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DOE/EV-0005/39 Suppl. 1

ANL-OHS/HP-84-103

FORMERLY UTILIZED MED/AEC SITES REMEDIAL ACTION PROGRAM

GEOHYDROLOGICAL AND RADIOLOGICAL SURVEY OF THE ALBANY RESEARCH CENTER UNITED STATES BUREAU OF MINES ALBANY, OREGON

July 1983

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

Operated by THE UNIVERSITY OF CHICAGO
for the U. S. DEPARTMENT OF ENERGY
under Contract W-31-109-Eng-38

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Printed in the United States of America
Available from
National Technical Information Service
U. S. Department of Commerce
5285 Port Royal Road
Springfield, VA 22161

NTIS price codes
Printed copy: A06
Microfiche copy: A01

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

DOE/EV-0005/39 (Supplement 1)
ANL-OHS/HP-84-103

ARGONNE NATIONAL LABORATORY
9700 South Cass Avenue
Argonne, Illinois 60439

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REMEDIAL ACTION PROGRAM

GEOHYDROLOGICAL AND RADIOLOGICAL SURVEY OF THE ALBANY RESEARCH CENTER UNITED STATES BUREAU OF MINES ALBANY, OREGON

July 1983

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June 1984

Work Performed under

Budget Activity DOE KN-03-60-40
and ANL 73706

PREFACE AND EXECUTIVE SUMMARY

This is one in a series of reports resulting from a program initiated in 1974 by the Atomic Energy Commission (AEC) for determination of the condition of sites formerly utilized by the Manhattan Engineer District (MED) and the AEC for work involving the handling of radioactive materials. Since the early 1940s, the control of over 100 sites that were no longer required for nuclear programs has been returned to private industry or the public for unrestricted use. A search of MED and AEC records indicated that for some of these sites, documentation was insufficient to determine whether the decontamination work done at the time nuclear activities ceased is adequate by current guidelines.

This report contains survey results describing the geohydrological conditions and supplemental radiological information describing the radiological conditions of two areas located at one such site--the United States Bureau of Mines' Albany Research Center in Albany, Oregon. These two areas are designated as the "BioMass Facility" and the "Back Forty." The BioMass Facility was most recently used as a pilot plant for the production of oil from wood waste; it consists of five structures on a two-acre site. At the time of the survey, the facilities were not being routinely used. The Back Forty is a vacant area of about 14 acres south of the BioMass Facility. Both areas were reportedly used in the past as dump sites for the Bureau of Mines operations and, therefore, are of some concern when related to previous operations.

During the periods 1954 to 1956 and 1960 to 1971, the Albany Research Center was engaged in metallurgical operations that included melting, machining, welding, and alloying of thorium. In addition, research on alloys of uranium and thorium started in 1955 and continued until suspended in 1978.

Records indicated that at the time the AEC contract was terminated, the buildings and surrounding areas were decontaminated to the general guidelines provided by the AEC. Those guidelines were not as specific as current guidelines, and details of the final decontamination were not documented at that time.

To determine if any radioactive contamination remained as a result of MED/AEC activities, a radiological assessment of the entire Albany Bureau of Mines site was initiated in June 1978. During September 1979, a survey was performed in the 14-acre field referred to as the "Back Forty." A preliminary survey of the BioMass Facility was undertaken at the same time. During September 1980, subsurface investigations of both the BioMass Facility and the Back Forty area were conducted. During September 1982, a detailed radiological survey of all structures, equipment, and material at the BioMass Facility was completed. The results of these surveys are presented elsewhere.[2]

During the subsurface investigations of the Back Forty area and around Buildings 3 and 31, water was encountered less than 3 m (10 ft) below the ground surface. After a short period of time, the water level would generally rise to 0.9 m (3 ft) and in one case, to the 0.3 m (1 ft) level. Radioactive contamination was encountered down to 2.7 m (9 ft) below the surface. Based on the survey results, the possibility of subsurface lateral migration of contaminants was recognized. Therefore, a geohydrological assessment was requested by the U.S. Department of Energy (DOE). The Argonne National Laboratory (ANL) Radiological Survey Group, along with a geohydrologist from the ANL Environmental Reserach (ER) Division conducted the survey in July 1983. The results are reported herein.

The survey included drilling bore holes to assess the hydraulic gradient, the groundwater flow direction, and the extent of subsurface migration of contaminants. All boreholes were sampled in continuous 0.3-m (1-ft) increments with a split-spoon sampler, and prior to backfilling, selected holes were logged with a 2-in. x 2-in. NaI(Tℓ) detector. All soil samples were analyzed for uranium by use of fluorometry, and for radium and thorium by use of high-resolution gamma spectrometric techniques. Radiochemical separation procedures and alpha spectroscopic techniques were used to further analyze some samples for plutonium. In addition, some samples with high uranium concentration and background radium concentrations were analyzed mass spectrometrically to determine the uranium isotopic ratios. Each soil sample was radiologically surveyed on the site with a gas-flow proportional detector for alpha and/or beta-gamma radiation and with a NaI crystal detector for x and gamma radiation.

During a search of various documents and literature prior to the survey, it was discovered that a network of drain tiles had been installed in the Back Forty area. The survey results indicated that groundwater in the area flows southwesterly from the contaminated area through the southern portion of the Back Forty area containing the drain tile field. The literature search had indicated that in general, groundwater in the region moves in a northwesterly direction. However, the near-surface flow in the Back Forty Area is controlled by the drain-tile field and is from south to north through the tiles.

Elevated radionuclide concentrations were found in some of the suspended solids and dissolved solids of the water removed from boreholes bordering the contaminated area and in a ditch south of that area. Elevated radionuclide concentrations were also measured in a few of the soil samples collected. These findings indicate that there appears to be lateral subsurface migration of radioactive materials. Elevated radionuclide concentrations also were detected off the site at the outfall of the drain tile field and at a leak in the main drain. Therefore, seemingly the contamination has migrated to the drain tile field. The radionuclides found at the leak in the main drain were ^{110m}Ag and ^{238}Pu. This evidence indicates that the Albany Research Center was engaged in operations with other radioactive materials than those previously specified above. These radionulides also appear to be migrating off of the site.

This survey was performed by the following Health Physics personnel of the Occupational Health and Safety Division, Argonne National Laboratory, Argonne, Illinois: R. A. Wynveen, W. H. Smith, C. M. Sholeen, K. F. Flynn, S. Y. Tsai and J. D. Thereon.

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GEOHYDROLOGICAL AND RADIOLOGICAL SURVEY
OF
THE ALBANY RESEARCH CENTER
UNITED STATES BUREAU OF MINES
ALBANY, OREGON

INTRODUCTION

During the Manhattan Engineer District/Atomic Energy Commission (MED/AEC) era, some work involving radioactive materials was performed at the Albany Research Center of the United States Bureau of Mines in Albany, Oregon (see Fig. 1). During the periods 1954 to 1956 and 1960 to 1971, metallurgical operations involving melting, machining, welding, and alloying thorium were conducted at the site. These operations also included research on alloys of both uranium and thorium that started in 1955, with some activities continuing until 1978 under Contract No. E(04-3)-906.

Records indicate that when the contract was suspended in 1978, structures of concern were decontaminated in accordance with general guidelines prescribed at the time. Those guidelines, however, were not as specific as current guidelines. Likewise, details of certain of the final decontamination activities were not documented to the extent necessary, particularly for the case of those activities that occurred in the 1950s. As a consequence, the U.S. Department of Energy (DOE) has undertaken a radiological characterization and assessment study to determine the radiological condition of this site. This study was initiated as part of a DOE program intended to ensure that residual radioactive material from past MED/AEC operations do not pose undue present or future radiological hazards. The entire Albany Research Center site has undergone a comprehensive radiological survey. Results of the initial survey activities for the BioMass Facility and the Back Forty portions of the site were presented in one report (ANL-OHS/HP-83-101, DOE/EV-0005/39); survey results for the remainder of the site were presented in a companion report (ANL-OHS/HP-83-102, DOE/EV-0005/40). The current report is a supplement to these previous two reports. The purpose of this report is to present details of follow-up investigations of certain conditions revealed by the results of the initial survey--specifically the potential for contamination of groundwater and for lateral subsurface migration of radioactive waste from contaminated areas on the Albany Research Center site.

As stated in the earlier reports, the comprehensive radiological survey of the Albany site indicated the presence of surface and subsurface contamination from thorium and uranium (see Fig. 2). The subsurface contamination around Buildings 3 and 31 occurred at depths between 0.3 and 1 m (1 and 3 ft)* below grade. Concentrations of contaminants ranged up to 416 pCi/g for thorium and 11.3 pCi/g for uranium in the first 0.3 m (1 ft) of soil. In the first 5 cm (2 in.) of soil the concentrations were as high as 637 pCi/g for thorium and 36.3 pCi/g for uranium.[1] During past operations, the BioMass and Back Forty areas were used as dump areas. The subsurface investigation of these areas revealed elevated concentrations of thorium (up to 57.7 pCi/g) between grade and 1.2 m (4 ft) below grade, radium (up to 33.2 pCi/g) between grade and 2.7 m (7 ft) below grade, and uranium (up to 340 pCi/g) between grade and 2.7 m (7 ft) below grade. In the first foot of soil, concentrations of up to 1850 pCi/g for thorium, 166 pCi/g for radium, and 196 pCi/g for uranium were detected.[2]

The septic tile field (see Fig. 2) was designed such that material dumped in a liquid waste disposal pit on the site would flow into a septic tank, then into the tile field. Liquid from the tile field flowed into the ground. During the September 1980 subsurface investigations of the septic tile field, the BioMass area, and the Back Forty area, investigators noticed that a hydrostatic head existed. Water that was encountered between 2.4 m (8 ft) and 2.7 m (9 ft) in boreholes drilled to 3.0 m (10 ft) would rise to 0.9 m (3 ft) after one or two hours (see Fig. 3). This hydrostatic head was also seen in July 1982 during subsurface investigations around Buildings 3 and 31. The source of this hydrostatic head was not identified either in 1980 or in 1982. Since the subsurface boring operations were performed in the dry season (July and September), the hydrostatic head and water table were low. In the wet months, the water table would be higher. Since contamination had been found in some areas to extend down to the 2.7-m (9-ft)

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*All measurements were originally taken using the English system. The Systems International (SI) units are to the nearest approximation.

level (below the water table during both the wet and dry parts of the year), the investigators concluded that it was possible that the contaminants were subject to subsurface lateral migration, thus raising the possibility that contamination could expand beyond that indicated by the surveys (see Fig. 2).

