dis/min-100 cm² alpha and 20 k dis/min-100 cm² beta-gamma. Initial efforts to decontaminate the floor with power scrubber (wire brush) and commercial detergent proved ineffectual. Therefore, the entire floor was stripped of paint with a nonflammable paint remover. One area of contamination activity revealed an increase in readings to 85 k dis/min-100 cm² alpha and 135 k dis/min-100 cm² beta-gamma when first stopped. The entire floor was scrubbed using Turco and WO₂ (commercial solvents) reducing the low-level areas to background. All remaining "hot spots" in the concrete were excised (jack hammer) and disposed of as solid radioactive waste (SRW). All contaminated wooden partitions, shelves, floor molding, floor plates, etc. were excised and disposed of as SRW. The furnace was cleaned to background levels.

The 50-gallon electric hot water heater was disconnected by a commercial plumber and moved onto plastic. The concrete floor beneath the heater read 85 k dis/min-100 cm² alpha, 144 k dis/min-100 cm² beta-gamma, and 5 k cts/min PRM-5-3. The heater base was cleaned to background, and the concrete floor under the heater was excised and disposed of as SRW. The heater was then returned to its original location and installed. Upon completion of the remedial action, direct and smear surveys taken from floors, walls, and overhead, indicated only background levels of radiation.

Library Room--Floor contamination also was prevalent in the library room, with areas reading up to 17 k dis/min-100 cm² alpha and 126 k dis/min-100 cm² beta-gamma. In addition, the inside wooden stairs leading to the first floor, the concrete stairs leading to the outside, a

cast iron hot water radiator and certain wooden partition areas were found to be contaminated. The floor was decontaminated by removing the tile, tile mastic, and paint. This was followed by several scrubblings using Turco and WO_2 . Areas not cleaned to background levels by these procedures were excised by jack hammer. The wooden stairs were decontaminated by first removing the paint and then shaving the wood. The concrete steps were cleaned by scabbling, and the radiator was cleaned to background levels by removing the paint.

Workshop Room--The floor area in the workshop room was considerably less contaminated than the previous two areas in the basement. Levels of up to 2 k dis/min-100 cm^2 alpha and 2.3 k dis/min-100 cm^2 beta-gamma were found on the floor, and 4 k dis/min-100 cm^2 alpha and 1 k dis/min-100 cm^2 beta-gamma were found on several pieces of wooden shelving. The floor was stripped of paint and scrubbed several times to background levels. The wooden shelving was disposed of as SRW.

This completed the radiological assessment, decontamination and post radiological assessment of the entire basement area. Various air sample and ambient penetration radiation results for the basement (and other areas of the property) are listed in Tables 3-5 and 8.

First Floor

General--A radiological assessment was conducted of the entire first floor (Figure 12, Table 10) area on a room-by-room basis. This procedure was used because of the need to remove furniture, rugs, padding, tile, and underlayment. When contamination was found, it was cleaned, shaved, or excised before moving on to the next room. Results for individual rooms are discussed in the following paragraphs.

Living Room--Seven spots and areas of contamination were found on the living room floor after furniture and rugs were removed (Figure 12). No contamination was found on vertical surfaces or overheads. Contamination levels ranged up to 26 k dis/min-100 cm² alpha and 18 k dis/min-100 cm² beta-gamma. Contaminated locations 240, 241, 242, 243 were cleaned to background levels. Locations 244 and 245 were shaved and location 246 was excised.

Foyer--Contamination was found at seven locations in the foyer area. No contamination was found on the vertical surfaces, but the plaster ceiling above location 251 had to be excised because of contaminant migration from the second floor landing. Contaminated beams in this area were shaved to background levels. After removal of the carpet and padding from the stairs and landings leading up to the second floor, contamination was found on the majority of horizontal stair treads and landings (location 252). Contamination levels ranged up to 29 k dis/min-100 cm² alpha, 63 k dis/min-100 cm² beta-gamma, and 15 k cts/min-PRM-5-3. A floor area in the Foyer closet, beneath the stairs leading to the second floor, was found to be contaminated with readings of 13 k dis/min alpha and 4.5 k dis/min-100 cm² beta-gamma.

Contamination locations 247, 248, 249 and 253 were cleaned to background levels. Locations 250 and 251 were excised and location 252 was cleaned and shaved to background.

Dining Room--Three contaminated areas were found on the floor area of the dining room. No contamination was found on the vertical surfaces or overhead. Contamination levels read up to 8.5 k dis/min-100 cm² alpha and 32 k dis/min-100 cm² beta-gamma. Locations 254, 255 and 256 were reduced to background levels by cleaning.

Breakfast Room--One contaminated area was found on the floor of the breakfast room after the tile was removed. No contamination was found on

the vertical surfaces. The overhead plaster ceiling (above a false ceiling) was excised because of contamination leakage from the second floor glass closet located directly above the breakfast room. Contamination readings at location 257 were background alpha and 0.8 k dis/min-100 cm² beta-gamma, which was reduced to background levels by shaving.

Kitchen--Two areas of contamination were found on the kitchen floor after the tile was removed. No contamination was found on the vertical surfaces or overhead. Contamination was found on four steps and the second floor landing on the stairway leading from the kitchen to the second floor sublanding. Contamination in the kitchen indicated readings up to background alpha, 1.8 k dis/min-100 cm² beta-gamma and 1.8 k cts/min PRM-5-3. The kitchen stairwell read up to background alpha and 16 k dis/min-100 cm² beta-gamma. Location 258 was reduced to background by cleaning. Radiation levels at location 259 were increased by shaving and the contamination was finally excised. Location 260 was reduced to background levels by removing the carpeting, vacuuming the stair treads, followed by cleaning of the stair. The contamination was found embedded in the backside of the carpeting, which was disposed of as SRW.

Cooking Room--No contamination was found on the floor, vertical surfaces, or overhead, before or after the removal of the floor tile from the cooking room.

Pantry--Two spots or areas of contamination were found on the linoleum floor covering after the removal of the floor tile. The contamination read up to 0.3 k dis/min-100 cm² alpha and 18 k dis/min-100 cm² beta-gamma. No contamination was found on the vertical surfaces or overhead. No contamination was found on the wooden floor after removal of the linoleum. Locations 261 and 262 were cleaned to background levels.

Bathroom--After removal of the first layer of tile from the bathroom, three spots or areas of contamination were found on the second tile flooring. Contamination read up to 6 k dis/min alpha and 18 k dis/min beta-gamma. No contamination was found on the vertical surfaces or overhead. Locations 263 and 264 were reduced to background levels by excising the tile. Location 265 was cleaned to background levels. The second layer of tile, a layer of linoleum, and a layer of hardboard all revealing background radiation levels, were removed. One area of contamination reading 0.9 k dis/min-100 cm² alpha and 1.8 k dis/min-100 cm² beta-gamma was found on the wooden flooring. The contamination at location 266 was removed to background levels by shaving.

Storeroom--Four spots or areas of contamination were found on the top tile flooring in the storage room. No contamination was found on the vertical surfaces or overhead. Contamination levels read up to 2.4 k dis/min-100 cm² alpha and 9 k dis/min-100 cm² beta-gamma. The contaminated top tile layer (locations 267, 268, 269 and 270) was excised, as was the second layer of tile, which adhered to the top layer. The tile was disposed of as SRW. After removal of the rest of the two layers of tile (a layer of linoleum and a layer of hardboard), a survey of the wooden floor beneath revealed two spots or areas of contamination (locations 271 and 272). Contamination levels read up to 4.3 k dis/min-100 cm² alpha and 4.5 k dis/min-100 cm² beta-gamma. After being shaved, these two were at background levels.

Examination Room--Two spots or areas of contamination (locations 273 and 274) were found on the linoleum floor covering after removal of the carpeting. Levels of contamination read up to 4 k dis/min-100 cm² alpha and 4.5 k dis/min-100 cm² beta-gamma. No contamination was found on vertical surfaces or overhead. Locations 273 and 274 were cleaned to background levels. A survey of the wooden floor, after removal of the linoleum, and pressed boards, indicated background levels.

East-West Transverse Corridor--The following spots or areas of contamination were found in the east-west corridor: four locations at the west end on the hardboard flooring with readings up to 8.5 k dis/min-100 cm² alpha and 27 k dis/min-100 cm² beta-gamma; one spot on carpet at pantry entry reading background alpha and 2.7 k dis/min-100 cm² beta-gamma; three spots at east end of corridor on hardboard flooring reading up to 0.85 dis/min-100 cm² alpha and 2.7 k dis/min-100 cm² beta-gamma; and three spots at the east end of corridor on the wooden flooring reading up to 1.7 k dis/min- 100 cm² alpha and 4.5 k dis/min-100 cm² beta-gamma. Location 275 (four spots) was cleaned and shaved to background levels; location 276 was excised; location 277 (three spots) was cleaned and shaved; and location 278 was shaved to background levels. No contamination was found on the vertical surfaces or overhead.

North-South Transverse Corridor--No contamination was found on the vertical surfaces, floor or flooring material, or overheads. However, there was an elevated gamma background level emanating from the floor area (see Doctor's Office).

Reception Room--One spot or area of contamination was found on the carpet padding in the reception room that read 2.5 k dis/min-100 cm² alpha and 6.9 k dis/min-100 cm² beta-gamma. Location 279 was excised. No other contamination was found on vertical surfaces, floors, flooring material, or overhead. However, the north end of the reception room indicated elevated gamma background levels (see Doctor's Office).

Doctor's Office--No contamination was found on the floor, flooring material, vertical surfaces, or overhead. However, it was in this general area that the gamma background level indicated a maximum level that was emanating from below the floor. Since access to the area under the floor was blocked by retaining walls, a hole was cut out of the flooring between two floor joists. Investigation revealed what appeared to be a concrete

patio 9 inches below floor level on which the floor joists were resting (see Figure 38). The extent of the concrete floor could not be determined. It should be noted that the reception room, north-south corridor, doctor's office, east-west corridor, examination room, storeroom, bathroom and pantry were not a part of the original structure but were additions added on at a later date. It is possible this was the front patio to the original structure. Surveys taken of the patio revealed the following readings:

PRM-7	18 $\mu\text{R/h}$ on wood floor above concrete 23 $\mu\text{R/h}$ on concrete
PRM-5-3W/PG2	4750 cts/min on wood floor 7500 cts/min on concrete
PAC-4G-3	0.34 k dis/min-100 cm^2 beta-gamma on wood floor 0.8 k dis/min-100 cm^2 beta-gamma on concrete Background alpha on wood floor and concrete

It should be noted that general ambient external penetrating radiation backgrounds throughout the facility ranged from 9 to 12 $\mu\text{R/h}$ at 3 ft. Smears taken from the concrete and the floor joists indicated background levels for both alpha and beta-gamma.

An in-situ gamma spectral analysis of the concrete was made using a 2"x2" NaI(Tl) crystal coupled to a portable battery operated multichannel analyzer. Results indicated the primary radionuclides to be ^{226}Ra plus daughter products.

No remedial action was taken because there appeared to be no elevated radon concentration in this area (see results of air sample no. 62, Table 4), the smears taken revealed background results, the ambient penetration radiation level at 3 ft did not exceed criteria (see

Appendix 6), and the direct reading alpha count was background. Had remedial action been necessary, a large portion of the structure would have had to have been demolished.

It is not known what caused the elevated gamma levels from the concrete, but it can be surmised that one (or both) of the two constituents of the concrete--the portland cement and aggregate--could have contained higher than normal concentrations of natural uranium.*

Second Floor

General--As was the case for the first floor area, the radiological assessment of the second floor was conducted on a room-by-room basis because of the need to remove the furniture, carpeting, and padding. Remedial action was initiated wherever contamination was found, and the radiation levels were reduced to background or the contaminated material was excised (Figure 13, Table 10).

*Natural uranium contains the standard amount of the uranium isotopes ^{238}U , ^{235}U and ^{234}U plus all of the daughter products in an approximate equilibrium condition. This includes ^{226}Ra in the uranium chain, as well as the daughter products in the actino-uranium chain.

Normal uranium contains the standard amount of uranium isotopes ^{238}U , ^{235}U and ^{234}U plus the daughter products ^{234}Th , $^{234\text{m}}\text{Pa}$ and ^{234}Pa of the uranium series and ^{231}Th of the actino-uranium series only.

The terms natural uranium and normal uranium are erroneously used interchangeably in many texts and standards.

Main Stairwell, 1st to 2nd Floor--The main stairwell consists of a flight of stairs to a sublanding, one step to a second sublanding, then up to the second floor landing. The staircase from the kitchen also terminates at the second sublanding (see Figure 12).

Twenty-one spots and areas of contamination were found on the main stairway and the two sublandings. Contamination levels ranged up to 29 k dis/min-100 cm² alpha and 63 k dis/min-100 cm² beta-gamma. Location 252 was reduced to background levels by cleaning and primarily shaving. Nine spots or areas of contamination were found on the second floor landing with readings up to 7 k dis/min-100 cm² alpha, 18 k dis/min-100 cm² beta-gamma and 75 k cts/min PRM-5-3. A spot, location 282, was found on one vertical surface on the north door frame leading to the "pink bedroom," indicated readings of background-100 cm² alpha, 63 k dis/min-100 cm² beta-gamma and 7 k cts/min PRM-5-3. Location 282 was reduced to background levels by cleaning and excising. Location 280, the floor was excised and contamination was found under the floor on the beams and on the plaster that formed the ceiling of the first floor foyer (see Figure 13). This contamination appeared to be due to a spill of a liquid.

Radiation levels were reduced to background by shaving the beams and excising the plaster. No contamination was found on the overhead of the stairwell or landings.

Main Bedroom--Contamination was found in three spots and areas of the carpet in the main bedroom. Initial attempts to remove the contamination with a carpet cleaner and commercial detergents failed, and the contaminated areas were excised. Contamination levels ranged up to background alpha, 27 k dis/min-100 cm² beta-gamma and 17 k cts/min PRM-5-3. No contamination was found on vertical surfaces or overhead. A survey of the bare floor revealed a general area of contamination leading from the glass closet to the living room with levels up to 8.5 k dis/min-100 cm² alpha and 27 k dis/min-100 cm² beta-gamma. This area was reduced to background levels by cleaning and shaving.

Glass Closet--Extensive contamination was found on the floor of the glass closet (formerly a sun room). Initial contamination levels were up to 8.5 k dis/min-100 cm² alpha and 23 k dis/min-100 cm² beta-gamma, and after several attempts at shaving, the levels increased to 8.5 k dis/min-100 cm² alpha and 180 k dis/min-100 cm² beta-gamma. The entire floor was excised, exposing the beams and plaster ceiling of the breakfast room below. Contamination that appeared to have originally been in liquid form, was found on the beams and plaster to the extent of 85 k dis/min-100 cm² alpha and 450 k dis/min-100 cm² beta-gamma. The beams were shaved and the plaster was excised. No contamination was found on the vertical surfaces or overhead. The floor was replaced with 3/4-inch plywood by contractor personnel.

Sewing Room--Extensive contamination was found on the floor of the sewing room, with readings up to 8.5 k dis/min-100 cm² alpha and 18 k dis/min-100 cm² beta-gamma. Three spots of contamination, reading up to 8.5 k dis/min-100 cm² alpha and 18 k dis/min-100 cm² beta-gamma, were found on the carpet padding. No contamination was found on the vertical surfaces or overhead. Cleaning the floor area was found to be ineffective. Contamination on the floor was reduced to background levels by shaving, and the contamination on the carpet padding was excised.

Sewing Room Hall--Three spots or areas of contamination were found on the floor of the sewing room hall. Contamination read up to 14 k dis/min-100 cm² alpha and 36 k dis/min-100 cm² beta-gamma. No contamination was found on vertical surfaces or overhead. The contaminated areas were reduced to background by shaving.

Bathroom, 2nd Floor N.W.--No contamination was found on the floor, vertical surfaces or overhead in the second floor northwest bathroom. New ceramic tile had been installed on the floor of this bathroom within the last several years. It was reported by the occupants that the original

tile, a white hexagonal ceramic used in the 1920s and 1930s, the grout, and the mastic (cement) were removed and disposed of as waste. Any presumptive contamination would have been on these materials and not on the subflooring. The new tile was not removed.

Sewing Room Hall Closet--No contamination was found on the floor, vertical surfaces, or overhead of the sewing room hall closet.

TV Room--Two spots or areas of contamination were found on the floor of the TV room reading up to 43 k dis/min-100 cm² alpha, 306 k dis/min-100 cm² beta-gamma and 10 k cts/min PRM-5-3. One spot in the TV room closet floor read 8.5 k dis/min-100 cm² alpha, 18 k dis/min-100 cm² beta-gamma and 1 k cts/min PRM-5-3. Two contamination spots were found on the padding, with readings up to 3.4 k dis/min-100 cm² alpha and 170 k dis/min-100 cm² beta-gamma, and six spots or areas of contamination on the carpet had readings of background alpha, 25.5 k dis/min-100 cm² beta-gamma, and 7 k cts/min PRM-5-3. No contamination was found on vertical surfaces or overhead. The wood floors were shaved to background levels and the spots in the padding were excised. Four of the six areas of contamination on the carpet were cleaned with rug cleaner and commercial detergents; two spots were excised.

Pink Bedroom--Three spots or areas of contamination were found on the floor of the pink bedroom reading up to 34 k dis/min-100 cm² alpha and 45 k dis/min-100 cm² beta-gamma. Three spots or areas of contamination were found on the padding, with readings up to 2.5 k dis/min-100 cm² alpha and 7 k dis/min-100 cm² beta-gamma. No contamination was found on the vertical surfaces or overhead. The areas of contamination on the floor were reduced to background by shaving, and the spots on the padding were excised.

Bathroom. 2nd Floor S.E.--No contamination was found on the floor, vertical surfaces or overhead in this bathroom. New ceramic tile had been installed on the floor of within the past several years and was not removed (see Bathroom, 2nd Floor NW for explanation).

Closet. 2nd Floor Landing--Three spots or areas of contamination were found on the floor of this closet that read up to 1.7 k dis/min-100 cm² alpha and 2.7 k dis/min-100 cm² beta-gamma. No contamination was found on the vertical surfaces or overhead. The contaminated areas were shaved to background levels.

Third Floor

General--As in the first and second floors, the radiological assessment was conducted on a room-by-room basis because of the need to remove furniture, carpeting, padding, and (in the east bedroom) additional layers of tile and pressboard. Remedial action was instituted wherever contamination was found, and the levels of contamination were reduced to background or the contamination was excised.