The Albany area has a temperate climate, characterized by wet winters and dry summers. Topography, nearness to the Pacific Ocean, and exposure to middle-latitude westerly winds are the principal climatic controls.

The average annual precipitation in the area is about 100 cm (39 in), occurring principally as rain. The wettest period of the year is November through January, when about 45% of the average annual precipitation occurs. In July and August, normal precipitation is less than 13 mm (0.5 in), and occasionally in midsummer no rain falls for periods of 30 to 60 days.[3]

In order to determine the hydraulic gradient and direction of groundwater flow for further defining the extent of the contaminated area and checking for possible subsurface lateral migration, DOE requested the Argonne National Laboratory (ANL) Radiological Survey Group (RSG) to conduct a geohydrological investigation of the site. The results and conclusions of that investigation are presented in this report.

SURVEY AND ANALYTICAL TECHNIQUES

General

The geohydrological investigation was started with a literature search to obtain any additional pertinent information. Five boreholes were drilled at the corners of the "Back Forty" area to measure the hydrostatic water levels (see Fig. 11). Soil samples were collected and radiological measurements were made of these samples during the drilling. Selected holes were logged to determine the radiological condition of the surrounding soil. The water level was measured with respect to existing grade at least two hours after the hole was drilled. The ground surface elevation was measured from a known bench mark. Additional boreholes were drilled, sampled, and logged to check the extent of contamination and to sample for the presence of lateral migration (see Fig. 12).

Literature Search

The literature search consisted of a trip to Oregon by a member of the ANL/RSG and a geohydrologist from the Environmental Research Division of ANL. The literature search included collection of information pertinent to the geohydrological condition of the site from the United States Geological Survey in Portland, Oregon, the United States Department of Agriculture in Tangent, the Oregon Water Resource Department in Salem, the City Hall in Albany, the Linn County Building in Albany, and the U.S. Bureau of Mines in Albany. During this trip, the team members made an inspection of the Back Forty area.

Instrumentation

Two types of portable survey instruments were used in the field to conduct the direct radiological surveys of soil samples. A gas-flow proportional detector with a window area of 51 cm^2 (using Eberline PAC-4G-3 electronics) was used to monitor for alpha and/or beta-gamma radiation. A NaI(Tℓ) crystal detector, 5 cm (2 in.) diameter by 2 mm thick (Eberline PG-2 with Eberline PRM-5-3 electronics), was used to monitor for low energy x and gamma radiation. Instrumentation and associated calibration procedures are detailed in Appendices 1 and 2. The appendices include generic information on instruments and procedures that were required for this particular survey and for other radiological surveys, including the original surveys of this site.

A 5-cm (2-in) diameter by 5-cm (2-in) thick sodium-iodide [NaI(Tℓ)] detector, coupled to a ND-100 multichannel analyzer, a teletype printer for hard copy read out, and punched tape for data storage were used to log the boreholes. A 300-second spectrum was collected at grade level and at 0.6-m (2-ft) increments thereafter.

Geohydrological Investigation

To evaluate groundwater flow characteristics in the Back Forty area, boreholes were drilled at each corner of the property (see Fig. 11). The depth of the holes ranged from 3 m (10 ft) to 7.6 m (25 ft). Water was allowed to rise in these holes, and the level of the water below grade was measured over a period of time until the static level was reached. The elevation at grade level was measured with a surveyor's transit with respect to a bench mark.

During the borehole drilling, soil samples were collected, surveyed with the portable instruments, bagged, and labeled for processing and laboratory analysis at ANL. The sample collection and analyses procedures are described in general below and in more detail in Appendix 4.

Miscellaneous Samples

Soil samples were collected at selected locations from holes dug by hand and from ditches. Soil samples were collected with hand trowels and hand augers. In two places, soil samples were removed at different depths. In both cases, the soil closest to grade level was labeled A and succeeding samples were labeled B and C, where C is the sample taken at the greatest depth. Water samples were collected from the boreholes, holes dug by hand, the tile field outfall, and standing water near the tile field outfall. Water samples were collected in 1-ℓ bottles.

A zucchini plant was found growing in a leaf pile on the south side of the dump. From previous investigations, it was known that radioactive materials (thorium, radium, uranium, etc.) had been dumped beneath the pile. The zucchini vegetable was cut and bagged as one sample. Leaves and stems were cut and bagged as a second sample.

Soil Borings

Boreholes were drilled to further define the extent of the dump area in the Back Forty and BioMass areas, and for purposes of the geohydrological investigation (see Fig. 12). Soil samples were taken in sequential 0.3-m (1-ft) sections from the holes by means of a hollow-stem, 9.2-cm (3-5/8 in) auger with a pilot bit and a split-spoon sampler (1½-in. inside diameter). After each sample was removed, the pilot bit was inserted in the stem and a 15-cm (6-in) diameter hole was drilled to the depth of the sequential section. The samples were surveyed with the portable instruments for alpha, beta and gamma radiation. The boreholes drilled for radiological purposes were all 3 m (10 ft) deep. All boreholes were identified by a number (e.g. 7-S158), and each sample was identified according to depth in feet (e.g. 7-S158-2 equates to bore hole 7-S158 sample from 1.0 ft to 2.0 ft below the surface).

Sample Preparation and Analyses

The soil samples were prepared for analyses by weighing each sample in its "as collected" state, drying it for approximately 48 hours at 80°C and then reweighing the sample to determine dry weight. Each sample was then put into a mill jar (8.7 ℓ) 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 concentration of deposited radioactive material. After sufficient milling, the sample material was sieved. Each fraction (rocks and dross vs. fines) was bagged and weighed separately (see Fig. 4). The weight of the samples are given in Table 1.

The soil samples were sent to the ANL Anlaytical Chemistry Laboratory for analysis. 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 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 considered to contain background levels. All processing equipment was scrubbed and air dried before introduction of the next sample.

After the gamma-spectral and uranium-fluorometric analyses were reviewed, six soil samples were sent for radiochemical separation of Pu followed by alpha spectrometric analysis for ^{239}Pu and ^{238}Pu. Fifteen samples were subjected to radiochemical separation of the uranium followed by mass-spectrometric analysis to determine the relative atomic abundances of uranium isotopes.

The water samples were sent in their "as collected" state to the ANL Analytical Chemistry Section of the Chemical Engineering Division. The suspended solids were filtered and the filtrate was evaporated to ascertain the dissolved solids. The volume and weight of each sample are listed in Table 2. The zucchini samples were processed in a blender followed by drying at 110°C. The weight of the vegetation samples before and after processing are listed in Table 1. The water and vegetation samples were analyzed by gamma spectrometry then dissolved and radiochemically analyzed (fluorometric) for uranium.

ANALYSIS OF SURVEY RESULTS

General

In the following section, the results of the various phases of the geohydrological and radiological survey are presented generally in the order that they were determined. Thus, the results of the literature search are presented first, followed by the results of the geohydrological investigation. Since the results of the standard analyses, gamma spectral and uranium-fluorometric, indicated the need for more information, those results are presented next. Then, additional information received from the Bureau of Mines in response to questions by the survey team, revealed the need for other special analyses. The results of those special analyses are presented last.

Literature Search and Onsite Investigation

The literature search indicated that the U.S. Bureau of Mines' Albany Research Center site is drained primarily by the Willamette and Calapooia Rivers (see Fig. 1). The Willamette River, which is the master stream, is west of the area and flows generally northward. The Calapooia River provides much of the local drainage for the Back Forty area and flows into the Willamette River north of the site. The Albany-Santiam Canal is about 1 km (0.6 mi) east of the Back Forty area. The water surface elevation in the canal is about 70 m (230 ft) mean sea level (MSL). The land surface elevations at the Bureau of Mines site range from 69 m (225 ft) MSL in the north to 66 m (215 ft) MSL in the south.

Soils contiguous to and on the Back Forty site consist of various types of silt loam. Distribution of the soil types on the site is shown in Figure 5. The depth of the soils varies from 0.3 to 1.5 m (1 to 5 ft). Also, soils in the area generally have high moisture content and are slightly acidic. Because of the nearly level terrain and the low permeability of the soil below the surface, subsurface drainage appears to be a problem associated with these types of soil. In addition, erosion due to surface runoff can also be a problem.[3] The subsurface drainage is actually a problem at this site. The extensive ground cover minimizes the erosion problem.

A geologic section crossing the Back Forty area is indicated in Figure 6. Based on data from drillers' logs of water wells, the distribution and thickness of various geologic units along this section are shown in Figure 7.[4,5] Evaluation of the well-log data shows that the Back Forty area is underlain by sand and gravel deposits interspersed with a mixture of sand, silt, and clay. In well 12ccd, which is about 300 m (1000 ft) from the site, the sand and gravel strata lie between a clay layer and shale of the Spencer Formation. Groundwater contained in these strata may be under confining pressure.[6]

The principal source of groundwater recharge in the area is infiltration of precipitation. Most of the precipitation evaporates, some is transpired to the atmosphere by vegetation, some runs off, and the rest infiltrates into the ground. Part of the water that infiltrates is retained as soil moisture; the remainder percolates downward to the zone of saturation.

Groundwater in the area occurs under perched, confined, and unconfined conditions.[6,7] Most of the groundwater in the unconsolidated deposits of the older and younger alluvia that underlie the valley plain is unconfined. However, at a few places, groundwater in these deposits is confined seasonally. Many of the fine-sand strata lie between clay and silt layers in the alluvium and contain water under a small confining pressure as seen during the borehole drilling operations in 1980, 1982, and 1983. In late winter and early spring, pressure builds to a point where water rises above land surface in some wells. However, during much of the year, water levels in the wells are typical of a water-table system.

A contour map showing the shape and slope of the groundwater table is presented in Figure 8. Those water-level contours were drawn based on available well-log data and by connecting points on the water table that have the same elevations. It should be noted that groundwater levels in the unconsolidated alluvial deposits can generally fluctuate about 3 to 4 m (10 to 12 ft) during the year.[6]

Examination of the contour map from Reference 6 (see Fig. 8) indicates that in the Albany area, groundwater generally moves from the edges of the valley plain toward the Willamette River and in a downstream direction. In the Back Forty area, groundwater appears to be moving in a northwesterly direction. The widely spaced contours in the Albany area also indicate that the slope of the water-table surface is gentle. This is probably due to a greater transmissivity of the materials through which the water is moving.

In the Back Forty area, a network of approximately 3350 m (11,000 ft) of drain tiles was installed in 1967 by the U.S. Soil Conservation Service for an Albany High School project (Fig. 9) to reduce the soil moisture content and to alleviate the subsurface drainage problem. However, this network of drain tiles increases the flow of water and might create the potential for contamination migration. The average depth of the tiles is about 1.2 m (4 ft) below the ground surface. The tiles were arranged such that part of the percolating water is drained from south to north and is intercepted by a collecting drain tile that appears to be within 15 to 30 m (50 to 100 ft) of the radioactive dump area. The collecting drain tile extends from east to west. Initially, it appeared that the collecting drain discharged into the sewer system along Broadway Street; however, during the survey team's search for the outfall, it was learned that the discharge point is actually offsite into a ditch on Queen Avenue (Fig. 10). Near-surface flow in the Back Forty area is controlled by the drain tiles and water in the tiles flows south to north. Water that is not intercepted by the drain tiles percolates downward to the groundwater system. The existence of this tile field was revealed for the first time during the literature search. Prior to installation of the drain tiles, the Back Forty area flooded in the wet season.

Onsite investigation also revealed that there are two high-voltage transmission lines traversing the Back Forty (see Fig. 10). Only one line was indicated on maps of the area. One line, belonging to the Bonneville Power Administration (BPA) runs from the southern boundary of the property in a northwestern direction and exits at Broadway at the northwestern edge of the Back Forty area. This line is a single-circuit, 115 kV, transmission line. The second line, not evident on city or county maps or in their records, runs from east to west along the northern section of the Back Forty property. This line, owned by the Pacific Power and Light (PPL) is a single-circuit, 115 kV, transmission line with a local power line approximately halfway down the poles. The complication brought about by the high-voltage transmission lines might somewhat limit the potential future use of this property which, as we understand, is to be surplused if permitted by the radiological conditions of the site.

Geohydrological Investigation

Boreholes were drilled at each corner of the Back Forty area (Fig. 11). During the drilling, groundwater was encountered between 4.0 and 4.3 m (13 and 14 ft) in the two boreholes (7-S151 and 7-S153) drilled to 4.6 m (15 ft) and between 2.4 and 2.7 m (8 and 9 ft) in the borehole (7-S154) drilled to 3.0 m (10 ft). Because of the confining pressure, the water level in the three holes rose gradually and in about one day reached a static level from 0.9 to 2.0 m (3 to 6.5 ft) below grade level. Borehole 7-S152, in the southwest quadrant, was drilled to a depth of 7.6 m (25 ft) without encountering subsurface water. A small amount of water was observed in the hole the day after drilling. However, this water was believed to be caused by either the surface runoff as rainfall or the subsurface seepage of infiltrating water, rather than the local groundwater flow. A similar situation was observed in an adjacent hole (7-S166) about 14 m (45 ft) east of borehole 7-S152. In the first three holes, water was encountered after the drill had broken through the layer of clay and gravel that confines the aquifer. In the last two holes, those in the southwest quadrant, the confining clay and gravel layer is greater than 7.6 m (25 ft) in depth.

After the boreholes were drilled, ground surface and equilibrium water levels were determined by transit using the reference elevation of 68.68 m (225.34 ft) MSL at a bench mark located at the northwest corner of the Bureau of Mines property (Fig. 10). The survey results at boreholes 7-S151, 7-S153, and 7-S154 are shown in Table 3. Using the static water levels in three boreholes, the groundwater contours and flow direction were delineated as shown in Figure 11. The results indicate that groundwater in the Back Forty area flows southwesterly from the contaminated area (dump site) through the southern portion of the Back Forty which contains the drain tile field with a hydraulic gradient of approximately 0.8% (9.5 inches per hundred feet). Since the grade level of the dump site is elevated with respect to the southern part of the Back Forty, surface water flows from the dump site, south to a ditch that extends in a westerly direction, and then discharges into the ditch paralleling Broadway Street (Fig. 9). This local groundwater flow direction is different than the regional flow direction, which is to the northwest, as shown in Figure 8 for the Albany area. This type of deviation is not unexpected because a nearby water body, such as the Calapooia River, can significantly influence the direction of local groundwater flow.

Standard Sample Analyses

The instrument survey revealed contamination in the soil in only one sample, 7-S154-2. Low-energy x and gamma radiation of 1000 cts/min was detected, including the background of 500 cts/min. As seen in Figure 11, this borehole, drilled for the geohydrological survey, was at the edge of the area known to be contaminated. Gamma spectrometric and uranium-fluorometric analyses of the sample also revealed concentrations of 11 pCi/g for thorium and 53 pCi/g for uranium (see Table 4). Only at the two-foot level in this hole did the borehole logging reveal an anomaly. Radiation from the thorium decay chain was detected by the NaI(Tℓ) crystal. The soil samples from the other holes revealed no radionuclide concentrations above background levels on the portable survey instruments.

- Outfall - Six samples were collected off the site from the area around the tile field outfall on the south side of Queen Avenue (see Fig. 10). The three samples (7-SS141, 7-SS143, and 7-SS144), taken from the ditch parallel to Queen Avenue revealed no contamination. However, 7-W142, water that flowed out of the main drain tile into the ditch, contained small but measurable concentrations of uranium (0.28 pCi/ℓ), thorium (9.4 pCi/ℓ), and cesium-137 (4.6 pCi/ℓ) in the dissolved solids. The source of these radionuclides is believed to be the Albany Site. The uranium and thorium is believed to be from the material dumped on the site. However, the origin of the cesium is unknown. As seen in Table 5, the limit of detection was 0.1 pCi/ℓ of uranium. The last two samples (7-W145 and 7-SS146), were taken from standing water in a ditch on the north side of Queen Avenue. The source of this standing water was both discharge from the Back Forty drain field and local surface runoff. Gamma-spectral analysis indicated a concentration of 11 pCi/g for ^{226}Ra plus daughters from the suspended solids. Uranium fluorometric analysis of this sample showed a uranium concentration of 2.7 pCi/g in the suspended solids. Therefore, the amount of ^{226}Ra plus daughters in excess of the amount in equilibrium with natural uranium equates to approximately 10 pCi ^{226}Ra/gram of suspended solids. There was also an elevated concentration of ^{226}Ra (3.4 pCi/ℓ) in the dissolved solids from this sample. The uranium in the dissolved solids was below detectable limits. The source-term of this excess ^{226}Ra is unknown, but it is presumed to be from the Bureau of Mines site.

Drain Tile Field - Several attempts were made to locate drain tiles in the Back Forty Area. From the declivities in the land in the Back Forty area and the pattern of tall grass, the subsurface tile field was approximated. A hole at 7-S147 (Fig. 12) was dug at what appeared to be the second lateral row of tiles west of Liberty Street. No tiles were found but a sample was removed for analysis. Another hole was dug at 7-S150. A lateral, apparently the sixth lateral west of Liberty Street, was found 1.3 m (4.2 ft) below the surface. Three samples were taken from the east side of the lateral with a 10-cm (4-in) hand auger. The samples were taken in successive 15-cm (6-in) depths from 1.1 m (3.5 ft) to 1.5 m (5 ft) and labeled A, B, and C. During the drilling of 7-S151, clay tile was found in the sample from the 0.3 m (1 ft) to the 0.6 m (2 ft) depth. The broken edge of a lateral tile could also be seen in the hole.

A sink hole was located in a ditch paralleling Broadway Street. The hole was dug deeper and the 30-cm (12-in) inside diameter concrete main was located approximately 1.5 m (5 ft) below the road level. Samples (7-S148-A and -B) at two successive depths were taken from the south side of the main with a hand auger. Water, apparently from the main tile, quickly rose to a height of 1.6 m (5.2 ft) below the road level. A sample of the water was removed and labeled as 7-W149. The noteworthy radionuclide concentrations found in the samples taken during the efforts to locate the tile field were the 2.1 pCi Ag-110m/g of suspended solids in 7-W149 (see note c of Table 5) and 10 fCi ^{238}Pu/g of soil in sample 7-S148 (see Table 6). The 13 fCi ^{239}Pu/g of soil is not an unusually high concentration from fallout.[9]

- Surface and Subsurface Migration - Three boreholes (7-S155 through 7-S157) were dug south of the ditch that crosses the northern section of the Back Forty area (Fig. 9) to determine whether subsurface lateral water migration had extended the contaminated area beyond the ditch. No radionuclide concentrations above background levels were detected in any of the soil samples (see Table 4). However, the concentration of cesium-137 in the dissolved solids of the water sample (7-W184) taken from hole 7-S156 was high (5 pCi/ℓ), as seen in Table 5.

  Three boreholes (7-S163 through 7-S165) were drilled in the ditch just south of the contaminated area (Fig. 12) to check for both subsurface lateral migration and penetration from the surface water flowing from the dump pile into the ditch. No radionuclide concentration above background levels were measured in any of the soil samples (see Table 4). However, all three water samples had elevated concentrations of thorium, radium, and/or uranium in either the dissolved solids or the suspended solids (see Table 5).

- Extent of the Contaminated Area - Eleven boreholes (7-S158 through 7-S162 and 7-S167 through 7-S172) were drilled around the perimeter of the previous dump area to more accurately locate the boundaries of the area of contamination. In three holes uranium concentrations up to 12 pCi/g and/or thorium concentrations up to 4 pCi/g were detected (see Table 4). The contaminated area in Figure 12 is drawn to indicate the results of the analyses. Water samples were taken from four of the holes. All four water samples contained elevated levels of radium-226 in the suspended solids (up to 22 pCi/g) and/or the dissolved solids (up to 11 pCi/ℓ). Although these levels are not high, they do indicate that there is subsurface lateral migration of contaminants. One sample (7-W180) also had elevated levels of thorium in both the dissolved and suspended solids. In another sample (7-W174), an elevated uranium concentration was detected in the dissolved solids (see Table 5).