Main Stairwell. 2nd to 3rd Floor--The main stairwell consists of a flight of stairs from the second floor to the first sublanding up one step to a second sublanding, then up a second flight of stairs to the third floor landing.

Eighteen spots and areas of contamination were found on the stairway and two sublandings, with levels reading up to 8.5 k dis/min-100 cm² alpha and 21 k dis/min-100 cm² beta-gamma. The second sublanding and the third floor landing were contaminated throughout with levels up to 0.9 k dis/min-100 cm² alpha and 2.7 k dis/min-100 cm² beta-gamma. No contamination was found on the vertical surfaces or overhead. The stair treads and landings were reduced to background levels by shaving.

East Bedroom--Contamination was found on the east bedroom carpet (two spots), the padding (one spot), the tile (three spots), the pressboard (six spots), and the original floor, 14 spots. Readings of up to 34 k dis/min-100 cm² alpha and 63 k dis/min-100 cm² beta-gamma were detected. No contamination of the vertical surfaces or overhead was found. All contaminated areas were reduced to background levels; the carpet and padding by cleaning and excising, the tile and pressboard by excising, and the original floor by shaving.

Bathroom, 3rd Floor--No contamination was found on the floor, vertical surfaces or overhead in this bathroom. New ceramic tile had been installed on the floor within the past several years and was not removed (see bathroom, 2nd Floor N.W. for explanation).

West Bedroom--The west bedroom floor was the third most highly contaminated area in the entire structure. A total of 40 spots and areas of contamination were found, with readings up to 34 k dis/min-100 cm² alpha, 63 k dis/min-100 cm² beta-gamma and 20 k cts/min PRM-5-3. No contamination was found on the vertical surfaces or overhead. The floor was excised at location 292 and contamination was detected on the underlying beams and insulation, with levels up to 90 k dis/min-100 cm² beta-gamma. The contamination was reduced to background by removing the insulation and shaving the beams. The remaining spot and areas were reduced to background by excising and shaving. Five spots or areas of contamination were found on the padding. Readings were up to 17 k dis/min-100 cm² alpha and 18 k dis/min-100 cm² beta-gamma. All areas were excised.

Walk-in Closet--Three spots or areas of contamination were found on the floor of the walk-in closet reading up to 43 k dis/min-100 cm² alpha and 90 k dis/min-100 cm² beta-gamma at location 294. No contamination

was found on the vertical surfaces or overhead. The contamination was reduced to background levels by shaving.

Garage

The separate garage, a 30-ft by 24-ft concrete block structure with a concrete floor, had been constructed several years before the remedial action activities. Apparently a contaminated table or bench, originally from the 105 Stratford Avenue residence, had been stored in Location 295 in the garage. The item was removed by a previous contractor, who also conducted surveys of the garage and engaged in a decontamination effort. A radiological assessment by the ANL Radiation Survey Group detected 12 contaminated areas on the floor (north side), an extensive area (approximately 20 ft²) on the west wall at location 296, two contaminated items on the truss beams overhead, and eight separate contaminated items. These included a chest of drawers, a wooden shelf base, a steel shelf, an envelope, a card-board box, a can of grease, an oil spout, and a tire. Contamination on the floor ranged up to 37 k dis/min-100 cm² alpha and 81 k dis/min-100 cm² beta-gamma, and on the west wall up to 26 k dis/min-100 cm² alpha and 9 k dis/min-100 cm² beta-gamma. The floor and wall areas were decontaminated to background levels by vigorous, repeated scrubbing with muriatic acid and commercial solvents. The wooden shelf base, cardboard box, envelope, can of grease, and oil spout were all disposed of as SRW. The rest of the items were cleaned to background levels.

Effluent Samples

A sewer water sample and a sump water sample were collected from each of two locations on the site (see Figure 7). One sample (20-SW-25) was taken from the residence sanitary system near the outfall to the main city sewer on Lansdowne Avenue. The second sample (20-SW-24) was from an open

sump located in the southwest corner of the basement. This sump pumps into the residential sanitary system.

Each effluent sample was analyzed for suspended solids (i.e., filterable material) and dissolved solids (i.e. material remaining after evaporation of the clear aqueous).

A significant level of radium chain contamination was found in the suspended solids fraction of both the sump water and sewer water samples (i.e., 361 pCi/gram and 18 pCi/gram respectively, see Table 9). This was not unexpected in light of the radium chain contamination found throughout the residence and its environs. These results confirm that the site sewer system is contaminated.

Exterior

The surface area surrounding the Lansdowne Avenue structures was surveyed to the lot lines with three portable survey instruments (PAC-4G-3, PRM-5-3 with PG-2 detector and PRM-7). Surface surveys indicated several large areas of contamination in the backyard and the driveway, locations 297, 298, 299 (see Figure 7).

Two large areas of contamination in the backyard (see Figures 7, 8 & 9) appeared to be locations where radioactive material had been dumped. The dumped material then contaminated adjacent areas by lateral migration, primarily to the south. Laboratory-type glassware, lead containers, and similar items, in conjunction with the elevated radiation readings, is additional evidence that radioactive material had been disposed of in these two areas. The driveway contamination was found to be all subsurface and extended from the west sidewalk of Lansdowne Avenue to a distance of approximately 126 ft west of the sidewalk. The subsurface contaminant in the driveway appeared to be a dark slag or dross type of material containing ^{226}Ra and daughter product material. It was layered 8 inches to 1.5 ft below grade.

Remedial action in the backyard consisted of removing the

contaminated soil from the several areas with an endloader, backhoe and hand shovels. The contaminated material was loaded into M-III bins with 10-mil polyethylene liners for transport and disposal as low specific activity (LSA) waste. Surveys of the contaminated areas were conducted almost exclusively with the PRM-5-3 w/PG-2 detector. The soil removal continued until in-situ surveys with the PRM-5-3 indicated radiation was at background levels and no individual hot spots remained. A composite soil sample, consisting of at least 20 aliquots or approximately 50 grams each, was then collected from the cleaned area. The sample was hand-mixed in a plastic bag and subjected to gamma spectrum analysis for quantification (see Appendix 8). Criteria levels used at this particular site were based on the U.S. Environmental Protection Agency standards for ^{226}Ra in soil that includes 5 pCi/gram averaged for the first 15 cm below grade and 15 pCi/gram averaged for every 15 cm layer of soil more than 15 cm below the surface. Since all of the contaminated areas evidenced ^{226}Ra contamination below 8 inches (20.3 cm), primarily the 15 pCi/gram criterion was invoked. All areas were refilled and graded with top soil (0.5 pCi/gram ^{226}Ra) in order to comply with criteria (see Figure 29).

The driveway, location 299, was decontaminated by using the back hoe and in several instances hand shovels (see Figure 30-34). A top layer, consisting of blacktop, gravel and concrete approximately 8 to 12 inches in depth, was removed and placed at the side of the driveway. This material was found to be below criteria levels. The contaminated material below the 8-12 inch level appeared to be layered, and varied in depth from 4 to 8 inches, below which there appeared to be a layer of clay.

Gamma spectral analysis of the layered material indicated quantities of ^{226}Ra to the extent of 21,000 pCi/g. Uranium fluorometric analyses of the same sample indicated uranium quantities of 4662 pCi/g (see Table 6, 20-S-75A). In natural uranium deposits and uranium ore, the ^{226}Ra activity is approximately 49% of the total uranium activity, or in this case 2284 pCi/g. However, the analysis indicated a ^{226}Ra concentration

of 21,000 pCi/g, or approximately 9.2 times the expected natural concentration. From the preceding analyses, it can be assumed that the layered material was feed stock for the process conducted at the 105E-107E Stratford Avenue site and not waste material from operations at that site.

At about 60-ft from the sidewalk, there appeared to be an elevated reading emanating from below a clay layer, 2.5 ft below grade and sandwiched by a second clay layer. A vein of Precambrian rock, a gneiss with quartz, feldspar, biotite and possibly amphiboles, was found (see Figure 32). Since this was considered natural, it was not removed. All other areas of the driveway were reduced to levels below the 15 pCi/gram criteria. Since this was a vehicular traffic area, the backfill consisted of clean 1/2-inch and 3-inch gravel. Rubble from the top of the driveway was transported to the local landfill. The results of the soil analyses are presented in Table 6 and the several locations are shown in Figure 7.

DOSE AND POTENTIAL HAZARD EVALUATION

External Exposure

To assess the potential radiological hazard from external exposure to the radiation field after remedial action was completed, a conservative (worst-case) situation was assumed. Since residential occupancy is involved, it was assumed that an individual would be exposed 168 hours per week, 52 weeks per year to the maximum interior ambient radiation level observed, which was 19 $\mu\text{R/h}$, which was found in the doctor's office. Remedial action had no effect on this ambient radiation level. The annual radiation dose from this source would be:

$$19 \mu\text{R/h} \times 168 \text{ h/W} \times 52 \text{ W/yr} \times .87 \text{ rem/R} = 0.144 \text{ rem/yr}$$

Since this dose is below the NRC limit of 500 mrem per year for members of the general public, no radiological hazard exists at this site in terms of external exposure.

Internal Exposure

To assess the potential for radiological hazard based on potential internal exposure, it was necessary to assume "conservative" but nevertheless plausible scenarios whereby the radioactive contamination was assimilated internally. A hypothetical, yet conceivable, worst-case situation was developed whereby an individual was assumed to be excavating the contaminated soil (dry) to a 1-ft depth for a working day (8 h). For this case, a resuspension factor of 10^{-6} m^{-1} and a breathing rate of $9.6 \text{ m}^3/\text{working day}$ were used. The assumption was made that the average concentration of contaminants in the soil was equal to the maximum measured value (a conservative assumption). All calculations are based on methods outlined in ORNL/NUREG/TM-190, Vol. 3. These calculations approximate the ICRP-30 guidelines for hazard analysis (see Appendix 8).

The maximum concentrations of soil contamination found prior to remedial action was 73,000 pCi $^{226}\text{Ra}/\text{g}$ (sample 20-S-11). Based on this level of contamination, the following hazard level (50-year dose commitment for one working day under the conditions identified above) was calculated as follows:

Adult inhalation of aerosol: (units: $\text{mrem}/\text{pCi} \times \text{pCi}/\text{m}^3 \times \text{m}^3 = \text{mrem}$)

Radium:	Bone:	$(0.092)(3.34 \times 10^4)(9.6)$	= 29.5 rem
(Prior to	Total Body:	$(0.0095)(3.34 \times 10^4)(9.6)$	= 3.0 rem
Remedial	Lung:	$(0.11)(3.34 \times 10^4)(9.6)$	= 46.5 rem
Action)			
Natural Uranium:	Bone:	$(0.238)(0.686)(9.6)$	= 1.57 mrem
	Total Body:	$(0.044)(0.686)(9.6)$	= 0.29 mrem
	Lung:	$(0.859)(0.686)(9.6)$	= 5.66 mrem

Natural Thorium:	Bone:	(0.200)(0.732)(9.6)	= 1.41 mrem
	Total Body:	(0.030)(0.732)(9.6)	= 0.21 mrem
	Lung:	(0.593)(0.732)(9.6)	= 4.17 mrem
Radium:	Bone:	(0.092)(5.58)(9.6)	= 4.93 mrem
(After Remedial	Total Body:	(0.0095)(5.58)(9.6)	= 0.51 mrem
Action)	Lung:	(0.11)(5.58)(9.6)	= 5.89 mrem

The radium insult, prior to remedial action, is based on the maximum level of radium contamination (73,000 pCi/g) found at location 20-S-11 (see Figure 7). The natural uranium insult is based on the natural levels of uranium in the soil (1.5 pCi/g), which were found in the background samples. The natural thorium insult was also based on the natural levels of thorium (1.6 pCi/g) found in the background samples. These levels of uranium and thorium in the soil are consistent with background levels for this geographical area. The radium insult, after remedial action, is based on the maximum level of radium contamination (12.2 pCi/g) found 1-ft below grade, at Location 20-S-45 (see Figure 7). As can be seen from these results, there was a potential for a hazard arising from airborne radium contamination prior to remedial action.

An attempt to put this risk in perspective has been made based on comparisons made by Cohen and Lee (see Appendix 7). The worst-case dose commitment, prior to remedial action, was the lung dose of 46.5 rem/50 years, which equates to smoking approximately 349 packs of cigarettes over a 50-year time span, a non-linear relationship.

The worst-case external dose commitment, after remedial action, is the annual external dose of 0.144 rem/year, which equates to smoking approximately 1.08 packs of cigarettes over a years time.

After remedial action, the internal dose assessments equate to approximately natural background levels. Therefore, the radiological hazard potential has been reduced to that which occurs with the natural radionuclides.

CONCLUSIONS

Based on the results of the comprehensive radiological assessment of the home, garage, and site exterior and the remedial action performed thereto, the following conclusions are made:

1. The radon (^{222}Rn) concentrations found within the house, with the exception of the basement, appear to be within criteria, i.e. 20 milli-Working Levels. Radon concentrations encountered in the basement appear to be higher after, rather than prior to decontamination. This is due to the ^{226}Ra naturally prevalent in the cement and concrete in the basement walls and floor. Elevated radon concentrations have been found to be universal in their occurrence in closely confined areas where cement, concrete, clay brick, etc. form an integral part of the confined structure. A minimal amount of ventilation dissipates the radon and eliminates the problem.
2. The sewer system, within the confines of the site, have been determined to be contaminated (see Table 9). However, this does not pose an immediate radiological hazard. Contamination may surface and be spread during cleaning operations, sewer back-up, or physical removal of the sewer lines when the site is demolished. These potential problems can be resolved by radiological assessment and control at the time they occur.
3. The chimney flue must be considered suspect, although because it was inaccessible, there was no direct evidence of the flue being contaminated. Contamination found on the fireplace hearth, on the basement floor near the furnace, and on the furnace itself, tends to make the flue suspect (see Figure 12). The present oil-fired furnace, replaced an original coal-fired furnace. It is well known that coal-fired furnaces were also used as combustible trash burners. The flue presents no immediate radiological hazard, but should be subject to radiological assessment during cleaning or in the event of demolition.
4. The elevated gamma levels detected in the first floor north-south corridor and the doctor's office presents no immediate radiological hazard since the levels are below criteria, i.e. 20 $\mu\text{R/h}$ above background (see Table 8). Background levels in the site area range from 7-10 $\mu\text{R/h}$. A radiological assessment of the concrete patio under the floor joists, the source of the elevated gamma levels, should be conducted whenever the structure is demolished.

5. Layered contaminated material was found to extend under the Borough's sidewalk in an easterly direction approximately 6-12 inches below grade (see Figure 34). This was an extension of the contaminated material in the driveway. The area and extent of the contamination could not be resolved since it was off the site boundaries. The contamination does not pose an immediate radiological hazard; however, the area should be subjected to radiological assessment and control in the event the integrity of the area is violated. The vein of natural radioactive material at 2 to 2.5 ft below grade may also extend beyond the confines of the site.
6. As a result of the remedial action taken, continuous occupancy of the entire house and garage should present no radiological hazard.
7. Due to the remedial action taken in the exterior areas, continuous occupancy, including maintaining a vegetable garden in the backyard and the growing of all types of vegetation, should present no radiological hazard.

Figure 1. Lansdowne and Philadelphia Area

Figure 2. 105 - 107 E. Stratford Ave. Lansdowne, Pa.

Figure 3. Locations - 186 N. Lansdowne and 105-107 E. Stratford.

Figure 4. 186 Lansdowne Ave. Lansdowne, Pa.

Figure 5. Background Soil Sample Locations.

Figure 6. Site Plan - 186 Lansdowne Ave.

Figure 7. Contamination Locations - Exterior.

Figure 8. West Dump Area.

Figure 9. East Dump Area.

Figure 10. Air Sample Locations - Exterior.

Figure II. Contamination Locations - Basement

Figure 12. Contamination Locations - First Floor.

Figure 13. Contamination Locations - Second Floor.

Figure 14. Contamination Locations - Third Floor.

Figure 15. Air Sample and Gamma Measurement Locations - Basement.

Figure 16. Air Sample and Gamma Measurement Locations - First Floor

Figure 17. Air Sample and Gamma Measurement Locations - Second Floor.

Figure 18. Air Sample and Gamma Measurement Locations - Third Floor.

Figure 19. Smear Locations - Basement.

- n SMEAR (n) OVERHEAD SMEAR
- [n] POINT OF ELEVATED ACTIVITY
- [n] OVERHEAD POINT OF ELEVATED ACTIVITY

Figure 20. Smear Locations - First Floor, East Side.

Figure 21. Smear Locations - First Floor, West Side.

Figure 22. Smear Locations - Second Floor.

Figure 23. Smear Locations - Third Floor.

Figure 24. Soil Sample Processing.

Figure 25. Gas Proportional Counters

Figure 26. High Purity Germanium Detector and Shield.

Figure 27. Alpha Spectrometer and Multichannel Analyzer.

Figure 28. Weighing and Loading Area.

Figure 29. Backyard after Decontamination and Backfill.

Figure 30. Driveway Prior to Decontamination

Figure 31. Driveway Decontamination.

Figure 32. Vein of Natural Material.

Figure 33. Driveway After Gravel Backfill.

Figure 34. Contaminated Area Under Borough Sidewalk.

Figure 35. Radioactive Material Bins (M-3).

Figure 36. Contaminated Ceiling Area, Foyer.

Figure 37. Oil Fired Furnace.

Figure 38. Patio Surface Under Dr. Office.

Figure 39. Garage (North Side).