A final hole, 7-S173 (Fig. 13) was drilled northwest of the BioMass area to delineate the extent of contamination in that area. Although the soil concentrations were at background levels, the concentration of thorium was 22 pCi/g in the suspended solids from the water sample (7-W178).

- Geohydrological Boreholes - Five boreholes (7-S151 through 7-S154 and 7-S166) were drilled for geohydrological purposes as discussed above. They were also analyzed for radionuclide concentrations. Only borehole 7-S154 had elevated concentrations of uranium (up to 53 pCi/g) and thorium (up to 11 pCi/g) in the soil of the samples from 1 foot to 3 feet below grade level. This sample was taken from the area known to be contaminated (see Fig. 11) from the previous surveys.[2] The water sample removed from this hole, 7-W175, had an elevated concentration of radium-226 (22 pCi/g) in the suspended solids.

- Miscellaneous Results - As seen in Table 5, no radionuclide concentrations above background levels were detected in the fruit (7-V182) and leaves and stems (7-V183) from the zucchini plant found growing in a leaf pile in the center of the contaminated area (Fig. 12). However, it is not known whether the roots of the plant penetrated below the leaves into the contaminated soil.

Additionally, the concentrations of radium-226 decay chain were reported erroneously in a previous report[2] for two samples. The correct values are listed in Table 4 and their locations are shown in Figure 13. In sample 7-S62-1, there was an excess of radium-226 for the amount of uranium. In the other, 7-S63-1, the concentration indicates natural uranium contamination.

Investigation of Ag-110m Anomalies

As seen in footnote c of Table 5, 2.1 pCi/g of the silver isotope Ag-110m was detected in the suspended solids of the water sample 7-W149 (see Fig. 13). This water sample was collected from the effluent of the main tile drain at Broadway. The same radionuclide also was detected in the suspended solids of the water sample 7-W132, which was collected from the API oil separator located in the BioMass Facility.[2] Since this radionuclide, which has a 250-day half-life, was detected in two separate samples, it was deemed important to try to identify its source. It should be noted that the Ag-110m is migrating since it was found in the water leaking from the main tile field drain as the effluent flows off the Back Forty site.

In response to an inquiry by the ANL survey team, personnel at the Albany Research Center forwarded information concerning a few separate projects at the Center that were either known to or could have involved Ag-110m. The most likely source-term was a project housed in Building 17. The project involved the development of a process for recovering tin from a 70% tin-25% copper alloy. The work was performed during the early 1950s. Since both copper and tin are known to contain silver impurities in their natural state, it is possible that the alloy also contained silver impurities. This alloy was processed for Hanford Operations at Richland, Washington. It was also known to contain 0.5% uranium and 1% aluminum.[8] The alloy may have been used as cladding for reactor fuel. In such a case, Ag-109 would have absorbed neutrons while the reactor was in a critical configuration. Silver-110m is produced when a neutron is absorbed by Ag-109 and a gamma-ray is emitted.

If material that was involved in the Hanford operations, was buried at the Albany site, then transuranic material could possibly be present. Also because of this potential, the uranium contamination at the Albany site could no longer be confidently assumed to be normal (uranium with isotopic ratios as found in nature but separated from its long-lived daughter products). Therefore, plutonium alpha spectrometric and uranium mass spectrometric analyses were performed on selected samples.

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Special Sample Analyses

Six samples from five locations in the BioMass and Back Forty areas were submitted for radiochemical separation of plutonium followed by alpha spectrometric analyses (see Appendix 4 for details). Four of the samples were chosen from those reported previously[2] that had a high concentration of uranium but background concentrations of radium-226. This indicates that the uranium was not natural; therefore, the uranium contamination could have been the result of dumping of waste from the tin separation. If the uranium was from a reactor, then there could also be plutonium contamination. As seen in Table 6, the plutonium concentrations are low for the first four samples (sample locations are shown in Fig. 13). However, the concentration of plutonium-238 in sample 7-S148-B is higher than normal. The concentration of ^{239}Pu could be from fallout.[9] Since this is from the sample collected beside the main tile drain at Broadway (see Fig. 12), it indicates migration of plutonium contamination off the site.

Fifteen soil samples were selected from 14 locations for mass spectrometric analyses of the uranium isotopes (see Table 7). Two samples (7-S22A and 7-S23A) indicated depleted uranium. As seen in Figure 13, these samples were collected near Building 31, where thorium had been processed. These samples also contained high concentrations of the thorium-232 decay chain.[1] Four other samples (7-S56-3, 7-S66-1, 7-S154-2 and 7-S158-1) from the contaminated area contained concentrations of uranium-236 above background levels. Although the concentrations in themselves cannot be considered significant, they are an indication that uranium other than normal uranium was dumped in the BioMass and Back Forty areas. One sample, 7-S158-1, also has a small but measurable concentration of uranium-233, a further indication that the uranium is other than normal uranium.

ESTIMATED EXTENT OF CONTAMINATION

Although the supplemental analyses indicated that lateral migration of contaminants is occurring off the site, there is insufficient information to clearly establish the extent of such migration. Therefore, for the purposes of estimating the extent of contamination, the boundaries set in Reference 2 have been used here.

It is estimated that between 9.9×10^3 and 14.8×10^3 m^3 (3.5×10^5 and 5.2×10^5 ft^3) of soil are contaminated in the BioMass Facility. The maximum estimated activity of this soil is 0.4 Ci radium-226, 41 Ci natural thorium, 2.2 Ci natural uranium and 2.1 Ci normal uranium. In the Back Forty area, between 3.6×10^3 and 8.9×10^3 m^3 (1.3×10^5 and 3.1×10^5 ft^3) of soil is contaminated. The maximum estimated activity of this soil is 0.01 Ci radium-226, 1.6 Ci natural thorium, 0.7 Ci natural uranium, and 0.2 Ci normal uranium. Details of the calculations are given in Appendix 7. The assumptions and approximations used are given in Reference 2.

DOSE AND POTENTIAL HAZARD EVALUATION

The estimated dose, based on survey results, has not increased from the previous report.[2] The maximum radiation dose from external exposures is 0.19 rem/year in the Back Forty area and 0.09 rem/year in the BioMass Facility.

The 50-year dose commitments for one year of intake are given below for the Back Forty area for soil concentrations of 87 pCi/g of natural uranium, 47 pCi/g of radium, and 200 pCi/g of thorium:

Child ingestion:	Natural uranium to the bone	287 mrem
	Natural uranium to the whole body	26 mrem
	Radium (^{226}Ra) to the bone	275 mrem
	Radium (^{226}Ra) to the whole body	25 mrem
	Natural thorium to the bone	240 mrem
	Natural thorium to the whole body	20 mrem
Adult Inhalation:	Natural uranium to the bone	89 mrem
	Natural uranium to the whole body	17 mrem
	Natural uranium to the lung	328 mrem
	Radium (^{226}Ra) to the bone	17 mrem
	Radium (^{226}Ra) to the whole body	2 mrem
	Radium (^{226}Ra to the lung	20 mrem
	Natural thorium to the whole body	26 mrem
	Natural thorium to the bone	175 mrem
	Natural thorium to the lung	518 mrem.

The 50-year dose commitment for one year of intake for radionuclide concentrations of 196 pCi/g natural uranium, 166 pCi/g radium, and 3700 pCi/g natural thorium as found in the BioMass Facility are:

Child ingestion:	Natural uranium to the whole body	59 mrem
	Natural uranium to the bone	647 mrem
	Radium (^{226}Ra) to the bone	1.08 Rem
	Radium (^{226}Ra) to the whole body	100 mrem
	Natural thorium to the bone	4.44 Rem
	Natural thorium to the whole body	370 mrem
Adult inhalation:	Natural uranium to the whole body	38 mrem
	Natural uranium to the bone	200 mrem
	Natural uranium to the lung	737 mrem
	Radium (^{226}Ra) to the whole body	7 mrem
	Radium (^{226}Ra) to the bone	67 mrem
	Radium (^{226}Ra) to the lung	78 mrem
	Natural thorium to the bone	3.25 Rem
	Natural thorium to the whole body	487 mrem
	Natural thorium to the lung	9.63 Rem.

Details of these calculations are given in Appendix 8 and Reference 2. There are no regulations that set an allowable limit for radionuclides with both long radiological half-lives and long biological half-lives such as the uranium, radium, and thorium that were found on this site. DOE Order 5480.1 Chg. 6, Chapter XI, defines dose commitment as "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." It also sets the radiation protection standard for external and internal exposure of individuals and populations groups in uncontrolled areas at 0.17 rem to the whole body, gonads or bone marrow and 0.5 rem to other organs. If the external, ingestion and inhalation doses were to continue at the levels stated above for 50 years, the dose commitments for a single year would be exceeded before the 50th year.

CONCLUSIONS

In light of the results of the geohydrological study and the radiological analyses, the following conclusions can be made:

- Geohydrological Conclusions

1. Surface Drainage - Surface drainage from the dump site is in a southerly direction at least to the ditch that parallels the dump site, which in turn drains in a westerly direction (see Fig. 12).

2. Near-Surface Drainage - The near-surface flow at the Back Forty site is through the drain-tile system beneath the site. For most of the area, water flows through this system in the direction south to north.

3. Subsurface Drainage - The direction of subsurface water flow is from the radioactive dump site to the southern part of the Back Forty and through the drain tile field.

- Radiological Conclusions

1. Extent of Contamination - Three soil samples at the edges of the contaminated area, in addition to one inside the contaminated area (see Fig. 12), showed elevated concentrations of uranium and/or thorium. Also, one of these samples had small but measurable abundances of U-233 and U-236. Three other samples from the dump area also had small but measurable abundances of U-236. Two of these samples had been collected prior to 1983. Therefore, the contaminated area is extended and there is an indication that material other than normal uranium and processed thorium have been dumped on this site.