TABLE 1. Miscellaneous Contaminated Items

Item Description	PAC-4G-3 ^{a,b} (dis/min-100 cm ²)		PRM-5-3 ^b (cpm)	Smears (dis/min)		
	Alpha	Beta		No.	Alpha	Beta
Reeds (grass)	6.8 k	8.1 k	NCD ^c		NT ^d	
2" x 4" (lumber)	42.5 k	90.0 k	7 k		NT	
Cushion	6.8 k	8.1 k	NCD		NT	
1"x12" (lumber)	25.5 k	45.0 k	0.5K		NT	
Canvas	0.7 k	3.6 k	NCD		NT	
Credenza (bottom)	374.0 k	450.0 k	15 k		NT	
Picture	11.9 k	27.0 k	NCD		NT	
Aquarium Lid	8.5 k	21.6 k	NCD		NT	
Stereo Lid w/speakers	13.6 k	23.4 k	NCD		NT	
Leather Bag	18.7 k	37.8 k	0.3K		NT	
Cardboard Box	3.4 k	10.8 k	NCD		NT	
Barbeque Grill (top)	8.5 k	18.0 k	NCD		NT	
Cardboard	5.1 k	6.3 k	NCD		NT	
Warming Plate	11.9 k	18.0 k	NCD		NT	
Air Rifle	4.6 k	5.4 k	NCD		NT	
"22" Rifle	6.8 k	9.0 k	NCD		NT	
Plastic Crate	7.5 k	10.0 k	NCD		NT	
Board	8.5 k	14.4 k	NCD		NT	
Seat Leg	8.5 k	19.8 k	NCD		NT	
Cart Bottom (shelf)	0.5 k	1.8 k	NCD		NT ^e	
Imitation Plant Vase	5.1 k	21.6 k	NCD		NT	
Cardboard	5.1 k	7.2 k	NCD		NT	
Bike Rack (auto)	2.6 k	4.5 k	NCD		NT	
1 gal. can Vynal Paste	5.1 k	14.4 k	NCD		NT	
Paper Bag	0.9 k	3.6 k	NCD		NT	
Cardboard	0.6 k	3.6 k	NCD		NT	
Metal Sign (Watch for Children)	15.3 k	27.0 k	NCD		NT	
Mangle Iron	374.0 k	540.0 k	30 k		NT	
Mangle Leg	374.0 k	900.0 k	NT		NT	
Plastic Pad (alcohol smear)	3.4 k	7.2 k	NT	10	160	138
Wooden Seat (dry smear)	0.9 k	2.7 k	NT	11	146	111
Wooden Seat (alcohol smear)	0.6 k	0.9 k	NT	12	232	134

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

^b The following are the normal area background readings for each instrument:
PAC-4G-3 150-400 cts/min-100 cm² Beta 0-5 cts/min-100 cm² alpha
PRM-5-3 400-2000 cts/min
PRM-7 3-10 R/h

^c NCD = No Contamination Detected.

^d NT = Not Taken.

^e Cleaned to NCD

TABLE 2. Gamma and Alpha Spectral and Uranium Fluorometric Analyses of Selected Smear Samples

Smear Sample Number	Gamma Spectra, Total pCi				Alpha Spectra, Total DPM			Uranium Fluorometric Total Nanograms
	^{137}Cs	^{226}Ra	$^{232}\text{Th}^a$	^{228}Th	^{227}Th	^{228}Th	^{232}Th	
10	1.1 $\pm$ 0.1	15 $\pm$ 12	BDL ^b	BDL	BDL	0.54 $\pm$ 10.02	0.74 $\pm$ 10.02	501
11	0.65 $\pm$ 0.06	31 $\pm$ 3	24 $\pm$ 2	16 $\pm$ 2	BDL	0.32 $\pm$ 0.02	BDL	319
12	0.83 $\pm$ 0.08	30 $\pm$ 3	40 $\pm$ 4	12 $\pm$ 1	1.17 $\pm$ 0.06	0.25 $\pm$ 0.01	BDL	441

^a Smear samples 11 and 12 do not contain ^{232}Th . This listing is due to the erroneous assumption, in this case, that the analyzed detectable ^{228}Ac is in equilibrium with ^{232}Th . Alpha spectral analysis reveals no ^{232}Th present, thus assuring that the presence of the short-lived ^{228}Ac is due to the long-lived precursor ^{228}Ra only.

^b BDL = Below Detectable Levels

Table 3. Air Sample Results for ^{219}Rn , ^{220}Rn , ^{222}Rn and Long-Lived Determinations

Sample Number	Location	Figure Number ^a	Radon ^{222}Rn (pCi/l)	Radon Daughters (mWL) ^b	Thoron ^{220}Rn (fCi/l)	Long-Lived (fCi/l)	Actinon ^{219}Rn (pCi/l)	Sample Number
1	Basement Furnace Room	15	0.78	7.8	1.45	0.6	BDL ^c	2
9	First Floor Living Room	16	1.73	17.3	7.7	BDL	BDL	7
13	Second Floor Landing	17	0.73	7.3	6.2	1.3	BDL	15
17	Third Floor	18	0.84	8.4	14.0	BDL	BDL	16
22	Basement Library Room After Decon.	15	8.4	84.0	55.0	BDL	BDL	19

^a Indicates figure showing location at which measurement was made.

^b Working Level (WL) is defined as any combination of short-lived radon-decay products in one liter of air that will result in the ultimate emission of 1.3×10^5 MeV of potential alpha energy. The numerical value of the WL is derived from the alpha energy released by the total decay through RaC' of the short-lived radon-daughter products, RaA, RaB, and RaC at radioactive equilibrium with 100 pCi of ^{222}Rn per liter of air. A milliWorking Level (mWL) is 10^{-3} WL.

^c BDL = Below Detectable Limits.

Table 4. Air Sample Results, Radon Gas Monitors

Location	Sample Number	Figure Number	Time On	Time Off	Maximum ^a	Minimum ^a	Average ^a	Monitor
					²²² Rn Concentration pCi/l	²²² Rn Concentration pCi/l	²²² Rn Concentration pCi/l	
Basement Workshop Room	55	15	1416 hrs 4/30/86	1416 hrs 5/2/86	12	0.38	6.48	RGM-1 #1
Basement Furnace Room	56	15	1200 hrs 4/30/86	0800 hrs 5/5/86	9.86	0.28	3.25	RGM-2 #23
First Floor Living Room	57	16	0958 hrs 5/5/86	1358 hrs 5/7/86	5.43	0.26	1.56	RGM-1 #1
First Floor Dining Room	58	16	1000 hrs 5/5/86	1500 hrs 5/7/86	1.49	0.29	0.7	RGM-2 #23
Second Floor Sewing Room	59	17	1405 hrs 5/13/86	1405 hrs 5/14/86	1.9	0.5	1.12	RGM-1 #1
Second Floor TV Room	60	17	1359 hrs 5/14/86	0759 hrs 5/16/86	3.37	1.75	2.26	RGM-1 #1
Third Floor West Bedroom	61	18	0953 hrs 5/16/86	0953 hrs 5/19/86	3.3	1.73	2.2	RGM-1 #1
First Floor Reception Room	62	16	1300 hrs 5/20/86	1400 hrs 5/21/86	5.72	0.49	1.44	RGM-2 #23
Basement Library Room After Decon.	63	15	1044 hrs 5/28/86	1144 hrs 6/2/86	16.0	1.87	9.6	RGM-1 #1
Basement Library Room After Decon.	64	15	1000 hrs 5/28/86	1200 hrs 6/2/86	14.1	0.75	7.08	RGM-2 #23

^aMaximum, minimum and average concentrations were derived after four (4) hours operation.

Table 5. Air Samples, Operational

Sample Number	Location	Figure Number	Time On	Time Off	Long-Lived Activity ^a	Long-Lived Activity
					Alpha fCi/ℓ	Beta fCi/ℓ
3	Basement Furnace Room	15	0930 5/2/86	1535 5/2/86	0.2	0.7
4	Basement Furnace Room	15	0855 5/5/86	1545 5/5/86	BDL ^b	0.1
5	1st Floor Living Room	16	0900 5/6/86	0940 5/6/86	BDL	BDL
6	1st Floor Living Room	16	0940 5/6/86	1530 5/6/86	BDL	0.1
8	Basement Workshop	15	1400 5/6/86	1540 5/6/86	0.2	0.6
10	Basement Workshop	15	0900 5/7/86	1515 5/7/86	0.2	BDL
11	Basement Furnace Room	15	0905 5/13/86	1315 5/13/86	0.2	0.4
12	Basement Furnace Room	15	1315 5/13/86	1545 5/13/86	BDL	BDL
14	Basement Furnace Room	15	0840 5/14/86	1520 5/14/86	0.2	0.3
18	Basement Furnace Room	15	0850 5/15/86	1530 5/15/86	0.9	0.6
20	Basement Furnace Room	15	0835 5/16/86	1445 5/16/86	0.4	0.3

Table 5. Air Samples, Operational (cont'd)

Sample Number	Location	Figure Number	Time On	Time Off	Long-Lived Activity ^a	Long-Lived Activity
					Alpha fCi/ℓ	Beta fCi/ℓ
21	Basement Furnace Room	15	0825 5/20/86	1455 5/20/86	0.4	1.2
21A	Basement Library Room	15	0840 5/28/86	0920 5/28/86	0.4	BDL
23	2nd Floor Sun Porch	17	0950 6/11/86	1455 6/11/86	BDL	0.2
24	1st Floor Front Corridor	16	0910 6/12/86	1445 6/12/86	BDL	BDL
25	1st Floor Foyer	16	1045 6/13/86	1445 6/13/86	BDL	BDL
26	1st Floor West Corridor	16	0845 6/16/86	1540 6/16/86	0.4	0.9
27	1st Floor West Corridor	16	0905 6/17/86	1545 6/17/86	0.2	0.1
28	2nd Floor Main Bedroom	17	0915 6/17/86	1405 6/17/86	0.5	0.1
29	1st Floor East End Corridor	16	0855 6/18/86	1515 6/18/86	BDL	0.1
30	1st Floor Exam Room	16	0925 6/24/86	1540 6/24/86	BDL	BDL
31	1st Floor Doc's Office	16	0915 6/25/86	1525 6/25/86	BDL	BDL

Table 5. Air Samples, Operational (cont'd)

Sample Number	Location	Figure Number	Time On	Time Off	Long-Lived Activity ^a	Long-Lived Activity
					Alpha fCi/ℓ	Beta fCi/ℓ
32	1st Floor Kitchen	16	0835 6/26/86	1435 6/26/86	BDL	0.2
33	2nd Floor Stairwell	17	0850 6/27/86	1505 6/27/86	BDL	0.3
34	2nd Floor Landing	17	0925 6/30/86	1535 6/30/86	BDL	BDL
35	2nd Floor Landing	17	0845 7/1/86	1515 7/1/86	BDL	0.1
36	2nd Floor Landing	17	0850 7/2/86	1515 7/2/86	BDL	0.1
37	2nd Floor Landing	17	0845 7/8/86	1535 7/8/86	BDL	0.4
38	2nd Floor Landing	17	0915 7/9/86	1500 7/9/86	BDL	BDL
39	2nd Floor Landing	17	0820 7/10/86	1500 7/10/86	BDL	0.2
40	2nd Floor Landing	17	0820 7/11/86	1500 7/11/86	BDL	BDL
41	3rd Floor Landing	18	0810 7/14/86	1510 7/14/86	BDL	0.4
42	3rd Floor Landing	18	0830 7/15/86	1505 7/15/86	BDL	BDL
43	3rd Floor Landing	18	0910 7/16/86	1520 7/16/86	BDL	BDL

Table 5. Air Samples, Operational (cont'd)

Sample Number	Location	Figure Number	Time On	Time Off	Long-Lived Activity ^a	Long-Lived Activity
					Alpha fCi/l	Beta fCi/l
44	3rd Floor Landing	18	0810 7/22/86	1430 7/22/86	BDL	BDL
45	Backyard	10	0955 9/12/86	1510 9/12/86	BDL	0.1
46	Backyard	10	0835 9/15/86	1415 9/15/86	BDL	0.1
47	Backyard	10	1035 9/16/86	1540 9/16/86	BDL	0.7
48	Backyard	10	0900 9/17/86	1520 9/17/86	BDL	0.2
49	Backyard	10	0910 9/23/86	1545 9/23/86	BDL	0.4
50	Backyard	10	0910 9/24/86	1510 9/24/86	BDL	BDL
51	Backyard	10	0845 9/25/86	1505 9/25/86	BDL	BDL
52	Backyard	10	1045 9/26/86	1535 9/26/86	BDL	BDL
53	Backyard	10	0840 9/29/86	1515 9/29/86	BDL	BDL
54	Garage	10	0935 10/7/86	1440 10/7/86	0.1	0.2

^aActivity present after a minimum of six (6) days decay.^bBDL Below Detectable Limits

Table 6. Soil Samples

Sample Number	Gamma Spectra, pCi/g $\pm$ 10%				Uranium Fluorometric		Comments
	^{137}Cs	^{226}Ra (a)	^{232}Th	^{228}Th	g/g $\pm$ 10%	pCi/g $\pm$ 10%	
20-S-1A	0.82 $\pm$ 0.12	1.9 $\pm$ 0.3	1.2 $\pm$ 0.2	1.4 $\pm$ 0.2	2.1 $\pm$ 0.2	1.4 $\pm$ 0.1	Environmental Sample
20-S-1B	0.76 $\pm$ 0.11	2.0 $\pm$ 0.3	1.5 $\pm$ 0.2	1.5 $\pm$ 0.2	1.9 $\pm$ 0.2	1.3 $\pm$ 0.1	Environmental Sample
20-S-1C	0.50 $\pm$ 0.08	2.4 $\pm$ 0.4	2.0 $\pm$ 0.3	2.0 $\pm$ 0.3	2.0 $\pm$ 0.2	1.4 $\pm$ 0.1	Environmental Sample
20-S-1D	0.16 $\pm$ 0.06	1.8 $\pm$ 0.3	2.1 $\pm$ 0.3	2.0 $\pm$ 0.3	1.7 $\pm$ 0.2	1.2 $\pm$ 0.1	Environmental Sample
20-S-2A	0.23 $\pm$ 0.06	1.8 $\pm$ 0.3	2.2 $\pm$ 0.3	1.8 $\pm$ 0.3	2.2 $\pm$ 0.2	1.5 $\pm$ 0.2	Environmental Sample
20-S-2B	0.26 $\pm$ 0.05	2.3 $\pm$ 0.3	2.2 $\pm$ 0.3	1.8 $\pm$ 0.3	2.3 $\pm$ 0.2	1.6 $\pm$ 0.2	Environmental Sample
20-S-2C	0.05 $\pm$ 0.03	1.7 $\pm$ 0.3	1.1 $\pm$ 0.2	1.3 $\pm$ 0.2	2.2 $\pm$ 0.2	1.5 $\pm$ 0.2	Environmental Sample
20-S-2D	0.05 $\pm$ 0.03	2.8 $\pm$ 0.4	1.4 $\pm$ 0.2	1.5 $\pm$ 0.2	2.0 $\pm$ 0.2	1.4 $\pm$ 0.1	Environmental Sample
20-S-3A	0.13 $\pm$ 0.05	3.6 $\pm$ 0.5	1.5 $\pm$ 0.2	1.6 $\pm$ 0.2	1.8 $\pm$ 0.2	1.2 $\pm$ 0.1	Environmental Sample
20-S-3B	0.52 $\pm$ 0.08	2.9 $\pm$ 0.4	1.9 $\pm$ 0.3	1.9 $\pm$ 0.3	2.1 $\pm$ 0.2	1.4 $\pm$ 0.1	Environmental Sample
20-S-3C	0.62 $\pm$ 0.09	3.3 $\pm$ 0.5	2.0 $\pm$ 0.3	2.0 $\pm$ 0.3	2.0 $\pm$ 0.2	1.4 $\pm$ 0.1	Environmental Sample
20-S-3D	0.22 $\pm$ 0.06	2.1 $\pm$ 0.3	2.1 $\pm$ 0.3	1.8 $\pm$ 0.3	2.2 $\pm$ 0.2	1.5 $\pm$ 0.2	Environmental Sample
20-S-4A	0.90 $\pm$ 0.14	4.0 $\pm$ 0.6	1.5 $\pm$ 0.2	1.3 $\pm$ 0.2	2.7 $\pm$ 0.3	1.8 $\pm$ 0.2	Environmental Sample
20-S-4B	0.76 $\pm$ 0.11	5.8 $\pm$ 0.9	1.4 $\pm$ 0.2	1.5 $\pm$ 0.2	2.7 $\pm$ 0.3	1.8 $\pm$ 0.2	Environmental Sample
20-S-4C	0.26 $\pm$ 0.05	2.7 $\pm$ 0.4	1.2 $\pm$ 0.2	1.3 $\pm$ 0.2	2.7 $\pm$ 0.3	1.8 $\pm$ 0.2	Environmental Sample
20-S-4D	0.11 $\pm$ 0.04	3.2 $\pm$ 0.5	1.8 $\pm$ 0.3	1.6 $\pm$ 0.2	2.7 $\pm$ 0.3	1.8 $\pm$ 0.2	Environmental Sample
20-SB-5	0.74 $\pm$ 0.07	1.3 $\pm$ 0.1	1.4 $\pm$ 0.1	1.8 $\pm$ 0.2	2.0 $\pm$ 0.2	1.4 $\pm$ 0.1	Background Sample
20-SB-6	1.10 $\pm$ 0.10	1.3 $\pm$ 0.1	1.6 $\pm$ 0.2	1.6 $\pm$ 0.2	2.2 $\pm$ 0.2	1.5 $\pm$ 0.2	Background Sample
20-S-7	1.40 $\pm$ 0.20	2084 $\pm$ 313	<0.04	<0.04	2.5 $\pm$ 0.3	1.7 $\pm$ 0.2	Location 300
20-S-8	<0.02	2546 $\pm$ 382	<0.04	<0.04	2.0 $\pm$ 0.2	1.4 $\pm$ 0.1	Location 298

Table 6. Soil Samples (cont'd)

Sample Number	Gamma Spectra, pCi/g $\pm$ 10%				Uranium Fluorometric		Comments
	^{137}Cs	^{226}Ra (a)	^{232}Th	^{228}Th	g/g $\pm$ 10%	pCi/g $\pm$ 10%	
20-S-9	<0.02	181 $\pm$ 27	1.8 $\pm$ 0.3	1.6 $\pm$ 0.2	2.1 $\pm$ 0.2	1.4 $\pm$ 0.1	Location 298
20-S-10	0.49 $\pm$ 0.07	416 $\pm$ 62	<0.04	<0.04	2.0 $\pm$ 0.2	1.4 $\pm$ 0.1	Location 298
20-S-11	<0.02	73,000 $\pm$ 11,000	<0.04	<0.04			Location 298
20-S-12	0.42 $\pm$ 0.06	82 $\pm$ 12	2.0 $\pm$ 0.3	1.9 $\pm$ 0.3	2.5 $\pm$ 0.3	1.7 $\pm$ 0.2	Cont. Soil Pile
20-S-13	0.56 $\pm$ 0.08	17 $\pm$ 2.6	1.7 $\pm$ 0.3	2.0 $\pm$ 0.3	2.1 $\pm$ 0.2	1.4 $\pm$ 0.1	Location 298
20-S-14	1.40 $\pm$ 0.2	5.5 $\pm$ 0.8	1.6 $\pm$ 0.2	1.6 $\pm$ 0.2	2.0 $\pm$ 0.2	1.4 $\pm$ 0.1	Location 298
20-S-15	0.32 $\pm$ 0.06	21.8 $\pm$ 3.3	1.4 $\pm$ 0.2	1.9 $\pm$ 0.3	2.2 $\pm$ 0.2	1.5 $\pm$ 0.2	Location 298
20-S-16	0.12 $\pm$ 0.04	6.5 $\pm$ 1.0	1.4 $\pm$ 0.2	1.8 $\pm$ 0.2	2.4 $\pm$ 0.2	1.6 $\pm$ 0.2	Location 298
20-S-17	-	428 $\pm$ 64	-	-	2.0 $\pm$ 0.2	1.4 $\pm$ 0.1	Location 297
20-S-26	-	7,330 $\pm$ 733	-	-	2.4 $\pm$ 0.2	1.6 $\pm$ 0.2	Location 297
20-S-27	-	418 $\pm$ 42	-	-	-	-	Location 297
20-S-28	-	88.6 $\pm$ 9	-	-	-	-	Location 297
20-S-29(c ₂)	-	6.38 $\pm$ 0.7	-	-	-	-	Bin #3A347
20-S-30(c ₂)	-	6.4 $\pm$ 0.6	-	-	-	-	Bin #3A352
20-S-31(c ₂)	-	110 $\pm$ 111	-	-	-	-	Bin #3A350
20-S-32(c ₂)	-	409 $\pm$ 41	-	-	-	-	Bin #3A340
20-S-33(c ₂)	-	19.34 $\pm$ 2	-	-	-	-	Bin #3A358
20-S-34(c ₂)	-	10.89 $\pm$ 1.1	-	-	-	-	Bin #3A332
20-S-35(c ₂)	-	7.79 $\pm$ 0.8	-	-	-	-	Bin #3A331
20-S-36(c ₁)	-	6.85 $\pm$ 0.7	-	-	-	-	Location 298 Criteria (b)
20-S-37(c ₁)	-	4.49 $\pm$ 0.5	-	-	-	-	Clean Area Criteria
							Near East Dump

Table 6. Soil Samples (cont'd)

Sample Number	Gamma Spectra, pCi/g $\pm$ 10%				Uranium Fluorometric		Comments
	^{137}Cs	^{226}Ra (a)	^{232}Th	^{228}Th	g/g $\pm$ 10%	pCi/g $\pm$ 10%	
20-S-38(c ₁)	-	4.8 $\pm$ 0.5	-	-	-	-	Area Criteria
20-S-39(c ₂)	-	6.58 $\pm$ 0.7	-	-	-	-	Bin #3A344
20-S-40(c ₂)	-	5.7 $\pm$ 0.6	-	-	-	-	Bin #3A336
20-S-41(c ₂)	-	5.1 $\pm$ 0.5	-	-	-	-	Bin #3A337
20-S-42(c ₁)	-	4.6 $\pm$ 0.5	-	-	-	-	Location 297 Criteria
20-S-43(c ₂)	-	4.9 $\pm$ 0.5	-	-	-	-	Bin #3A413
20-S-44(c ₁)	-	3.44 $\pm$ 0.3	-	-	-	-	Location 298 Criteria
20-S-45(c ₁)	-	12.2 $\pm$ 1.2	-	-	2.2 $\pm$ 0.2	1.5 $\pm$ 0.2	Location 298 Criteria
20-S-46(c ₂)	-	29.0 $\pm$ 2.9	-	-	-	-	Bin #3A349
20-S-47(c ₁)	-	5.4 $\pm$ 0.5	-	-	2.1 $\pm$ 0.2	1.4 $\pm$ 0.1	Location 301 Criteria
20-S-48(c ₁)	-	0.53 $\pm$ 0.05	-	-	-	-	Top Soil Fill Criteria
20-S-49(c ₁)	-	4.7 $\pm$ 0.5	-	-	8.2 $\pm$ 0.8	5.6 $\pm$ 0.6	Driveway 0'-10' Criteria
20-S-50(c ₁)	-	11.4 $\pm$ 1.1	-	-	-	-	Driveway 10'-23' Criteria
20-S-51(c ₂)	-	73.5 $\pm$ 7.4	-	-	-	-	Bin #3A339
20-S-52(c ₁)	-	2.1 $\pm$ 0.2	-	-	-	-	Driveway 23'-34' Criteria
20-S-53(c ₁)	-	138.4 $\pm$ 13.8	-	-	-	-	Bin #3A343
20-S-54(c ₁)	-	2.1 $\pm$ 0.2	-	-	-	-	Driveway 34'-44' Criteria
20-S-55(c ₂)	-	44.8 $\pm$ 4.5	-	-	-	-	Bin #3A330
20-S-56(c ₁)	-	2.6 $\pm$ 0.3	-	-	-	-	Driveway 44'-54' Criteria
20-S-57(c ₂)	-	30.2 $\pm$ 3	-	-	-	-	Bin #3A346
20-S-58(c ₁)	-	4.5 $\pm$ 0.5	-	-	-	-	Driveway Clean Soil-Criteria
20-S-59(c ₂)	-	69.3 $\pm$ 6.9	-	-	-	-	Bin #3A341

Table 6. Soil Samples (cont'd)

Sample Number	Gamma Spectra, pCi/g $\pm$ 10%				Uranium Fluorometric		Comments
	¹³⁷ Cs	²²⁶ Ra (a)	²³² Th	²²⁸ Th	g/g $\pm$ 10%	pCi/g $\pm$ 10%	
20-S-60(c ₂)	-	127.0 $\pm$ 12.7	-	-	-	-	Bin #3A329
20-S-61(c ₁)	-	9.4 $\pm$ 0.9	-	-	8.2 $\pm$ 0.8	5.6 $\pm$ 0.6	Driveway 54'-64' Criteria
20-S-62(c ₁)	-	5.9 $\pm$ 0.6	-	-	-	-	Driveway 64'-74' Criteria
20-S-63(c ₂)	-	45.1 $\pm$ 4.5	-	-	-	-	Bin #3A424
20-S-64(c ₂)	-	14.6 $\pm$ 1.5	-	-	-	-	Bin #3A425
20-S-65(c ₁)	-	9.5 $\pm$ 1.0	-	-	-	-	Driveway 74'-84' Criteria
20-S-66(c ₂)	-	24.3 $\pm$ 2.4	-	-	-	-	Bin #3A426
20-S-67(c ₂)	-	36.4 $\pm$ 3.6	-	-	-	-	Bin #3A405
20-S-68(c ₁)	-	11.4 $\pm$ 1.1	-	-	-	-	Driveway 84'-94' Criteria
20-S-69(c ₂)	-	65.4 $\pm$ 6.5	-	-	-	-	Bin #3A408
20-S-70(c ₂)	-	53.9 $\pm$ 5.4	-	-	-	-	Bin #3A409
20-S-71(c ₁)	-	7.6 $\pm$ 0.8	-	-	-	-	Driveway 94'-104' Criteria
20-S-72(c ₁)	-	9.0 $\pm$ 0.9	-	-	-	-	Driveway 104'-114' Criteria
20-S-73(c ₁)	-	4.9 $\pm$ 1.0	-	-	-	-	Driveway 114'-126' Criteria
20-S-74	-	882 $\pm$ 5	-	-	645 $\pm$ 65	439 $\pm$ 44	Driveway Layered Material
20-S-75(A)	-	2.1 $\pm$ 0.2E4	-	-	6900 $\pm$ 690	4662 $\pm$ 466	Driveway Layered Material
20-S-75(B)	-	2.1 $\pm$ 0.2E4	-	-	6340 $\pm$ 634	4284 $\pm$ 428	Driveway Layered Material
20-S-75(C)	-	2.9 $\pm$ 0.6	1.6 $\pm$ 0.6	1.6 $\pm$ 0.6	9.2 $\pm$ 0.9	6.4 $\pm$ 0.6	Driveway Veing Material

a Background of 1.3 pCi/gram not subtracted (total quantity).

b Criteria means determining the release criteria for ²²⁶Ra in soil below the 15 cm (6 inch) depth which is 15 pCi/gram, except 20-S-48 and 20-S-58 which is 5 pCi/gram.

c₁ Composite sample consisting of at least 20 aliquots, 40-50 grams each, to determine criteria compliance.

c₂ Composite sample consisting of at least 10 aliquots, 40-50 grams each, to determine Bin quantity of ²²⁶Ra.

Table 7. Identification of Miscellaneous Samples

Sample Number	Results	Comment
20-Carpet-18	^{226}Ra plus daughter products	Contaminated Carpet; Master Bedroom, 2nd Flr.
20-Carpet-19	^{226}Ra plus daughter products	Contaminated Carpet; Master Bedroom, 2nd Flr.
20-Carpet-20	^{226}Ra plus daughter products	Contaminated Underlayment; TV Room, 2nd Flr.
20-Wood-21	^{226}Ra plus daughter products	Contaminated Wood from Floor; 3rd Flr. Bay Area
20-Debris-22	^{226}Ra plus daughter products	Contaminated Wood Scrapings of Floor; 3rd Flr. Bay Area
20-Debris-23	^{226}Ra plus daughter products	Contaminated Wood Scrapings of Floor; 3rd Flr. Landing Area

Table 8. Ambient Penetrating Radiation Measurements

Location	Figure Number ^a	Sample Number	Reuter Stokes RSS-111			PRM-7 ^b (μ R/h)
			Time (h)	Activity (μ R)	Rate (μ R/h)	
Basement Library Room	15	1	118	1818	15.4	10-11
First Floor Foyer	16	2	54	617	11.4	9-11
Second Floor Landing	17	3	65	636	9.8	8-11
Third Floor Landing	18	4	74	722	9.8	9-10
First Floor Doctor's Office	16		-	-	-	12-19
Backyard	6		-	-	-	10-15
Driveway Prior to Remedial Action	6		-	-	-	8-35
Driveway After Remedial Action	6		-	-	-	8-10

^aIndicates figure showing location where measurements were made.

^bMeasurements taken 3 ft above floor or grade level.

TABLE 9. Gamma Spectral and Uranium Fluorometric Analyses of Sewer Samples

Sample Type and Number	Gamma Spectra				Uranium Fluorometric		Total Solids (grams)	Total Solution (ml)
	¹³⁷ Cs	²²⁶ Ra	²³² Th	²²⁸ Th	gU/gram	gU/liter		
	Decay Chain	Decay Chain						
<u>Suspended Solids (pCi/g)</u>								
20-SW-24	0.4±0.06	361 ±72	< 0.04	-	6.06±0.6		0.14	
20-SW-25	0.6±0.1	18 ± 2	< 0.04	0.4±0.06	0.48±0.05		2.87	
<u>Dissolved Solids (pCi/l)</u>								
20-SW-24	1.6±0.1	18 ± 2	3.9±0.4	-		0.078±0.008		3984
20-SW-25	<0.02	1.8±0.2	< 0.04	1.4±0.2		0.21 ±0.02		3870

Table 10. Specifically Identified Contamination Areas

Location	Identification Number	Figure Number	PAC-4G-3 Direct Reading (Max.) (dis/min-100 cm ²)		PRM-5-3 (cts/min)
			Beta	Alpha	
Basement	237	11	135 k	85 k	25 k
"	238	11	126 k	17 k	BKGD
"	239	11	2.3 k	2 k	BKGD
1st Floor	240	12	27 k	8.5 k	BKGD
"	241	12	9 k	6 k	BKGD
"	242	12	6 k	2.5 k	BKGD
"	243	12	9 k	2.5 k	BKGD
"	244	12	18 k	BKGD	BKGD
"	245	12	0.5 k	0.4 k	BKGD
"	246	12	45 k	26 k	BKGD
"	247	12	2 k	0.4 k	BKGD
"	248	12	3 k	BKGD	BKGD
"	249	12	6 k	4 k	BKGD
"	250	12	63 k	BKGD	30 k
"	251	12	14 k	BKGD	20 k
"	252	12	63 k	17 k	15 k
"	253	12	54 k	29 k	10 k
"	254	12	4.5 k	2.5 k	BKGD
"	255	12	32 k	8.5 k	BKGD
"	256	12	4.5 k	BKGD	BKGD
"	257	12	0.8 k	BKGD	BKGD
"	258	12	1.8 k	BKGD	BKGD
"	259	12	0.8 k	BKGD	1.8 k
2nd floor	260	13	29 k	BKGD	1.8 k
1st floor	261	12	18 k	0.3 k	BKGD
"	262	12	2.7 k	0.4 k	BKGD
"	263	12	2.7 k	0.9 k	BKGD
"	264	12	5 k	3 k	BKGD
"	265	12	0.3 k	BKGD	BKGD
"	266	12	18 k	6 k	BKGD
"	267	12	9 k	2.5 k	BKGD
"	268	12	4.5 k	1.7 k	BKGD
"	269	12	4.5 k	0.9 k	BKGD
"	270	12	BKGD	0.9 k	BKGD
"	271	12	4.5 k	0.9 k	BKGD
"	272	12	9 k	4 k	BKGD
"	273	12	9 k	4 k	BKGD
"	274	12	0.9 k	BKGD	BKGD
"	275	12	2.7 to 27 k	0.3 to 8.5 k	BKGD
"	276	12	2.7 k	BKGD	BKGD
"	277	12	6.3 k	1.7 k	BKGD
"	278	12	1.8 k	0.7 k	BKGD
"	279	12	9 k	2.5 k	BKGD

Table 10 - (cont'd.)

Location	Identification Number	Figure Number	PAC-4G-3 Direct Reading (Max.) (dis/min-100 cm ²)		PRM-5-3 (cts/min)
			Beta	Alpha	
2nd Floor	280	13	9 k	0.36 k	25 k
"	281	13	18 k	7 k	2 k
"	282	13	63 k	7 k	75 k
"	283	13	450 k	85 k	5 k
"	284	13	2.7 to 18 k	8.5 k	25 k
"	285	13	2.7 to 36 k	BKGD to 14 k	6 k
"	286	13	306 k	43 k	10 k
"	287	13	2.7 to 45 k	0.9 to 34 k	1.5 k
"	288	13	0.9 to 2.7 k	0.6 to 1.7 k	BKGD
3rd Floor	289	14	21 k	8.5 k	BKGD
"	290	14	2.7 k	0.9 k	BKGD
"	291	14	63 k	34 k	BKGD
"	292	14	63 k	34 k	20 k
"	293	14	63 k	34 k	10 k
"	294	14	90 k	43 k	12 k
Garage	295	7	81 k	37 k	-
"	296	7	9 k	26 k	-
Backyard	297	7	-	-	100 k
"	298	7	-	-	>500 k
Driveway	299	7	-	-	>500 k
South of Driveway	300	7	-	-	200 k
Basement Entry	301	7	-	-	50 k
2nd Floor	302	13	2.7 to 27 k	BKGD to 8.5 k	7 to 20 k

Table 11. Smear Results

Location	Identification Number	Figure Number	Results <u>dis/min</u>		Comment
			Alpha	Beta	
Basement	1	19	9	10	Contaminated
"	2	19	47	110	Floor Areas
"	3	19	23	52	
"	4-9	19	BKGD	BKGD	
Yard	10	-	143	353	Misc. Items
"	11	-	136	334	See Table 2
"	12	-	208	391	
Basement	13-28	19	BKGD	BKGD	
1st Floor	29-46	21	BKGD	BKGD	
"	47	20	180	149	Contaminated Area
"	48-54	20-21	BKGD	BKGD	
"	55	20	2	4	Contaminated Area Fireplace
"	56-94	20-21	BKGD	BKGD	
"	95	21	2	BKGD	Contaminated Area Foyer
"	96-113	20	BKGD	BKGD	
2nd Floor	114-123	22	BKGD	BKGD	
"	124	22	2	26	"Glass Closet" Contaminated Area
"	125-160	22	BKGD	BKGD	
"	161	22	BKGD	10	Contaminated Area Landing
"	162	22	BKGD	13	Contaminated Area Main Bedroom
3rd Floor	163	23	BKGD	19	Contaminated Area East Bedroom
"	164-196	23	BKGD	BKGD	
1st Floor	197-213	21	BKGD	BKGD	
2nd Floor	214-225	22	BKGD	BKGD	
1st Floor	226-227	20	BKGD	BKGD	
2nd Floor	228-229	22	BKGD	BKGD	
3rd Floor	230	23	BKGD	BKGD	
Basement	231-236	19	BKGD	BKGD	
1st Floor	303-305	20			

Table 12. Radiochemical Analyses of Selected Soil Samples for Thorium

Sample Number	Concentrations (pCi/g)				Comment
	^{232}Th	^{230}Th	^{228}Th	^{227}Th	
20-S-26	1.18 ± 0.16	0.85 ± 0.14	1.17 ± 0.17	0.94 ± 0.19	Bin sample
20-S-45	1.47 ± 0.07	1.33 ± 0.07	1.46 ± 0.07	0.62 ± 0.05	Soil, criteria sample
20-S-47	0.94 ± 0.11	1.45 ± 0.14	1.20 ± 0.12	0.60 ± 0.10	Soil, criteria sample
20-S-49	1.45 ± 0.10	7.60 ± 0.29	1.49 ± 0.10	0.58 ± 0.07	Soil, driveway 1 ft below grade
20-S-61	2.00 ± 0.44	8.75 ± 1.20	1.57 ± 0.40	-	Soil, driveway 1 ft below grade
20-S-74	0.97 ± 0.06	273 ± 5.96	0.98 ± 0.06	12.05 ± 0.32	Driveway, layered material
20-S-75(A)	-	77720 ± 3117	186 ± 30	2738 ± 154	Driveway, layered material
20-S-75(B)	-	68082 ± 2929	507 ± 91	2413 ± 228	Driveway, layered material
20-S-75(C)	1.33 ± 0.21	48 ± 2	1.06 ± 0.18	2.37 ± 0.31	Driveway, vein material
20-S-77	-	0.44 ± 0.05	0.25 ± 0.02	0.01 ± 0.04	Concrete, basement floor
20-S-82	0.05 ± 0.01	0.30 ± 0.05	0.06 ± 0.01	-	Credenza sample from garage
20-S-85	-	6.91 ± 0.58	0.67 ± 0.17	0.39 ± 0.16	Scrapings, glass closet
20-S-86	0.09 ± 0.03	0.08 ± 0.06	0.19 ± 0.04	0.07 ± 0.06	Floor padding, TV room
20-S-87	-	9.26 ± 0.75	-	1.27 ± 0.04	Contaminated paper from garage

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 8 contains calibration and analysis procedures for soil.