2. Subsurface Migration - Four water samples were taken from the edge of the contaminated area; three from the ditch, and one north of the BioMass area. All had elevated levels of one or more radionuclides (up to 11 pCi/ℓ for ^{226}Ra, 4.7 pCi/ℓ for normal uranium, 9 pCi/ℓ for ^{232}Th, or 3 pCi/ℓ ^{137}Cs in the dissolved solids and up to 22 pCi/g for ^{226}Ra, 22 pCi/g for ^{232}Th or 2.3 pCi/g for ^{137}Cs in the suspended solids). Also,

a ^{137}Cs concentration of 5 pCi/ℓ was measured in the dissolved solids of the water sample collected south of the ditch. Therefore, the radionuclides are migrating through the soil.

3. Drain-Tile System - Concentrations of radionuclides unexpected for work involving only uranium and thorium were detected in the water and soil collected at the drain tile field as it exits the Bureau of Mines site.

   The presence of ^{110m}Ag in the suspended solids of the water taken both from the tile field and the API oil separator in the BioMass Facility indicates migration of this radionuclide.

   The concentration of ^{238}Pu, approximately five times the background level at the point of the tile field exit from the Back Forty, also indicates migration.

   The actual concentrations that were measured are not considered hazardous; however, they are indicators that the contamination is from many different sources and that it is migrating from the soil into the drain-tile system and subsequently off the site. This should be no surprise since the septic tile field by Buildings 17 and 34 was designed to dump the waste into the subsurface soil.

4. Outfall - Radionuclide concentrations in excess of background levels were measured in the water flowing out of the drain-tile at the outfall (9.4 pCi/ℓ for ^{232}Th decay chain and 0.3 pCi/ℓ for uranium in the dissolved solids). Standing water also contained elevated concentrations of ^{226}Ra in the suspended solids (11 pCi/g) and in the dissolved solids (3.4 pCi/ℓ). Therefore, the contaminated material from the dump area is migrating through the drain-tile system off the site into the ditch on Queen Avenue.

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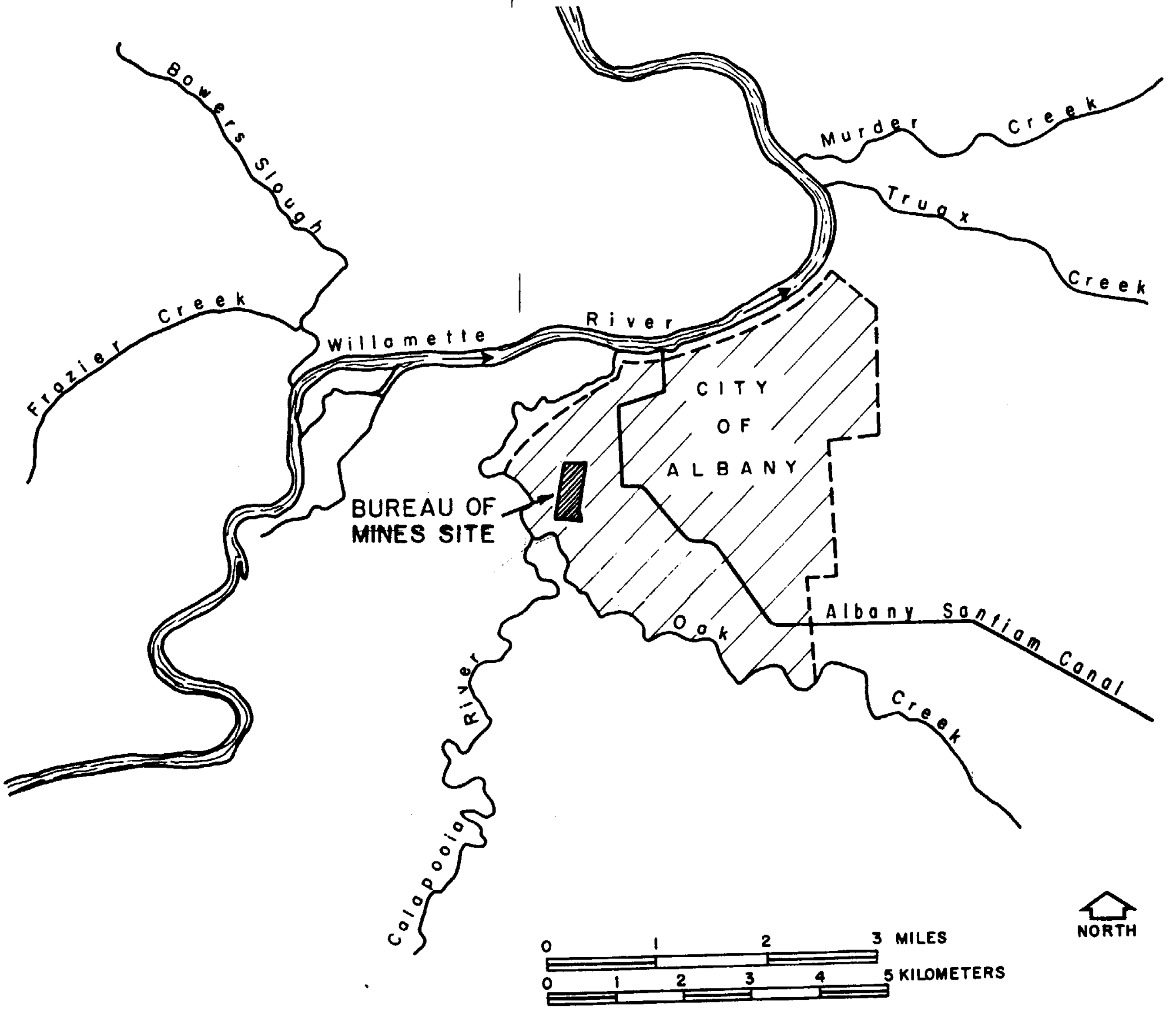

Figure 1. Location of Bureau of Mines Site.

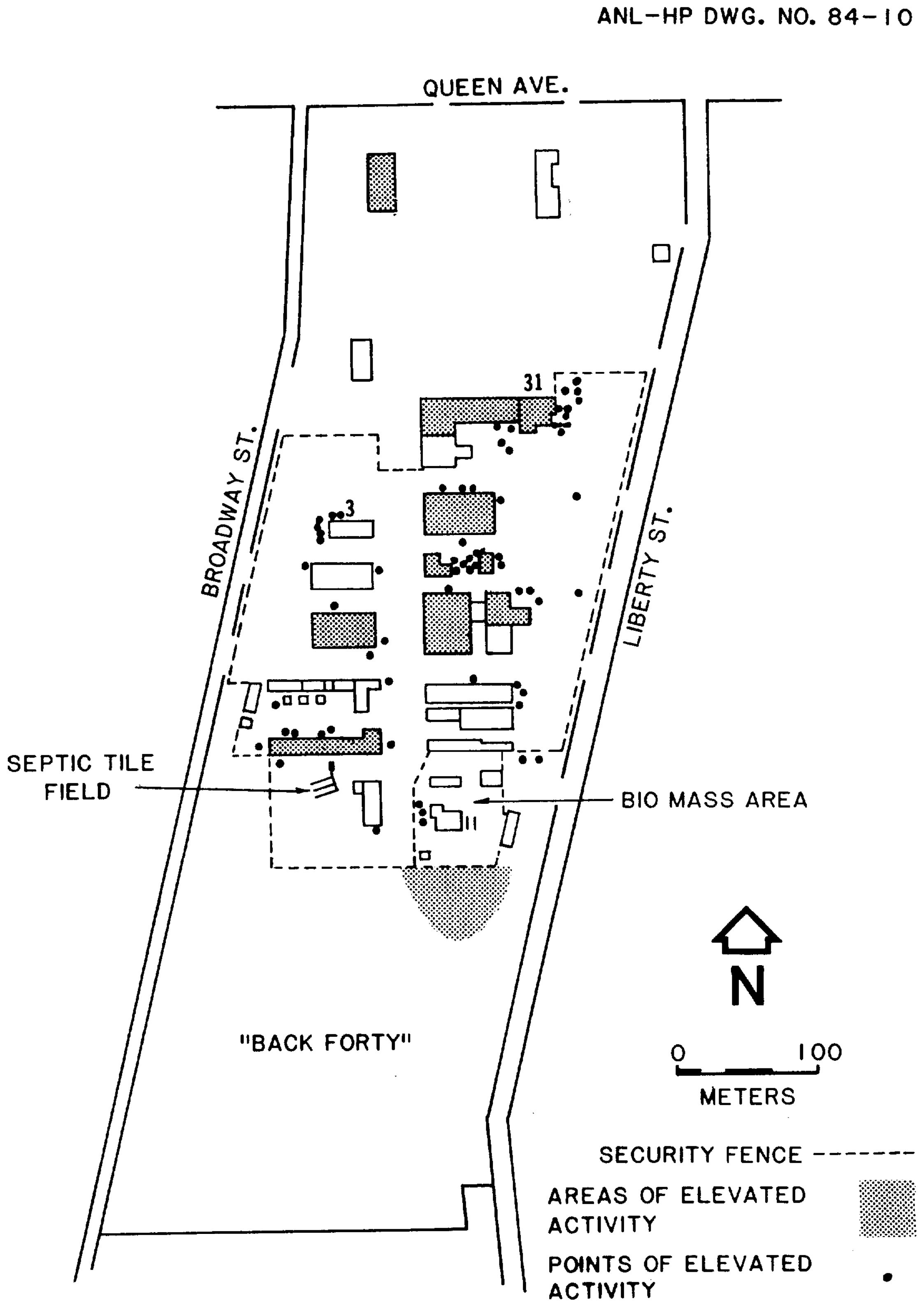

Figure 2. Surface Contamination at the U.S. Bureau of Mines.