APPENDIX 1

INSTRUMENTATION

I. PORTABLE RADIATION SURVEY METERS

A. Gas-Flow Proportional Survey Meters

The Eberline PAC-4G-3 usually is the primary instrument used for surveying. This instrument is a gas-flow proportional counter that utilizes a propane gas-proportional detector, 51 cm² (AC-21), 100 cm², or 325 cm² (AC-22) in 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 is initially used in the beta mode. In that mode, the detector responds to alpha and beta particles and x- and gamma-rays. When areas indicate a higher count rate than the average instrument background, the beta-mode reading is recorded, and the instrument is 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. The alpha voltage is set to 1600 V, and the input discriminator is set to 1.5 mV. The instrument is then calibrated in the alpha mode with four flat-plate, infinitely-thin NBS-traceable ²³⁹Pu standards, 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 is found with a PAC instrument, a reading is taken 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, making the window density approximately 7 mg/cm². At this density, the instrument is not sensitive to the majority of alpha emissions. 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. This instrument is calibrated in mR/h with a ²²⁶Ra standard.

C. Low-Energy Gamma Scintillation Survey Meter

An Eberline Model PRM-5-3 with a PG-2 gamma scintillation detector is used to determine low-energy x and gamma radiation.

APPENDIX 1 (cont'd.)

The PG-2 detector consists of a thin NaI(Tl) scintillation crystal 5 cm in diameter by 2 mm thick. This instrument is calibrated on three separate high voltages for three energy regions using ^{239}Pu (17 keV), ^{241}Am (59.5 keV), and ^{235}U (185.7 keV) sources. This instrument can be operated in either a differential (to discriminate between different energy regions) or integral mode.

D. High-Energy Micro "R" Scintillation Survey Meter

An Eberline Micro "R" meter model PRM-7 is used to detect high-energy gamma radiation. This instrument contains an internally mounted NaI(Tl) scintillation crystal 2.5 cm in 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 to survey ambient background radiation. It is held 1 m from the surface during the survey. This instrument is also calibrated with a standard ^{226}Ra source and checked daily with a ^{137}Cs - ^{137m}Ba source.

E. Integrating Radiation Meter

In addition to the PRM-7, a pressurized ion chamber (Reuter Stokes Model RSS-111) is used at selected locations to determine the ambient radiation field. The RSS-111 has three output modes: (1) instantaneous exposure rate, (2) strip chart differential readout, and (3) integrated exposure. The chamber is mounted on a tripod, 3 ft above the surface, and has a uniform energy response from about 0.2 MeV to about 4 MeV. A three-hour period of operation is usually sufficient to obtain significant data.

II. SMEAR-COUNTING INSTRUMENTATION

A. Large Area Counter

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

APPENDIX 1
(cont'd)B. Proportional Counters

Any smear taken from a contaminated area is counted individually in a Nuclear Measurements Corporation gas-flow proportional counter (PC-5 or PC-3A). These instruments have been modified to contain a double-aluminized Mylar spun top window. This top is placed over nonconducting media (e.g. paper smears) to negate the dielectric effect on the counter. This counter also uses P-10 counting gas. Smears are counted in both the alpha and beta modes.

C. Calibration Procedures

A PC counter is calibrated by adjusting the input discriminator with the high voltage set at 700 V until it begins to count an alpha source. The plateaus are run to establish the operating voltages for alpha and beta-gamma. The MS-2 input discriminator is set to 2 mV, and again plateaus are run to establish the operating voltages.

D. Liquid Scintillation Counter

In areas where low-energy beta-emitting nuclides (e.g., ^3H and ^{14}C) are known to have been used, the smear survey is performed using expanded polystyrene. The polystyrene is dissolved in a liquid scintillation cocktail. The vial of liquid is counted in a Nuclear Enterprises, Inc., Liquid Scintillation Counter, LSC-2, designed to measure picocurie quantities of these nuclides. Dual channels with associated single-channel analyzers provide capability for counting beta spectra at two energy regions simultaneously.

III. AIR-SAMPLING DEVICE

A. ANL Radon Progeny Pump (Filter Queen)

Air samples are collected using a commercially available (ANL-modified Filter Queen) vacuum cleaner. Air is drawn through a filter medium at a flow rate of $40 \text{ m}^3/\text{h}$. The filters consist of 200-cm^2 sheets of Hollingsworth-Vose (HV-70) or LB5211-9 mil filter paper. The collection efficiency at these flow rates for $0.3\text{-}\mu\text{m}$ particles is about 99.9%.

B. Actinon Pump

A separate air sample can be taken with a positive displacement pump drawing about 20 liters/min through a Millipore membrane (0.5 to $0.8 \text{ }\mu\text{m}$) filter paper for about one hour. An alpha

APPENDIX 1 (cont'd.)

spectrum can be measured from a section of this filter paper. The ratio of actinon (^{219}Rn) daughters (6.62 MeV α , AcC) to radon (^{222}Rn) daughters (7.69 MeV α , RaC') can be determined from this spectrum.

C. Tritium

A cold trap is set up with dry ice and methanol. An air sample is taken with a positive displacement pump drawing about 20 /min through the cold trap for two to three hours. The water vapor from the air condenses on the sides of the cold trap. At the end of sampling, a 1 ml aliquot of the condensed water vapor and 10 ml of scintillation cocktail are mixed in a 20 ml counting vial.

The windows on the Liquid Scintillation Counter (LSC-2) are set to count the beta particles from ^{14}C and ^3H . The samples in the vials are counted for four minutes after they have settled and cleared.

The relative humidity reading is measured with a sling psychrometer. The wet and dry bulb readings are recorded.

IV. GAMMA SPECTRAL INSTRUMENTATION

A. Contamination Identification

A Nuclear Data Multichannel Analyzer Model ND-100, utilizing a 7.6-cm (3-in.) diameter by 7.6-cm (3-in.) thick NaI(Tl) lead shielded scintillation crystal is commonly used for determining a gamma spectrum. The crystal and lead shielding are located inside the radiological survey vehicle. This instrument is calibrated with NBS-traceable gamma sources. This system can be used to identify contaminant radionuclides by analyzing the gamma-rays emitted by samples from contaminated areas.

Hyperpure Germanium detectors (ORTEC-17% efficiency right-circular cylinders) can be used when more sophisticated gamma-ray analyses are required. These detectors are coupled to Nuclear Data Multichannel Analyzers (Models ND-60, ND-66, or ND-100).

B. Borehole Logging

The gamma-ray spectrum of a borehole is logged using the Bicon 5.1 cm (2 in.) by 5.1 cm (2 in.) NaI crystal and either the ND-66 or the ND-100. This crystal is specially designed to with-

APPENDIX 1
(cont'd.)

stand the temperature changes that can be encountered in boreholes. Permanent records of the spectrum are produced by the teletype printer and paper tape punch or the Centronix Printer and Magnetic Tape Drive.

C. Portable Analyzer

A Nuclear Data portable multichannel analyzer, ND-6, utilizing a 5.1 cm diameter by 5.1 cm thick (2-inch by 2-inch) NaI(Tl) scintillation crystal is commonly used for determining the gamma-ray spectrum of items or areas that cannot be taken to the mobile laboratory. The instrument is battery operated and has both internal storage capabilities and a tape cassette. This instrument is also calibrated with NBS-traceable gamma-ray sources and is used to identify contaminant radionuclides from their emitted gamma-rays.

APPENDIX 2

CONVERSION FACTORS

I. INSTRUMENTATION

The factors used to convert the instrument readings to 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</u> <u>(51 cm²)</u>		<u>PAC-4G-3</u> <u>(100 cm²)</u>		<u>Floor</u> <u>Monitor</u> <u>(FM-4G)</u>	
	<u>Alpha</u>	<u>Beta</u>	<u>Alpha</u>	<u>Beta</u>	<u>Alpha</u>	<u>Beta</u>
To 100 cm ²	1.96	1.96	1.00	1.00	0.31	0.31
dis/min per cts/min for ⁹⁰ Sr- ⁹⁰ Y	-	2	-	2	-	2
dis/min per cts/min for ²³⁹ Pu	2	-	2	-	2	-
dis/min per cts/min for normal U	3.5	2.7	2.7	2.4	3.0	2.5
dis/min per cts/min for ²²⁶ Ra plus daughters	1.7	1.8	1.7	1.8	1.7	1.8

B. Derivation of Conversion Factors· Floor Monitor

Window Area: 325 cm²

Conversion to 100 cm² = 0.31 times floor monitor readings

· PAC-4G-3

Window Area: 51 cm²

Conversion to 100 cm² = 1.96 times PAC reading

Window Area: 100 cm²

Conversion to 100 cm² = 1.00 times PAC reading

· 2π Internal Gas-Flow Counter, PC Counter

Geometry: Solid Steel Spun Top - 0.50

APPENDIX 2
(cont'd.)

Geometry: Mylar Spun Top - 0.43

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

The PAC-4G-3 and PC counters were calibrated as described in Appendix 1. With a flat-plate, infinitely thin ^{226}Ra plus short-lived daughters standard used as a source of alpha emissions, the plate was counted in a 2π Internal Gas-Flow Counter (PC counter) with the source leveled to an apparent 2π geometry. The alpha counts per minute (cts/min) reading was found to be 1.86×10^4 cts/min, or $1.86 \times 10^4 \div 0.51 = 3.65 \times 10^4$ disintegrations per minute (dis/min) alpha. Since the source was infinitely-thin, the alpha component was used as the total alpha dis/min of the source.

The same ^{226}Ra plus daughters source, when counted with the PAC instrument in the alpha mode, was found to be 2.18×10^4 cts/min at contact. The conversion factor for cts/min to dis/min for the PAC instrument is $3.65 \times 10^4 \div 2.18 \times 10^4 = 1.7$ dis/min per cts/min alpha.

The same source was covered with two layers of conducting paper, each 6.31 mg/cm^2 , to absorb the alpha emissions. With the PC counter in the beta mode and the paper in good contact with the chamber, the count was found to be 1.17×10^4 cts/min, or $1.17 \times 10^4 \div 0.50 = 2.35 \times 10^4$ dis/min beta. With the PAC-4G-3 in the beta mode and in contact with the covered source in the center of the probe, the count was found to be 1.36×10^4 cts/min. This indicates a conversion factor of $2.35 \times 10^4 \div 1.36 \times 10^4 = 1.7$ dis/min per cts/min beta-gamma. All three detectors (51 cm^2 , 100 cm^2 and 325 cm^2) gave readings similar to those reported above for the alpha and beta-gamma modes.

Utilizing a 1.25 inch x 1.25 inch x 0.005 inch normal uranium foil as a source of uranium alpha emissions, the foil was counted in a PC counter with the source leveled to an apparent 2π geometry. The same normal uranium source, covered with two layers of conducting paper in good contact with the chamber, each 6.31 mg/cm^2 to negate the alpha emissions, was counted for composite beta and gamma emissions in the PC counter. The source was leveled to an apparent 2π geometry; however, no provision was made for backscatter.

*The value of 0.51 includes the following factors: geometry (g)=0.50; backscatter factor (bg)=1.02; sample absorption factor (sa)=1.0; window air factor (waf)=1.0. The product of $g \times bg \times sa \times waf$ is 0.51

APPENDIX 2 (cont'd.)

The normal uranium source was also counted with the PAC instruments using all three detector areas in the alpha mode and covered with two layers of conducting paper in the beta mode. The conversion factors were calculated as for ^{226}Ra .

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 the Mylar spun top.

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

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

If energies of the isotope are known, the appropriate window air factor (waf) is used; if the energies of the isotopes are not known, the (waf) of ^{239}Pu is used.

The (waf) for alpha from ^{226}Ra plus daughters is 0.55.

B. Conversion Equation (Beta)

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

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 is used when determining beta activity on a filter media.

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

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

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

APPENDIX 2
(cont'd.)

III. TRITIUM SMEAR COUNT

The conversion equation for cts/min-100 cm² to dis/min-100 cm² for popcorn smear counts is given below:

$$C_e = \frac{A_e - B}{Y}$$

where: C_e = dis/min removable contamination
 A_e = measured cts/min of removable contamination
 B = measured background of clean popcorn dissolved in the scintillation cocktail.
 Y = combined yield of the counter and scintillation cocktail as given in more detail in Appendix 3, Section V.

For the Nuclear Enterprises, Inc., Liquid Scintillation Counter (LSC-2), the high voltage is set to 900 Volts. The A channel threshold is set at 360 and the window is set at 999 for ¹⁴C. The B gain is set at times ten (x10). The B channel threshold is set at 150 and the window is set at 825 for ³H.

APPENDIX 3

AIRBORNE RADIONUCLIDE CONCENTRATION CALCULATIONS

Calculations for determining radon concentrations in air samples collected with an Argonne National Laboratory-designed air sampler using HV-70 or LB-5211 filter media are summarized in Sections I through IV of this appendix. The basic assumptions and calculations used to derive the air concentrations also are included. Calculations for determining tritium concentrations in air samples collected by condensing water vapor from the air are summarized in Section V of this appendix.

I. RADON CONCENTRATIONS

The following postulates are assumed in deriving the radon (^{222}Rn) concentrations based on the RaC' alpha count results:

- A. RaA, RaB, RaC, and RaC' are in equilibrium.
- B. RaA is present only in the first count and not the 100-minute decay count.
- C. One-half of the radon progeny is not collected on the filter media, (i.e., unattached fraction).
- D. The geometry factor (g) is 0.43 for both the alpha and beta activity.
- E. The backscatter factor (bf) for the alpha activity is 1.0.
- F. The sample absorption factor (sa) for RaC' is 0.77.
- G. The window air factor (waf) for RaC' is 0.8.
- H. RaB and RaC, being beta emitters, are not counted in the alpha mode.
- I. The half-life of the radon progeny is approximately 36 minutes, based on the combined RaB and RaC half-lives.
- J. Thoron and long-lived alpha emitters are accounted for using the 360-minute decay count and the seven-day count, respectively.
- K. For all practical purposes, RaC' decays at the rate of the composite of RaB and RaC, which is about 36 minutes.

The following postulates are assumed in deriving the thoron (^{220}Rn) concentrations:

- L. ThA, ThB, ThC, and ThC' are in equilibrium.
- M. ThA and RaC' have decayed by the 360-minute decay count.

APPENDIX 3
(cont'd.)

- N. The geometry factor (g), backscatter factor (bf), sample absorption factor (sa) and window air factor (waf) all are the same for thoron as for radon.
- O. ThB and 64% of ThC, being beta emitters, are not counted in the alpha mode.
- P. The half-life of the thoron progeny is 10.64 hours (638.4 minutes) based on the ThB half-life.
- Q. For all practical purposes, 36% of the ThC (alpha branch) and the ThC' decay at the same rate as ThB, which is 638.4 minutes.
- R. The counter does not differentiate between ThC alphas and the ThC' alphas.

The following postulates are assumed in deriving the actinon (^{219}Rn) concentrations:

- S. AcA, AcB, and AcC are in equilibrium.
- T. AcA has decayed by the 100-minute decay count.
- U. The geometry (g), backscatter (bf), sample absorption (sa), and window air factor (waf) factors all are the same for actinon as for radon.
- V. AcB, being a beta emitter, is not counted in the alpha mode.
- W. The half-life of the actinon progeny is 36.1 minutes based on the AcB half-life.
- X. For all practical purposes, the AcC decays at the same rate as AcB, which is 36.1 minutes.
- Y. 84% of the AcC decays by 6.62 MeV alpha emissions and 16% decays by 6.28 MeV alpha emissions.

The following postulate is assumed in deriving the long-lived concentration:

- Z. The long-lived activity, as determined from the seven-day count, is assumed to be constant during the entire counting period. This assumption is valid for isotopes with half-lives longer than a few years.

APPENDIX 3
(cont'd.)

II. EQUATIONS USED TO DERIVE AIR CONCENTRATIONS

$$A_0 = \frac{A}{e^{-\lambda t}}$$

where: A_0 = activity (dis/min) present at the end of the sampling period (usually 40 minutes).

A = activity (dis/min) at some time, t , after end of the sampling period.

t = time interval (minutes) from end of sampling period to counting interval (usually ~100 minutes).

$$\lambda = \frac{0.693}{t_{1/2}}$$

$t_{1/2}$ = half-life of isotope (minutes).

Concentration is determined by the following equation.

$$C = \frac{A_0 \lambda}{f} \times \frac{1}{1 - e^{-\lambda t_s}}$$

where: C = concentration (dis/min-m³)

A_0 = activity on filter media at end of sampling period (dis/min)

f = sampling rate (m³/min = m³/h x 1 h/60 min)

t_s = length of sampling time (min)

$$\lambda = \frac{0.693}{t_{1/2}}$$

$t_{1/2}$ = half-life of isotope or controlling parent (min).

III. ACTINON CORRECTION

Since the actinon (²¹⁹Rn) progeny (AcB & AcC) decays at the AcB half-life of 36 minutes, it cannot be distinguished from the radon (²²²Rn) progeny using standard air sampling with HV-70 or LB-5211 filter media and standard alpha-counting techniques. A positive displacement pump is used to collect a sample on Millipore membrane (0.5 to 0.8 μm) filter media. The sample rate is approximately 20 liters/minute for a

APPENDIX 3 (cont'd.)

sampling time of at least 90 minutes. The center portion of the sample is removed and counted in an alpha spectrometer which exhibits the 6.62 MeV AcC alpha emissions and the 7.69 MeV RaC' alpha emissions. If these two peaks are observed in the spectrum, then the following calculations are performed:

$$B_j = \sum_{i=1}^n b_{ij}$$

where: B_j = summation of the counts in n channels under peak j.

b_{ij} = the number of counts in channel i of peak j.

j = 1 for the 6.62 MeV peak of actinon; 2 for the 7.69 MeV peak of radon

n = total number of channels in the summation.

The fractions of the activity with a 36-minute half-life due to actinon and radon are then:

$$\text{Actinon} = \frac{B_1/0.84}{B_1/0.84 + B_2}$$

$$\text{Radon} = \frac{B_2}{B_1/0.84 + B_2}$$

where 1 refers to actinon progeny and 2 refers to radon progeny.

IV. EXAMPLE CALCULATION

Data have been created to correspond to values likely to occur if all possible types of contamination are present in the air of a room where a sample is collected. The applications of the equations for determining all types of activity and their concentrations are given below:

f = 40 m³/60 min
at t = 100 min
at t = 360 min
at t = 7 days

t_s = 40 min
A = 2000 dis/min
A = 140 dis/min
A = 5 dis/min

For long-lived activity:

$$A_0 = A = 5 \text{ dis/min}$$

APPENDIX 3
(cont'd.)

$$C(L) = A_0 / fxt_s = \frac{5}{40/60 \times 40} = 0.19 \text{ dis/min-m}^3.$$

For thoron:

$$A_0 = \frac{140-5}{\exp - \frac{0.693 \times 360}{638.4}} = 199.6 \text{ dis/min}$$

$$C(Tn) = \frac{199.6 \times \frac{0.693}{638.4}}{40/60} \times \frac{1}{1 - \exp - \frac{0.693 \times 40}{638.4}} = 7.6 \text{ dis/min-m}^3$$

For radon (^{222}Rn) and actinon (^{219}Rn), activity due to thoron at $t = 100$ min:

$$A = \frac{135}{\exp - \frac{0.693 \times 260}{638.4}} = 179 \text{ dis/min.}$$

Activity due to the isotopes with a 36-minute half-life:

$$A = 2000 - 179 - 5 = 1816 \text{ dis/min}$$

$$A_0 = \frac{1816}{\exp - \frac{0.693 \times 100}{36}} = 12,454 \text{ dis/min}$$

$$C(36) = \frac{12,454 \times \frac{0.693}{36}}{40/60} \times \frac{1}{1 - \exp - \frac{0.693 \times 40}{36}} = 669.7 \text{ dis/min-m}^3$$

When an actinon peak is seen at 6.62 MeV, the counts under the two peaks are summed. For example, if 10 channels are summed, the following counts are found:

For 6.62 MeV peak: 44 counts in 10 channels, where the 6.62 alpha emissions are 84% of the total.

For 7.69 MeV peak: 601 counts in 10 channels, where the 7.69 MeV alpha emissions are 100% of the total.

APPENDIX 3
(cont'd.)

$$B_1 = 44 \text{ counts}$$

$$B_1/0.84 = 52 \text{ counts}$$

$$B_2 = 601 \text{ counts}$$

$$\text{Actinon} = 52/653 = 0.08$$

$$\text{Radon} = 601/653 = 0.92$$

$$C(\text{Rn}) = C(36) \times \text{Radon\%} = 669.7 \times 0.92 = 616.1 \text{ dis/min-m}^3$$

$$C(\text{Am}) = C(36) \times \text{Actinon\%} = 669.7 \times 0.08 = 53.6 \text{ dis/min-m}^3.$$

Since we assume that on the average half of the progeny is not adhered to the filter paper, the above concentrations are then doubled to determine actual concentrations in the air. We assume that there is no unattached fraction for the long-lived activity.

C actual = C measured x progeny correction factor

$$C(L) = 0.19 \text{ dis/min-m}^3$$

$$C(\text{Tn}) = 7.6 \text{ dis/min-m}^3 \times 2 = 15.2 \text{ dis/min-m}^3$$

$$C(\text{An}) = 53.6 \text{ dis/min-m}^3 \times 2 = 107.2 \text{ dis/min-m}^3$$

$$C(\text{Rn}) = 616 \text{ dis/min-m}^3 \times 2 = 1232 \text{ dis/min-m}^3.$$

These would then be the resulting concentrations in dis/min-m^3 . To convert to pCi/l , divide the concentrations by 2.2×10^3 :

$$C(L) = \frac{0.19 \text{ dis/min-m}^3}{2,220 \text{ dis/min-m}^3 \text{ pCi/l}} = 8.6 \times 10^{-5} \text{ pCi/l}$$

$$C(\text{Tn}) = \frac{15.2 \text{ dis/min-m}^3}{2,220 \text{ dis/min-m}^3 \text{ pCi/l}} = 0.0068 \text{ pCi/l}$$

$$C(\text{An}) = \frac{107.2 \text{ dis/min-m}^3}{2,220 \text{ dis/min-m}^3 \text{ pCi/l}} = 0.048 \text{ pCi/l}$$

$$C(\text{Rn}) = \frac{1232 \text{ dis/min-m}^3}{2,220 \text{ dis/min-m}^3 \text{ pCi/l}} = 0.55 \text{ pCi/l}.$$

APPENDIX 3
(cont'd.)

V. RADON MONITORING INSTRUMENTS

Continuous monitoring of the radon concentration (and concomitant Working Level) is conducted with a commercially available Eberline Radon Gas Monitor Model 2 (RGM-2) and/or an Environmental Working Level Monitor Model 2 (EWLM-2) designed and built at Argonne National Laboratory. Details of these instruments can be found in their respective operating manuals. The manual for the former instrument is available from the Eberline Division of the Thermo Electron Corp., P.O. Box 2108, Santa Fe, New Mexico 87501. The manual for the latter instrument is available from the authors of this report at Argonne National Laboratory. Each instrument is briefly described below.

A. Radon Gas Monitor (RGM-2)

The Model RGM-2 Radon Gas Monitor is a complete, semiportable system for continuous measurement of radon gas. The instrument incorporates a 1-liter scintillation cell detector for radon gas detection and a microcomputer for data analysis. A pump is included for continuous gas flow, and an alphanumeric printer is used to record the data for unattended operation. The electronics section contains a variable high voltage supply and a charge-sensitive input amplifier. The power supply source is designed to operate from normal power line sources or from a dc power source, and it incorporates an internal battery as backup for power source disturbances. All the electronic circuits are solidstate with integrated circuits used extensively to enhance reliability.

The microcomputer is programmed to provide data output, in pico-curies per liter (pCi/l), by computing the data from gross detector counts divided by the detector calibration factor and subtracting the detector background counts. Normal data output is printed hourly, and a 24-hour average is printed at the end of a 24-hour period. A test routine; status conditions of alarm, power and airflow; and day/time-of-day functions are included. Operator control is provided by a 16-key keyboard.

The instrument is housed in an insulated steel cabinet for environmental protection. Detachable legs and handles are provided for ease of transportation.

B. Environmental Working Level Monitor (EWLM-2)

The Environmental Working Level Monitor (EWLM) is an instrument used to automatically monitor airborne Rn-daughter concentrations and the Working Level (WL). It is an ac powered, microprocessor based instrument with an external inverter provided for dc operation if desired. The microprocessor's power control power unit (CPU) controls the actuation of the detector assembly and processes its output signals to yield the measurements in the proper units. The detectors are fully automated and require

APPENDIX 3
(cont'd.)

no manual operations once the instrument is programmed. They detect and separate the alpha emitters of RaA and RaC', as well as the beta emitters of RaB and RaC. The resultant pulses from these detected radioisotopes are transmitted to the CPU. The programmed microprocessor performs the mathematical manipulations necessary to output accurate Rn-daughter concentrations and the WL. A special subroutine within the system program enables the EWLM to run a calibration procedure on command which yields calibration data. These data can then be processed in a separate program on most computers capable of BASIC programming. This calibration program results in the derivation of coefficients and beta efficiencies required by the main system program to assure proper calibration of the individual EWLM's.

Each of these instruments requires calibration procedures to ensure that output numbers are commensurate with the radon levels and Working Levels being ascertained.

The Radon Gas Monitor (RGM-2) is calibrated with a Radon bubbler constructed from an NBS standard radium source. The efficiency determined in this fashion is consistent with the efficiency value supplied by the manufacturer. The RGM-2 determines picocuries per liter of radon. Assuming equilibrium between the radon parent and the short-lived daughters, these values are readily converted to Working Levels.

The Environmental Working Level Monitor (EWLM-2) is calibrated by determining the efficiency of each detector using standard sources. The instrument then determines the Working Level from these efficiencies and the radioactivity in the radon daughter products collected on the filter paper. Since only one-half of the radon progeny are collected on the filter paper (see Section IC of this appendix) the values determined with this instrument are increased by a factor of two to account for the "un-attached fraction" of radon daughters present in the air but not collected on the filter paper.

VI. TRITIUM CONCENTRATIONS

It is assumed that all the tritium in the air is part of a water molecule and that all the water vapor is collected in the cold trap.

A. Yield

A secondary tritium standard is made by taking a primary standard of known concentration and diluting it with distilled water to make a secondary standard of approximately 5×10^4 dis/min. The activity of the secondary standard is calculated from the dilution ratio and by using the decay equation:

APPENDIX 3

(cont'd.)

$$I = I_0 e^{-\lambda t}$$

where: I_0 = dis/min of the primary standard at the date indicated for this standard.

$$\lambda = \frac{0.693}{t_{1/2}}$$

$t_{1/2}$ = half-life of ^3H or 12.28 years.

t = time interval from the primary standard date to the time of mixing the secondary standard.

I = dis/min of the secondary standard at the time it was mixed with distilled water.

The scintillation standard is mixed at the time of use by taking a 1 ml aliquot of the secondary standard and dissolving it in 10 ml of the scintillation cocktail. The activity of this scintillation standard is calculated using the decay equation above. Now, however,

I_0 = dis/min of the secondary standard at the time of mixing

t = time interval from mixing the secondary standard to mixing the scintillation standard.

I = dis/min of the scintillation standard at the time it was mixed with the cocktail.

The combined yield of the counter and the scintillation cocktail are determined using the following equation:

$$Y = \frac{As - B}{I}$$

where: Y = yield

As = measured counts of a tritium standard

B = measured background

I = dis/min of the standard in the scintillation cocktail at the time of calibration as calculated from the decay equation given above.

APPENDIX 3 (cont'd.)

B. Humidity

The grams of water per cubic meter of dry air (ϵ) are determined from the composite humidity chart (see Figure on page 112).

C. Tritium

The activity of 1 ml of the condensate is then:

$$C_e = \frac{A_e - B}{Y}$$

where: C_e = dis/min-ml of the water vapor

A_e = measured counts of the water vapor sample

B = measured background of distilled water dissolved in the scintillation cocktail.

The concentration of tritium in the air is then:

$$C_a = \frac{C_e \times \epsilon}{\rho \times 2.22 \text{ dis/min-pCi}}$$

where: C_a = $\mu\text{Ci/m}^3$

ϵ = humidity ($\text{gmH}_2\text{O/m}^3$ dry air)

ρ = water density (1 gm/ml).

D. Example

The secondary standard was mixed April 5, 1984, in the liquid scintillation cocktail. The activity of the scintillation standard was calculated and the information recorded on the scintillation vial as indicated:

Data on April 5, 1984: $I_o = 4.14 \times 10^4 \text{ dis/min}$ of the tritium scintillation standard at the time it was prepared.

Data on May 1, 1984: $A_s = 8854.75 \text{ cts/min}$ from the tritium standard.

$B = 29.25 \text{ cts/min}$ background

Wet bulb = 56°F, Dry Bulb = 68°F

$A_e = 78 \text{ cts/min}$ from the water vapor sample

Source strength at the time the sample was collected:

APPENDIX 3
(cont'd.)

$$I = 4.14 \times 10^4 \times \exp - \frac{0.693 \times 0.0712}{12.28} = 4.12 \times 10^4$$

Combined counter and scintillation cocktail yield:

$$Y = \frac{8854.75 - 29.25}{4.12 \times 10^4} = 0.214$$

Humidity: $\epsilon = 8.25 \text{ g/m}^3$

Concentration in a 1 ml aliquot of the condensate:

$$C_e = \frac{78 - 29.25}{0.214} = 228 \text{ dis/min-ml}$$

Concentration in the air: $C_a = \frac{228 \times 8.25}{1 \times 2.22} = 847 \text{ pCi/m}^3$

$$847 \text{ pCi/m}^3 \times 10^{-3} \text{ m}^3/\ell = 0.85 \text{ pCi/l.}$$

PSYCHROMETRIC CHART **FOR ATMOSPHERIC WATER VAPOR CONCENTRATIONS**

DATA: U.S. WEATHER BUREAU BULLETIN No. 1071
 HANDBOOK OF CHEMISTRY & PHYSICS, 60th Ed. 1979-90
 SMITHSONIAN TABLES

APPENDIX 4

SAMPLE PREPARATION AND ANALYSIS. GENERIC PROTOCOL

I. SOIL-SAMPLE PREPARATION

Soil samples are acquired as previously described. These samples are bagged and identified at the collection site and returned to ANL. If there is an indication of radioactive contamination, the sample is sealed in a Nalgene jar. At ANL, the soil samples are logged into the soil-sample book, and each sample is weighed (on a tared balance scale) and the weight is marked on the container. This weight is recorded in the soil book as a "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 (approximately 48 hours). The sample is returned to the original container and reweighed using a tared balance scale. This weight is also marked on the container and in the soil-sample book, where it is referred to as a "dry weight."

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

After milling, each sample is sieved through a number 30 standard testing sieve (600 μ mesh, about 5 minutes) and transferred to a 12" x 12" ziplock bag. Rocks and dross are bagged separately from the sieved material. The bags are marked with the sample number, the sieve number and R(rocks) or S(soil). The balance is tared and the weights of the soil (or rocks) are measured and recorded in the soil-sample book. A 100-g sample of the sieved material is transferred to a 4-oz. Nalgene bottle. These samples are analyzed by suitable analytical techniques, including, as a minimum, gamma spectroscopy (GeLi). A 5-g sample of the sieved material is transferred to a 1-oz. Nalgene bottle. One gram of this

APPENDIX 4
(cont'd.)

sample is used for the determination of uranium by laser fluorometry; 100 grams of this are needed for radiochemical analysis for Pu, Am, and Th if these analyses are required. The bottles containing these weighed samples are marked with sample number and date, and this information is recorded in the soil-sample book. The rocks (and dross) and remaining soil are placed in storage.

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

II. EQUIPMENT DECONTAMINATION

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

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

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

APPENDIX 4
(cont'd.)

III. WATER AND SLUDGE

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

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

IV. VEGETATION, TRASH, AND RUBBLE

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

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

Trash and rubble samples are forwarded to a certified radiochemistry laboratory for analysis.

V. TRITIUM FROM SOLID MATERIALS

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

VI. SOIL ANALYSIS PROCEDURES

A 100-g fraction from each soil sample is analyzed by high resolution gamma-ray spectroscopy using a germanium crystal detector

APPENDIX 4
(cont'd.)

coupled to a multichannel analyzer. This analysis allows for a quantitative determination of the ^{226}Ra decay chain (via the 609 keV gamma-ray of ^{214}Bi) and the ^{232}Th decay chain (via the 911 keV gamma-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 soil is determined by an acid leach of the soil sample followed by laser fluorometry of the leached sample.

Thorium analysis consists of an acid leach of the soil (using a ^{234}Th spike for yield determination) followed by plating a thin source of the radiochemically separated thorium and determining the thorium isotopes (^{228}Th and ^{232}Th) by alpha spectroscopy.

The results of the above measurements allow for quantitative determination of the relative amounts of normal uranium, natural uranium, tailings (i.e., ^{226}Ra decay chain), thorium (^{232}Th), mesothorium (^{228}Ra decay chain), radiothorium (^{228}Th decay chain), plutonium (^{238}Pu , $^{239,240}\text{Pu}$), and americium (^{241}Am) present in the contaminated material.

A mass spectrometric analysis of the uranium fraction is conducted when it is known or it is surmised that depleted or enriched uranium might be present.

APPENDIX 5

CALCULATION OF URANIUM SPECIFIC ACTIVITY

The specific activity for normal uranium was obtained by summing the measured specific activities for the individual isotopes weighted according to their normal abundances. Best values for these specific activities were taken from A. H. Jaffey et al., Phys. Rev. C 4 1889 (1971). The half-life for each isotope was taken from David C. Kocher, "Radioactive Decay Tables-A Handbook of Decay Data for Application to Radiation Dosimetry and Radiological Assessments" (1981). The percent abundances 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.

Isotope	Specific Activity (dis/min- g)	Half-life (years)	Abundance (atom %)	Atomic Weight (grams)	Abundance (wt %)
^{234}U	1.387×10^4	2.446×10^5	0.0054	234.0409	0.0053
^{235}U	4.798	7.038×10^8	0.720	235.0439	0.7110
^{238}U	0.746	4.4683×10^9	99.2746	238.0508	99.2837
			100.0000		100.0000

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

$$\frac{(\text{atom } \%)_i (\text{atomic weight})_i}{\sum_{\text{all } j} (\text{atom } \%)_j (\text{atomic weight})_j} = \frac{(\text{atom } \%)_i (\text{atomic weight})_i}{238.0289}$$

Specific activity for normal uranium:

$$\begin{aligned} 0.746 \times 0.99284 \times 2 &= 1.481 \text{ dis/min- } \mu\text{g for } ^{234}\text{U} \text{ \& } ^{238}\text{U} \\ 4.798 \times 0.00711 &= \underline{0.034} \text{ dis/min- } \mu\text{g for } ^{235}\text{U} \\ &1.515 \text{ dis/min- } \mu\text{g for normal U} \end{aligned}$$

$$\text{or } (1.515 \text{ dis/min-}\mu\text{g}) / (2.22 \text{ dis/min-pCi}) = 0.683 \text{ pCi}/\mu\text{g}$$

where ^{234}U is assumed to be in secular equilibrium with the ^{238}U parent.

Note that 2.24% of the total activity is due to ^{235}U and 48.88% each is due to ^{234}U and ^{238}U .

Calculation of the specific activity of other than normal mixtures of uranium isotopes is performed in a similar manner. For example, uranium having the isotopic composition (atom %) 238(0.99268), 236(0.000007), 235(0.007233), 234(0.000064) and 233(0.000012) as determined by mass spectrometry would have the composition (weight %) of 238(.99278), 236(0.000007), 235(0.007142), 234(0.000063), and 233(0.000012) and the following specific activity:

APPENDIX 5

(cont'd.)

0.99278 x 0.746	- 0.7406 dis/min- μ g from ^{238}U
0.000007 x 1.436 x 10^2	- 0.0010 dis/min- μ g from $^{236}\text{U}^*$
0.007142 x 4.798	- 0.0343 dis/min- μ g from ^{235}U
0.000063 x 1.387 x 10^4	- 0.8738 dis/min- μ g from ^{234}U
0.000012 x 2.140 x 10^4	- <u>0.2568</u> dis/min- μ g from $^{233}\text{U}^{**}$
	1.9065 dis/min-g U total

corresponding to:

$$(1.9065 \text{ dis/min-}\mu\text{g}) / (2.22 \text{ dis/min-pCi}) = 0.859 \text{ pCi/g U}$$

*The half-life for ^{236}U (2.342×10^7 yr) and the corresponding specific activity (1.436×10^2 dis/min- μ g) were taken from K. F. Flynn et. al., J. Inorg. Nucl. Chem. 34 1121 (1972).

**The half-life for ^{233}U (1.5911×10^5 yr) and the corresponding specific activity (2.140×10^4 dis/min- μ g) were taken from A. H. Jaffey, K. F. Flynn et. al., Phys. Rev. C 9 1991 (1974).