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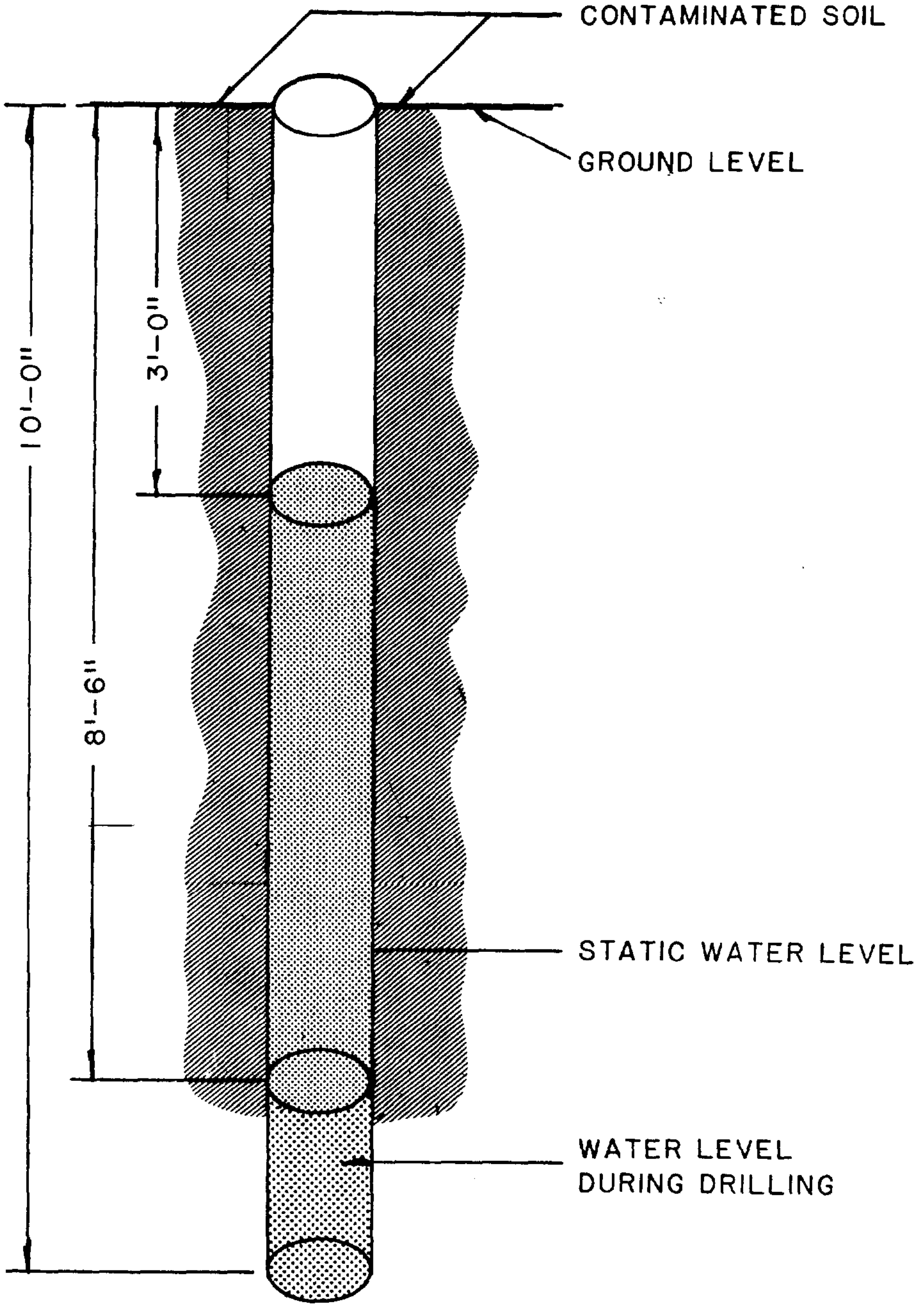

Figure 3. Typical Hydrostatic Head.

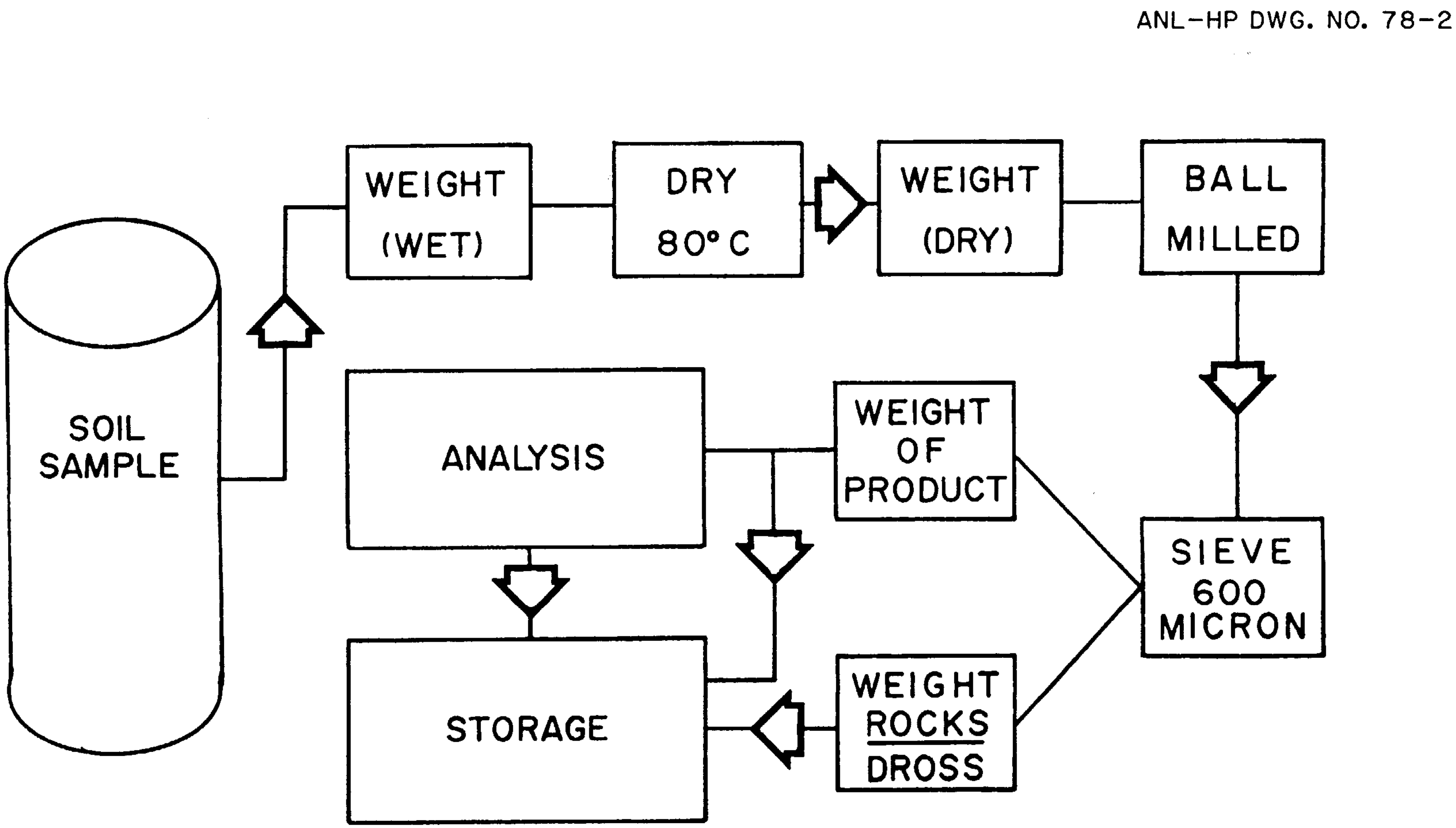

Figure 4. Soil Sample Processing.

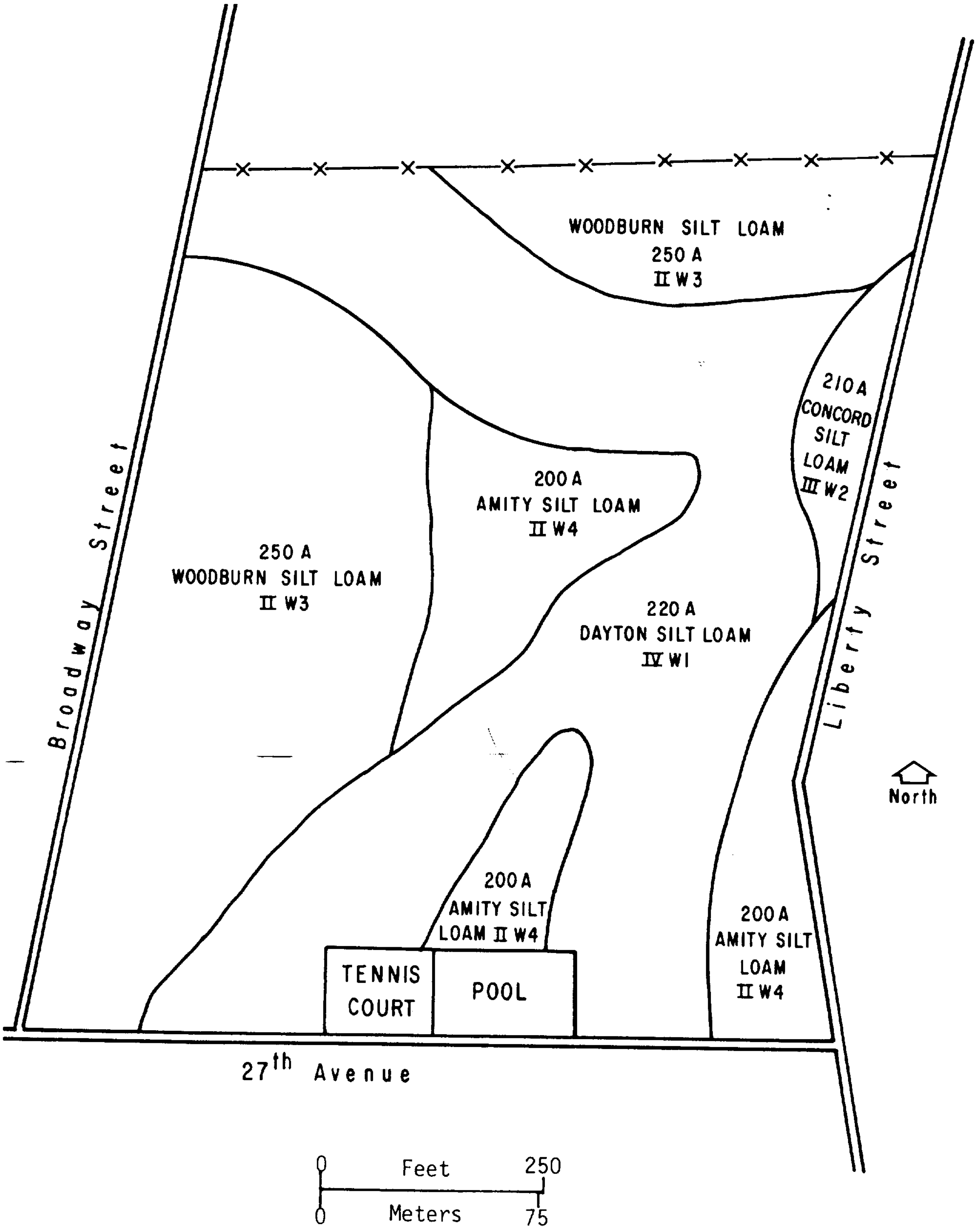

Figure 5. Soil Distribution in the Back Forty Area.