APPENDIX 6

PERTINENT RADIOLOGICAL REGULATIONS.
STANDARDS, AND GUIDELINES

I. U.S. NUCLEAR REGULATORY COMMISSION
DIVISION OF FUEL CYCLE AND MATERIAL SAFETY
WASHINGTON, D.C.
July 1982

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

(These have been retyped for
purposes of this report)

The instructions in this guide, in conjunction with Table 1, specify the radioactivity and radiation exposure rate limits which should be used in accomplishing the decontamination and survey of surfaces or premises and equipment prior to abandonment or release for unrestricted use. The limits in Table 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 applying the covering. A reasonable effort must be made to minimize the contamination prior to use of any covering.
3. The radioactivity on the interior surfaces of pipes, drain lines, or 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

APPENDIX 6
(cont'd.)

continuing work with radioactive materials, or conversion of facilities to a long-term storage or standby status. Such request must:

- a. Provide detailed, specific information describing the premises, equipment or scrap, radioactive contaminants, and the nature, extent, and degree of residual surface contamination.
 - b. Provide a detailed health and safety analysis which reflects that the residual amounts of materials on surface areas, together with other considerations such as prospective use of the premises, equipment or scrap, are unlikely to result in an unreasonable risk to the health and safety of the public.
5. Prior to release of premises for unrestricted use, the licensee shall make a comprehensive radiation survey which establishes that contamination is within the limits specified in Table 1. A copy of the survey report shall be filed with the Division of Fuel Cycle and Material Safety, USNRC, Washington, D.C. 20555, and also the Director of the Regional Office of the Office of Inspection and Enforcement, USNRC, having jurisdiction. The report should be filed at least 30 days prior to the planned date of abandonment. The survey report shall:
- a. Identify the premises.
 - b. Show that reasonable effort has been made to eliminate residual contamination.
 - c. Describe the scope of the survey and general procedures followed.
 - d. State the findings of the survey in units specified in the instruction.

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

APPENDIX 6
(cont'd.)

TABLE 1
ACCEPTABLE SURFACE CONTAMINATION LIMITS

NUCLIDES ^a	AVERAGE ^{bcf}	MAXIMUM ^{bdf}	REMOVABLE ^{bef}
U-nat, ²³⁵ U, ²³⁸ U and associated decay products	5000 dis/min-100 cm ² α	15,000 dis/min-100 cm ² α	1000 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	1000 dis/min-100 cm ²	3,000 dis/min-100 cm ²	200 dis/min-100 cm ²
Beta-gamma emitters (nu- clides with decay modes other than alpha emission or spontaneous fission) except ⁹⁰ Sr and others noted above.	5000 dis/min-100 cm ² βγ	15,000 dis/min-100 cm ² βγ	1000 dis/min-100 cm ² βγ

APPENDIX 6
(cont'd.)

TABLE 1

ACCEPTABLE SURFACE CONTAMINATION LEVELS

- a Where surface contamination by both alpha and beta-gamma emitting nuclides exists, the limits established for alpha and beta-gamma emitting nuclides should apply independently.
- b As used in this table, 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.
- c Measurements of average contaminant should not be averaged over more than 1 square meter. For objects of less surface area, the average should be derived for each such object.
- d The maximum contamination level applies to an area of not more than 100 cm².
- e The amount of 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.
- f The 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 6
(cont'd.)II. SURGEON GENERAL'S GUIDELINES
as included in 10 CFR Part 712
Grand Junction Remedial Action Criteria

712.1 Purpose

(a) determination by DOE of the need for, priority of and selection of appropriate remedial action to limit the exposure of individuals in the area of Grand Junction, Colorado, to radiation emanating from uranium mill tailings which have been used as construction-related material.

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

712.2 Scope

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

712.3 Definitions

As used in this part:

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

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

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

(d) "DOE" means the U.S. Department of Energy or any duly authorized representative thereof.

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

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

(g) "Indoor radon daughter concentration level" means that concentration of radon daughters determined by: (1) averaging the results of six air samples each of at least 100 hours duration,

APPENDIX 6
(cont'd.)

and taken at a minimum of 4-week intervals throughout the year in a habitable area of a structure, or (2) utilizing some other procedure approved by the Commission.

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

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

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

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

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

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

(n) A "Working Level" (WL) is the term used to describe radon daughter products in air. This term is defined as any combination of short-lived radon daughter products in 1 liter of air that will result in the ultimate emission of 1.3×10^5 MeV of potential alpha energy. 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.

712.4 Interpretations

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

APPENDIX 6
(cont'd.)

712.5 Communications

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

712.6 General radiation exposure level criteria for remedial action.

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

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

712.7 Criteria for determination of possible need for remedial action

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

(a) Where DOE approved data on indoor radon daughter concentration levels are available.

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

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

APPENDIX 6
(cont'd.)

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

(1) For dwellings and schoolrooms:

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

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

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

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

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

(2) For other structures:

(i) An external gamma radiation level of 0.15 mR/h above background averaged on a room-by-room basis.

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

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

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

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

APPENDIX 6
(cont'd.)

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

- (a) Classification of structure. Dwellings and schools shall be considered first.
- (b) Availability of data. Those structures for which data on indoor radon daughter concentration levels and/or external gamma radiation levels are available when the program starts and which meet the criteria in 712.7 will be considered first.
- (c) Order of application. Insofar as feasible remedial action will be taken in the order in which the application is received.
- (d) Magnitude of radiation level. In general, those structures with the highest radiation levels will be given primary consideration.
- (e) Geographical location of structures. A group of structures located in the same immediate geographical vicinity may be given priority consideration particularly where they involved similar remedial efforts.
- (f) Availability of structures. An attempt will be made to schedule remedial action during those periods when remedial action can be taken with minimum interference.
- (g) Climatic conditions. Climatic conditions or other seasonable considerations may affect the scheduling of certain remedial measures.

712.10 Selection of appropriate remedial action.

- (a) Tailings will be removed from those structures where the appropriately averaged external gamma radiation level is equal to or greater than 0.05 mR/h above background in the case of dwellings and schools and 0.15 mR/h above background in the case of other structures.
- (b) Where the criterion in paragraph (a) of this section is not met, other remedial action techniques, including but not limited to sealants, ventilation, and shielding may be considered in addition to that of tailings removal. DOE shall select the remedial action technique or combination of techniques, which it determines to be the most appropriate under the circumstances.

APPENDIX 6
(cont'd.)III. 40 CFR Part 192
HEALTH AND ENVIRONMENTAL PROTECTION STANDARDS
FOR
URANIUM MILL TAILINGS

(Excerpts have been retyped for purposes of this report)

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 a 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--

(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.

APPENDIX 6
(cont'd.)

(c) A Working Level (WL) is the term used to describe radon daughter products in air. This term is defined as any combination of short-lived radon daughter products in 1 liter of air that will result in the ultimate emission of 1.3×10^5 MeV of potential alpha energy. 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.

(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 microrentgens per hour.

APPENDIX 6
(cont'd.)

- IV. DOE 5480.1 Chg. 6, Chapter XI
(Excerpts have been retyped for purposes of this report)

REQUIREMENTS FOR RADIATION PROTECTION

(Excerpts have been retyped for purposes of this report. Table XI-1 has been modified to reflect the fundamental definition of the Curie as a unit of radioactivity. The designation of uranium is changed to reflect the original usage of the terms normal and natural.)

1. PURPOSE This chapter establishes radiation protection standards and requirements for Department of Energy and Department of Energy contractor operations based upon the recommendations of the Environmental Protection Agency and the National Council on Radiation Protection and Measurement.
2. DEFINITIONS
 - a. Controlled Area. Any area to which access is controlled in order to protect individuals from exposure to radiation and radioactive materials.
 - b. Dose Commitment. The dose equivalent (rem) received by specific organs during a period of one calendar year, that was the result of uptakes of radionuclides by a person occupationally exposed.
4. REQUIREMENTS
 - a. Occupationally Related Exposure of Individuals in Controlled Areas. Radiation exposures shall be limited to levels reasonably achievable within the standards prescribed below.
 - (1) Radiation Protection Standards for External and Internal Exposures

<u>Type of Exposure</u>	<u>Exposure Period</u>	<u>Dose Equivalent (Dose or Dose Commitment rem)¹</u>
Whole body, head and trunk, gonads, lens of the eye ² , red bone marrow, active blood-forming organs.	Year	5 ³
	Calendar Quarter	3
Unlimited areas of the skin (except hands and forearms). Other organs, tissues, and organ systems (except bone)	Year	15
	Calendar Quarter	5

APPENDIX 6
(cont'd.)

Bone	Year	30
	Calendar Quarter	10
Forearms ⁴	Year	30
	Calendar Quarter	10
Hands ⁴ and Feet	Year	75
	Calendar Quarter	25

- 1 To meet the above dose commitment standards, operations must be conducted in such a manner that it would be unlikely that an individual would assimilate in a critical organ, by inhalation, ingestion, or absorption, a quantity of radionuclide or mixture of radionuclides that would commit the individual to an organ dose that exceeds the limits specified in the above table.
- 2 A beta exposure below a maximum energy of 700 keV will not penetrate the lens of the eye; therefore, the applicable limit for these energies would be that for the skin (15 rem/year).
- 3 In special cases, with the approval of EP-30, a worker may exceed 5 rem/year, provided his or her average exposure per year since age 18 will not exceed 5 rem per year. This does not apply to emergency situations.
- 4 All reasonable effort shall be made to keep exposures of forearms and hands to the general limit for the skin.

(2) Procedural Requirements

(a) Restrictions

- 1 An individual under age 18 shall neither be employed in, nor allowed to enter, controlled areas in such a manner that he or she will receive doses of radiation in amounts exceeding one-tenth the standards in paragraph 4a(1) above.
- 2 Dose to students under age 18 exposed to radiation during educational activities shall not exceed 0.1 rem/year. This exposure shall be considered a part of the 0.5 rem/year limit for workers under age 18 and not supplemental to it.

- (b) Combining Internal and External Dose. Current year whole body internal dose commitment from radionuclides for which the whole body is the critical organ must be combined with the external whole body dose. Where both

APPENDIX 6
(cont'd.)

the external penetrating dose and internal dose to critical organ are known, they shall be combined for that organ.

- b. Exposure of Individuals and Population Groups in Uncontrolled Areas. Exposures to members of the public shall be as low as reasonably achievable levels within the standards prescribed below.

(1) Radiation Protection Standards for External and Internal Exposure.

Type of Exposure	Annual Dose Equivalent or Dose Commitment ¹	
	Based on Dose to Individuals at Points of Maximum Probable Exposure	Based on Average Dose to a Suitable Sample of the Exposed Population ²
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)

¹ In keeping with Department of Energy Policy on lowest practicable exposures, exposures to the public shall be limited to as small a fraction of the respective annual dose limits as is reasonably achievable.

² See Paragraph 5.4, Federal Radiation Council Report No. 1, for discussion on concept of suitable sample of exposed population.

- (2) Monitoring Requirements. To assure that doses to the public are maintained as low as reasonably achievable consistent with dose standards set forth in paragraph 4b(1) above, effluents to the environment, and other parameters shall be monitored and documented in accordance with DOE 5484.1.

(3) Concentration Guides.

- (a) Concentration Guides in Attachment XI-1, Table II, were derived for the most part from the dose standards for individuals in paragraph 4b(1) above (assume 168 hours of exposure per week). These guides shall be reduced by

APPENDIX 6
(cont'd.)

a factor of three when applied to a suitable sample of the population. Where transient exposures can be calculated, the concentration guides other than those in Attachment XI-1, Table II, may be used to evaluate compliance with the dose commitment standard.

- (b) There may be situations where it is not feasible or desirable to evaluate the exposure of individuals and samples of exposed populations to effluents to assure compliance with standards in paragraph 4b(1) above. In those cases, effluent releases to uncontrolled areas shall be such that average concentrations of radioactivity at the point of release are within the concentration guides and are as low as reasonably achievable. The point of release shall be considered to be the point at which the effluents pass beyond the site boundary. Radioactivity concentrations may be averaged over periods up to 1 year.
- (4) Further Limitations on Effluent Discharges. In any situation in which the effluents discharged by one or more activities of the Department, Department contractors, or others cause exposure to approach the standards specified in subparagraph b(1) above, appropriate effluent discharge limits may be set for these operations. In such cases, the manager of the field organization may take the necessary corrective action if all activities concerned are within his or her area of responsibility. Otherwise, each case will be referred to EP-30 for appropriate action including, where appropriate, coordination with actions taken by the Nuclear Regulatory Commission under the Code of Federal Regulations, Title 10, Part 20.106(e).
- (5) Discharge to Sanitary Sewage Systems.
 - (a) Effluents may be discharged to public sanitary sewage systems provided:
 - 1 The quantity of radioactivity released in any one month, if diluted by the average monthly quantity of water released by the installation, will not result in an average concentration exceeding the concentration guide in Attachment XI-1, Table I, Column 2.
 - 2 The radiation protection standards in paragraph (1), above, are not exceeded.

APPENDIX 6
(cont'd.)

- (b) Concentrations or quantities of radioactive materials greater than those specified in paragraphs 4(b) and (5)(a) 1 and 2, above, may be released to chemical or sanitary sewage systems owned by the Federal Government provided the standards in paragraph 4b(1) above are not exceeded in uncontrolled areas.

Attachment XI-1

CONCENTRATIONS IN AIR AND WATER ABOVE NATURAL BACKGROUND

Element (atomic number)	Isotope soluble (S) insoluble (I)			Table I Controlled Area		Table II Uncontrolled Area	
				Column 1	Column 2	Column 1	Column 2
				Air (pCi/l)	Water (pCi/l)	Air (pCi/l)	Water (pCi/l)
Hydrogen (1)	H	3	S	5000	1×10^8	200	3×10^6
			I	5000	1×10^8	200	3×10^6
Cobalt (27)	Co	60	S	300	1×10^6	10	5×10^4
			I	9	1×10^6	0.3	3×10^4
Silver (47)	Ag	110m	S	200	9×10^5	7	3×10^4
			I	10	9×10^5	0.3	3×10^4
Cesium (55)	Cs	137	S	60	4×10^5	2	2×10^4
			I	10	1×10^6	0.5	4×10^4
Europium (63)	Eu	152	S	10	2×10^6	0.4	8×10^4
			I	20	2×10^6	0.6	8×10^4
Lead (82)	Pb	212	S	20	6×10^5	0.6	2×10^4
			I	20	5×10^5	0.7	2×10^4
Radon (86)	Rn	220	S	300		10	
		222	S	100		3	
Radium (88)	Ra	226	S	0.05	400	0.003	30
			I	0.05	9×10^5	0.002	3×10^4

APPENDIX 6
(cont'd.)

Thorium (90) ¹ natural	S	0.06	2×10^4	0.002	2000
	I	0.06	6×10^5	0.002	2×10^4
Uranium (92) ² normal	S	0.14	4×10^4	0.006	1200
	I	0.12	1×10^6	0.004	4×10^4

¹ The curie is the activity of that quantity of radioactive material in which the number of disintegrations per second is 3.7×10^{10} . In DOE Order 5480.1, Chapter XI, the curie was redefined to 3.7×10^{10} dis/sec from Th-232 plus 3.7×10^{10} dis/sec from Th-228. In order to make the above table consistent with the real definition of curie, the concentrations for natural thorium were multiplied by a factor of 2.

² In this report, the terms natural uranium and normal uranium are used as they were commonly used in the early days of MED work. Natural uranium is uranium as found in nature in equilibrium with all its daughter products. Normal uranium is uranium that has been processed to separate it from its long-lived daughter products (i.e., the daughter products Th-230 through Pb-206).

In DOE Order 5480.1 Chapter XI, the curie is redefined as 3.7×10^{10} dis/sec from U-238 plus 3.7×10^{10} dis/sec from U-234 plus 1.7×10^9 dis/sec from U-235. This is also called natural uranium in these regulations. In order to make the above table consistent with the real definition of curie, the concentrations for uranium were multiplied by a factor of 2.046. Also, the uranium is called normal uranium as the term is used elsewhere in this report and since the regulation implies that the uranium has been separated from its long-lived daughter products. This is consistent with the earliest use of these terms.

APPENDIX 7

EVALUATION OF RADIATION EXPOSURES

I. INTRODUCTION

A. 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 other 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 those 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.

APPENDIX 7
(cont'd.)

Most atoms of the elements in our environment remain structurally stable. With time, an atom of potassium, for instance, may change its association with other atoms in chemical reactions and become part of other compounds, but it will always remain a potassium atom. Radioactive atoms, on the other hand, are not stable and will spontaneously emit radiation in order to achieve a more stable state. Because of this spontaneous transformation, the ratio of protons and neutrons of the nucleus of an atom is altered toward a more stable condition. Radiation may be emitted from the nucleus as alpha particles, beta particles, neutrons, or gamma-rays, depending uniquely upon each particular radionuclide. Radionuclides decay at characteristic rates dependent upon the degree of stability and characterized by a period of time called the half-life. In one half-life, the number of radioactive atoms and, therefore, the amount of radiation emitted, decrease by one half.

The exposure of man to terrestrial radiation is due to naturally occurring radionuclides and also to "man-made" or technologically enhanced radioactive materials. Several dozen radionuclides occur naturally, some having half-lives of at least the same order of magnitude as the estimated age of the earth. The majority of these naturally-occurring radionuclides are isotopes of the heavy elements and belong to three distinct radioactive series headed by uranium-238, uranium-235, and thorium-232. Each of these decays to stable isotopes of lead (Pb) through a sequence of radionuclides of widely varying half-lives. Other naturally occurring radionuclides, which decay directly to a stable nuclide, are potassium-40 and rubidium-87. It should be noted that even though the isotopic abundance of potassium-40 is less than 0.012%, potassium is so widespread that potassium-40 contributes about one-third of the radiation dose received by man from natural background radiation. A major portion of the exposure (dose) of man from 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 cosmic 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

APPENDIX 7
(cont'd.)

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 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 provides 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 concept behind the unit "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 effect 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

APPENDIX 7
(cont'd.)

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

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

APPENDIX 7
(cont'd.)

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), about 125 mrem per year to the lung, about 25 mrem per year to the bone marrow, and about 117 mrem per year to the bone (osteocytes).

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

In addition to 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 an exposed individual's offspring.

APPENDIX 7
(cont'd.)

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.