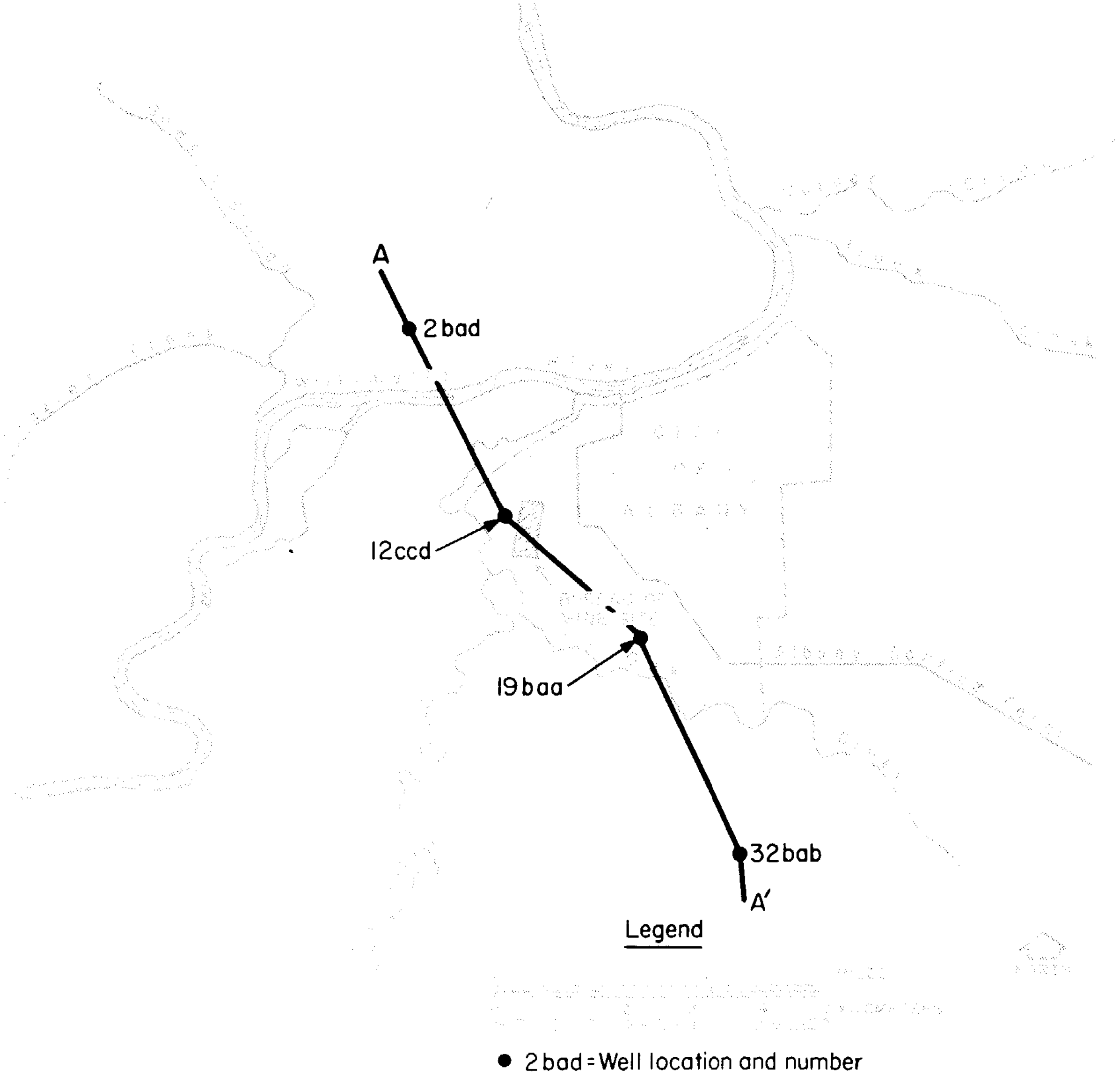

Figure 6. Selected Geologic Section Crossing the Back Forty Area.

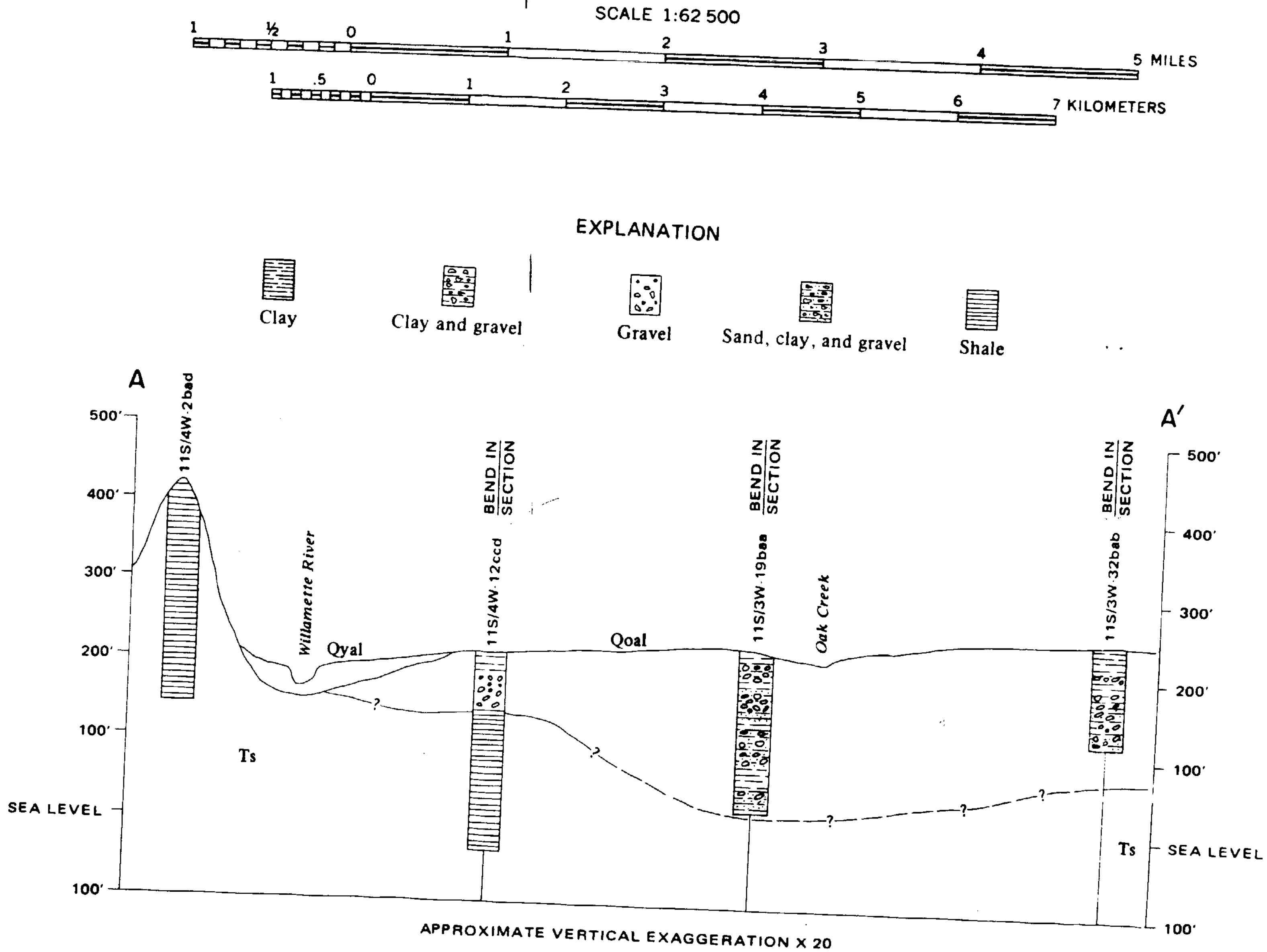

Figure 7. Geologic Cross Section of the Back Forty Area.