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

Estimates of health effects from radiation doses are usually based on risk factors as provided in reports issued by the International Commission on Radiological Protection (ICRP), National Research Council Advisory Committee on the Biological Effects of Ionizing Radiation (BEIR), or United Nations Scientific Committee on the Effects of Atomic Radiation (UNSCEAR). 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

APPENDIX 7 (cont'd.)

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

IV. DOSE DETERMINATION CALCULATION

A. External Exposure

External penetrating radiation dose rates are measured on contact with an end-window beta-gamma Geiger-Mueller (GM) detector (7 mg/cm² window), and at 1 meter with an NaI crystal detector (1-in. diameter by 1-inch thick) manufactured by Eberline Corporation (PRM-7 μ R Meter). For the purpose of these calculations, the following conservative assumptions are made. First, it is assumed that the half-life of the contaminant is long and, therefore, the dose rate is constant with respect to time. Second, it is assumed that a person is stationary at the location of maximum dose for 40 hours per week for 50 weeks per year. For such a situation, the annual dose (A) for a 0.3 mR/h radiation field (about ten times normal background) would be:

$$A = 40 \text{ h/week} \times 50 \text{ weeks/yr} \times 0.3 \text{ mR/h} = 600 \text{ mR/yr}$$

For the purposes of this example, it is assumed that one milli-Roentgen of penetrating radiation is equivalent to one millirem of dose. Hence, the maximum dose for this case would be 600 mrem. This value is then compared with the allowable limit of 500 mrem per year for a person nonoccupationally exposed.⁽¹⁾

APPENDIX 7
(cont'd.)

B. Internal Exposure From Soil

The internal radiological hazard from inhalation/ingestion of contamination in soil is assessed by postulating hypothetical "worst case" scenarios. To this end two cases are considered. The first case is based on the situation whereby a child would eat 100 g per year of the contaminated soil. The second case assumes a home gardener would rototill the contaminated soil (dry) to a 1-ft depth for a working day (eight hours) once a year. For this latter case, a resuspension factor of 10^{-6} m^{-1} , a breathing rate of $9.6 \text{ m}^3/\text{working day}$ and a soil density of 1.5 g/cm^3 are used. This means 4.39 g ($1 \text{ ft} \times 0.305 \text{ m/ft} \times 1.5 \text{ g/cm}^3 \times 10^6 \text{ m}^{-1} \times 9.6 \text{ m}^3$) of soil are inhaled each year. In both cases, it is assumed that the average concentration of contaminants in the soil is equal to the maximum measured value (a conservative assumption). All calculations are based on methods outlined in ORNL/NUREG/TM-190, Vol. 3.⁽²⁾ These calculations approximate the ICRP-30 guidelines for hazard analysis.

The adult inhalation and ingestion dose commitment factors for the bone, lung and total body from ^{238}Pu , ^{235}U , ^{234}U and ^{232}Th (and all their significant daughters), as determined in Reference 2, are given in Table 1. For calculation purposes, normal uranium is assumed to be composed of 2.26% ^{235}U , and 97.74% ^{234}U and ^{238}U (in equilibrium) by activity.

An example calculation is given below that is based on the above scenarios assuming a soil contamination level of 5 pCi/g of radium-226 EPA limit. This gives the following dose levels (50-year dose commitment):

Ingestion (consumption of 100 g/yr of soil):

Bone: $6.5 \times 10^{-2} \text{ mrem/pCi} \times 5 \text{ pCi/g} \times 100 \text{ g} = 32.5 \text{ mrem}$
Total Body: $5.5 \times 10^{-3} \text{ mrem/pCi} \times 5 \text{ pCi/g} \times 100 \text{ g} = 2.75 \text{ mrem}.$

Inhalation (rototilling and breathing ensuing aerosol):

Lung: $1.1 \times 10^{-1} \text{ mrem/pCi} \times 5 \text{ pCi/g} \times 4.39 \text{ g} = 2.4 \text{ mrem}$
Bone: $9.2 \times 10^{-2} \text{ mrem/pCi} \times 5 \text{ pCi/g} \times 4.39 \text{ g} = 2.0 \text{ mrem}$
Total Body: $9.5 \times 10^{-3} \text{ mrem/pCi} \times 5 \text{ pCi/g} \times 4.39 \text{ g} = 0.2 \text{ mrem}.$

There is no regulation setting an allowable limit for radionuclides with both a long radiological half-life and a long biological half-life such as radium.

C. Internal Exposure from Building Materials

The internal radiological hazard from inhalation of contamination on a brick wall is assessed by postulating a hypothetical "worst case" scenario. To this end, a case is considered whereby a person is using a portable concrete saw in the dry mode of operation to cut a brick wall for

APPENDIX 7
(cont'd.)

an electrical outlet. A typical saw blade used in cutting masonry would have a 30.5-cm (12-in) diameter, a 0.32-cm (1/8-in) thickness, and a 11.1-cm (4 3/8-in) cutting depth. The wobble of the blade would probably increase the width of the cut to a kerf of 0.4 cm. If the cut were 10 cm by 10 cm (4 in by 4 in), the perimeter would then be 41 cm (16 in). The overlap of the cuts upon the brick wall would extend the total span of the cuts to 89 cm (35 in). The area of the brick wall that the blade would consume is then 36 cm². It is assumed that 50% of the brick becomes airborne and respirable. The room has a total volume of 60 m³, and the dust created becomes dispersed throughout the entire room. One person is involved and the job requires one hour. The person inhales 1.2 m³ of air per hour. This means 0.36 cm² (36 cm² x 0.5 x 1.2 m³/h x 1 h/60 m³) of the brick surface would be inhaled. This calculation is also based on methods outlined in ORNL/NUREG/TM190, Vol. 3,² which approximates the ICRP 30 guidelines for hazard analysis.

An example calculation is given below that is based on the above scenario assuming a surface contamination of 3.6x10⁵ dis/min-100 cm² normal uranium or 1.62x10³ pCi/cm². This gives the following dose levels (50-year dose commitment):

Inhalation (cutting brick):

Lung:	7.5x10 ⁻³ mrem/pCi x 1620 pCi/cm ² x 0.36 cm ²	= 4.4 mrem.
Bone:	1.5x10 ⁻² mrem/pCi x 1620 pCi/cm ² x 0.36 cm ²	= 8.7 mrem.
Total Body:	5.1x10 ⁻¹ mrem/pCi x 1620 pCi/cm ² x 0.36 cm ²	= 4.4 mrem.

D. Comparative Risks

An attempt has been made by Cohen and Lee (Health Physics 36, 707, 1979) to compare the risk associated with radiation with risks associated with common individual actions. The following table exemplifies this comparison.

Risk in Individual Actions

<u>Individual Action</u>	<u>Minutes Life Expectancy Lost</u>
smoking a cigarette	10
calorie-rich dessert	50
non-diet soft drink	15
diet soft drink	0.15
crossing a street	0.4
extra driving	0.4/mile
non-fastening seat belt	0.1/mile
1 mrem of radiation	1.5
coast-to-coast drive	1,000
coast-to-coast flight	100
skipping annual PAP test	6,000
moving to unfavorable state	800,000
buying a small car	7,000
choose Vietnam army duty	600,000

APPENDIX 7
(cont'd.)

As can be seen from this table, the highest risk identified above (600 mrem total body) would be equivalent to smoking 4½ packs of cigarettes per year.

TABLE 1

FIFTY-YEAR DOSE COMMITMENT FACTORS (inhalation/ingestion)^a
(mrem/pCi assimilated)

Nuclide ^b	Inhalation			Ingestion	
	Bone	Lung	Total Body	Bone	Total Body
²³⁸ U	7.1x10 ⁻³	4.8x10 ⁻¹	1.5x10 ⁻²	2.8x10 ⁻⁴	2.1x10 ⁻⁵
²³⁴ U	7.9x10 ⁻³	5.4x10 ⁻¹	1.6x10 ⁻²	3.1x10 ⁻⁴	2.4x10 ⁻⁵
²³⁰ Th	3.1x10 ⁻¹	5.3x10 ⁻¹	3.8x10 ⁻²	1.2x10 ⁻³	9.2x10 ⁻⁵
²²⁶ Ra	4.9x10 ⁻²	5.6x10 ⁻²	4.7x10 ⁻³	4.3x10 ⁻²	3.4x10 ⁻³
²¹⁰ Po	8.1x10 ⁻⁴	4.6x10 ⁻²	1.3x10 ⁻³	5.2x10 ⁻⁴	4.1x10 ⁻⁴
²¹⁰ Pb	4.2x10 ⁻²	6.2x10 ⁻³	3.5x10 ⁻³	2.1x10 ⁻²	1.7x10 ⁻³
Total Chain	4.2x10 ⁻¹	1.7	7.9x10 ⁻²	6.6x10 ⁻²	5.6x10 ⁻³
²²⁶ Ra Chain	9.2x10 ⁻²	1.1x10 ⁻¹	9.5x10 ⁻³	6.5x10 ⁻²	5.5x10 ⁻³
²³⁸ U+ ²³⁴ U	1.5x10 ⁻²	1.0	3.1x10 ⁻²	5.9x10 ⁻⁴	4.5x10 ⁻⁵
²³⁵ U	7.2x10 ⁻³	4.8x10 ⁻¹	1.5x10 ⁻²	2.8x10 ⁻⁴	2.2x10 ⁻⁵
²³¹ Pa	9.6x10 ⁻¹	5.9x10 ⁻¹	1.4x10 ⁻¹	1.8x10 ⁻²	2.1x10 ⁻³
²²⁷ Ac	5.4x10 ⁻¹	1.0	1.0x10 ⁻¹	1.2x10 ⁻²	1.3x10 ⁻³
²²³ Ra	9.6x10 ⁻⁴	4.6x10 ⁻²	8.6x10 ⁻⁴	1.2x10 ⁻³	2.3x10 ⁻³
²²⁷ Th	4.8x10 ⁻⁴	6.9x10 ⁻²	1.1x10 ⁻³	2.7x10 ⁻⁵	5.1x10 ⁻⁶
Total Chain	1.5	2.2	2.6x10 ⁻¹	3.2x10 ⁻²	3.7x10 ⁻³
²³² Th	3.3x10 ⁻¹	4.5x10 ⁻¹	3.8x10 ⁻²	1.3x10 ⁻³	9.6x10 ⁻⁵
²²⁸ Th	4.4x10 ⁻²	7.2x10 ⁻¹	1.9x10 ⁻²	4.5x10 ⁻⁴	3.8x10 ⁻⁵
²²⁸ Ra	2.9x10 ⁻²	4.8x10 ⁻³	2.5x10 ⁻³	2.1x10 ⁻²	1.7x10 ⁻³
²²⁴ Ra	3.0x10 ⁻⁴	8.8x10 ⁻³	1.8x10 ⁻⁴	4.0x10 ⁻⁴	7.5x10 ⁻⁵
²¹² Pb	2.6x10 ⁻⁵	1.8x10 ⁻³	2.9x10 ⁻⁵	1.8x10 ⁻⁵	2.6x10 ⁻⁶
Total Chain	4.0x10 ⁻¹	1.2	6.0x10 ⁻²	2.3x10 ⁻²	1.9x10 ⁻³

^aData taken from Reference 2.

^bNuclides in the chain that contribute negligibly (e.g., < 10⁶ mrem) have not been included.

APPENDIX 7
(cont'd.)REFERENCES

1. U.S. Department of Energy. 1981. Requirements for Radiation Protection. DOE 5480.1, Chapter XI.
2. D. E. Denning, Jr., et al. 1981. Estimates of Internal Dose Equivalent to 22 Target Organs for Radionuclides Occurring in Routine Releases from Nuclear Fuel-Cycle Facilities. Volume III. ORNL/NUREG/TM-190/V3. Oak Ridge National Laboratory for U.S. Nuclear Regulatory Commission.

APPENDIX 8

CALIBRATION AND ANALYSIS PROCEDURES FOR SOIL

Identification and quantification of radionuclides in soil, by gamma spectrum analysis, is generally a time consuming effort of soil preparation, and extended sample counting intervals. This method is not feasible or practical when involved with an ongoing decontamination effort. In situ detection with portable instrumentation, i.e. PRM-5-3 w/PG-2 detector, is sufficient and the primary step in determining areas or spots of contamination when the radiation levels encountered are high enough. Portable instrumentation, however, cannot be used to quantify microcurie level soil concentrations due to the geometric anomalies encountered in in situ detection. The following is a field expedient method used to determine ^{226}Ra in soil in the "Son of Lansdowne" Project.

Primary equipment included a 2K channel multi-channel analyzer coupled to a 17% eff. high purity germanium detector housed in a five-sided portable shield, a gram balance, and six 0.5 liter Marinelli beakers (see Figures 25-28).

Calibration

Initially, the analyzer was calibrated with NBS traceable ^{109}Cd (.088 MeV) and ^{60}Co (1.332 MeV) to 2 KeV per channel over one half the memory; that is to say 0-2 MeV over 1000 channels. A region of interest (ROI) about the ^{214}Bi peak of 0.609 MeV (Channel 305) that extended from 0.602 MeV (Channel 301) to 0.618 MeV (Channel 309) was set up. A ^{226}Ra standard was used to check the ROI locations. Bismuth-214 is a primary radionuclide in the Radium-226 chain and the gamma peak from this radionuclide (0.609) MeV is a predominant peak that is utilized in identification and quantification of Radium-226. This assumes secular equilibrium. With the particular analyzer utilized, in this instance, an ND-60, the region of interest counts are automatically integrated and the background counts integrated and subtracted. The result is displayed as the Region of Net Activity (RNA) in counts and the Region of Background Activity (RBA) in counts. The background in the region of interest is a composite of intrinsic counts in the individual channels as well as counts from the continuum. A two-point linear calculation is used to quantify the background over the nine channels utilized, which in turn is subtracted from the total integrated counts in the region of interest to form the RNA. The RNA results are used for all calibration and quantification of the gamma emitting radionuclides and in this instance for ^{226}Ra .

Several samples of soil were taken from Sayers Field, a park some six blocks southeast of the "Son of Lansdowne" site. The soil samples served two purposes; one to determine the ^{226}Ra background in soil in the Lansdowne Area and also as a calibration source for the ^{226}Ra component in soil. An aliquot of the Sayers Field soil was processed and submitted to the Analytical Chemistry Laboratory at Argonne National Laboratory for ^{226}Ra analysis and quantification. The sample submitted was not aged

APPENDIX 8 (cont'd.)

since the samples at the site would not and could not be aged. Gamma spectral analysis based on the 0.609 MeV peak indicated the soil from Sayers Field contained 1.3 pCi/gram of radium-226. A standard for Radium-226 in soil was developed by loading this soil, unprocessed, in a 0.5-liter Marinelli beaker. Prior to loading, the empty beaker was weighed and counted for background. This composite system and beaker background was taken after each beaker was cleaned and prior to loading another sample. A five-minute count was taken for backgrounds and for high-level concentrations, and a 50-minute count for low-level analysis and quantification. Calibrations, both channel location and the ^{226}Ra soil standard, were performed daily and whenever a "glitch" occurred, e.g. line voltage bump, power outage, etc.

Calibration for ^{226}Ra efficiency or yield of the system was accomplished by filling the 0.5-liter Marinelli beaker with "as sampled" soil from Sayers Field that had been well mixed in a 12-inch ziplock bag. The soil weight was then determined and the beaker placed over the HPGe detector housed in the portable shield assembly. The standard was counted for 50 minutes, and the yield for ^{226}Ra in soil was determined. Each day, the beaker containing the standard soil was opened and agitated in order to maintain an "as sampled" condition. The following is an example of a yield determination:

Weight of Beaker: 183.1 grams
 Weight of Beaker plus Soil: 706.4 grams
 Weight of Soil: $706.4 - 183.1 = 523.3$ grams
 RNA: 537 cts/50 min
 Background Count of Beaker and System: 3.8 cts/min

Calibration of Yield:

$$\frac{537 \text{ cts}}{50 \text{ min}} - 3.8 \text{ cts/min} = \frac{6.9 \text{ cts/min}}{1.51 \times 10^{-3} \text{ dpm}} = 4.60 \times 10^{-3} \text{ cpm/dpm}$$

$$523.3 \text{ grams} \times 1.3 \text{ pCi/gram} \times 2.22 \text{ dpm/pCi} = 1.51 \times 10^{-3} \text{ dpm}$$

The following is an example of ^{226}Ra concentration in soil:

Weight of Beaker: 183.1 grams
 Weight of Beaker plus Soil: 690 grams
 Weight of Soil: 506.9 grams
 Background Beaker & System: 3.4 cts/min
 RNA: 10610 cts/5 min.

²²⁶Ra Concentration in Soil:

$$\frac{2122 \text{ cts/min} - 3.4 \text{ cts/min}}{506.9 \text{ g} \times 4.6 \times 10^{-3} \text{ cpm/dpm} \times 2.22 \text{ dpm/pCi}} = \frac{2118.6 \text{ cts/min pCi/g}}{5.18 \text{ g/pCi}} = 409 \text{ pCi/g}$$

This example sample was from the west dump area, location 58. This particular method for the quantification of gamma emitting radionuclides in soil, has demonstrated an accuracy of from 10 to 15%. This is based primarily on the geometric uniformity and bulk density between the standard used and the "as sampled" samples.

The "Particle Problem" is the inability to generate reproducible results from separate aliquots of the same sample due to inhomogeneity. This was evident in several of the high-level samples encountered at the "Son of Lansdowne" site. The low-level samples were all within 10-15% of the ACL results for the several samples submitted for dual analysis. Total dissolution of the sample is the standard method of resolving the particle problem. It requires a radiochemical laboratory and is a very time consuming method, and therefore is not a feasible alternative in this case.

Distribution for ANL-SSD/HP-86-102Internal

H. Drucker	W. H. Smith (40)
J. D. DePue	J. Unik
K. F. Flynn	R. A. Wynveen
R. L. Herriford	SSD/HP Publications (15)
D. P. O'Neil	ANL Patent Dept.
E. G. Pewitt	ANL Contract File
M. J. Robinet	ANL Libraries (2)
C. M. Sholeen	TIS Files (5)

External

DOE-TIC, for distribution per UC-70A (100)
H. J. Rausch, Manager, Chicago Operations Office, DOE
J. E. Fletcher, Chicago Operations Office, DOE
R. A. Mayes, Chicago Operations Office, DOE
M. M. Samber, Chicago Operations Office, DOE
R. Selby, Chicago Operations Office, DOE (3)
J. O. Hunze, Chicago Operations Office, DOE
J. C. Haugen, Chicago Operations Office, DOE
S. Jarvela, Environmental Protection Agency, Region III (50)