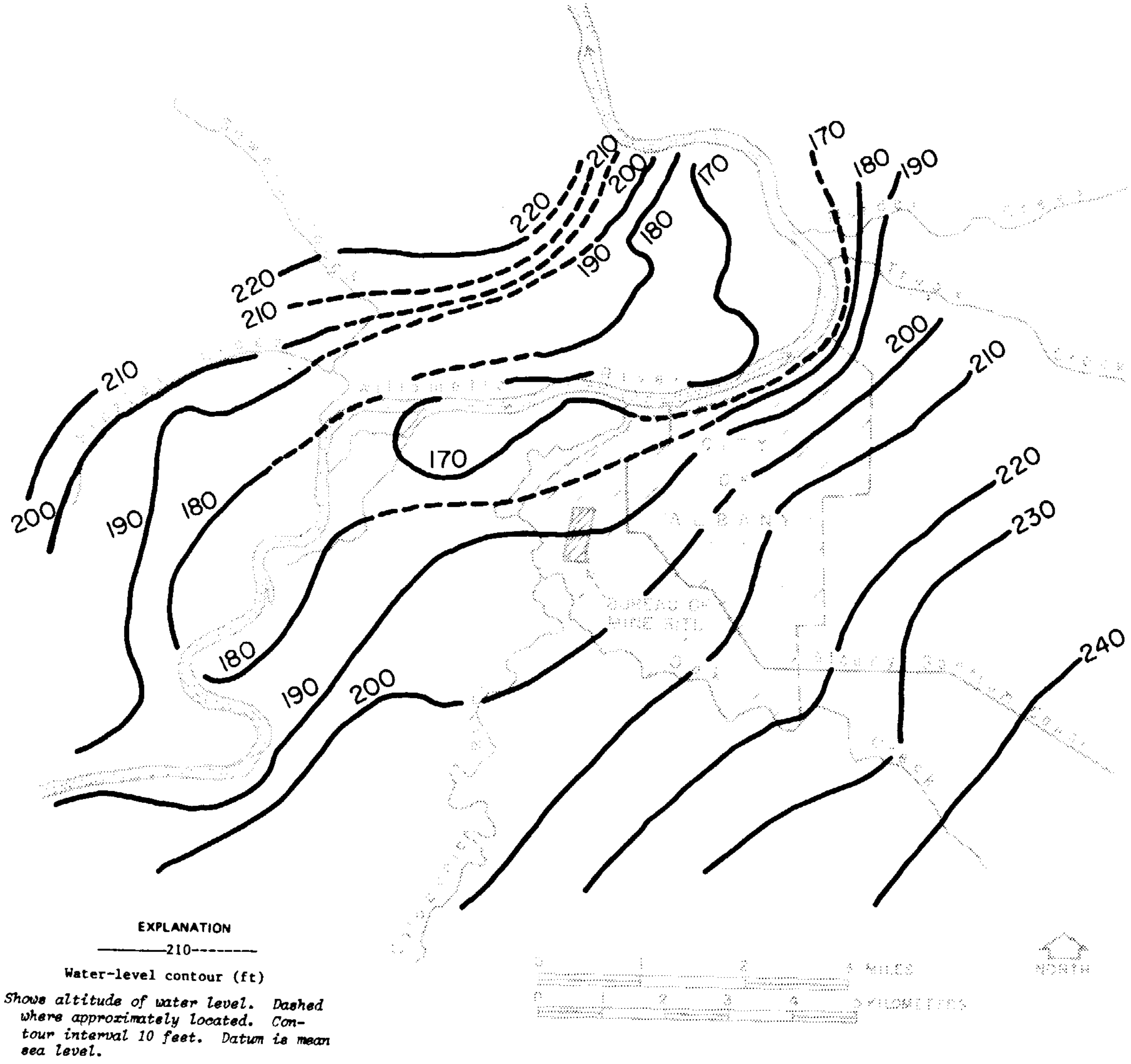

Figure 8. Water-Level Contours in the Albany Area.

ANL-HP DWG. NO. 83-62

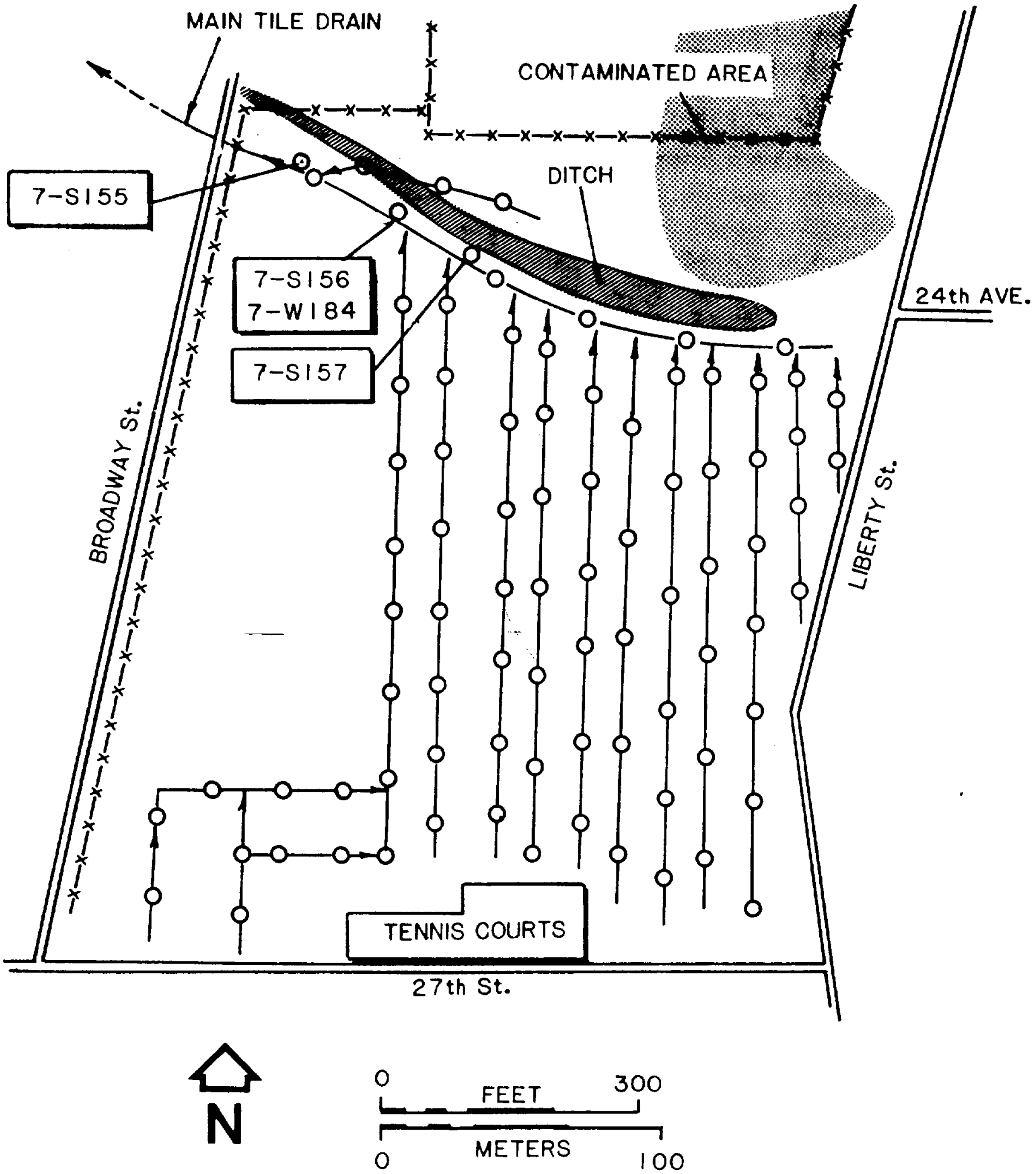

Figure 9. Drain Tile Field.

ANL-HP DWG. NO. 83-62

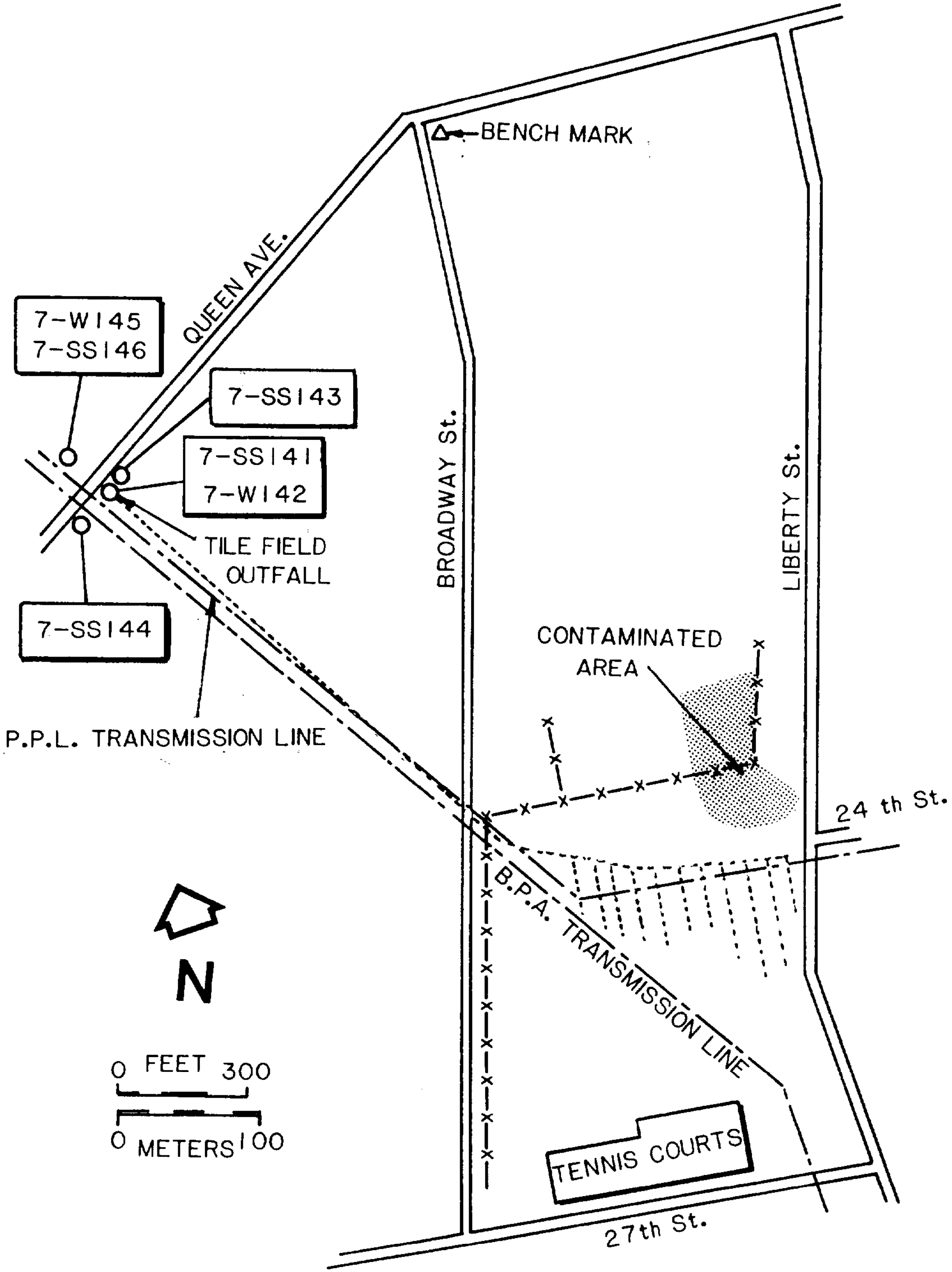

Figure 10. Transmission Lines and Tile-Field Outfall.

ANL-HP DWG. NO. 83-63

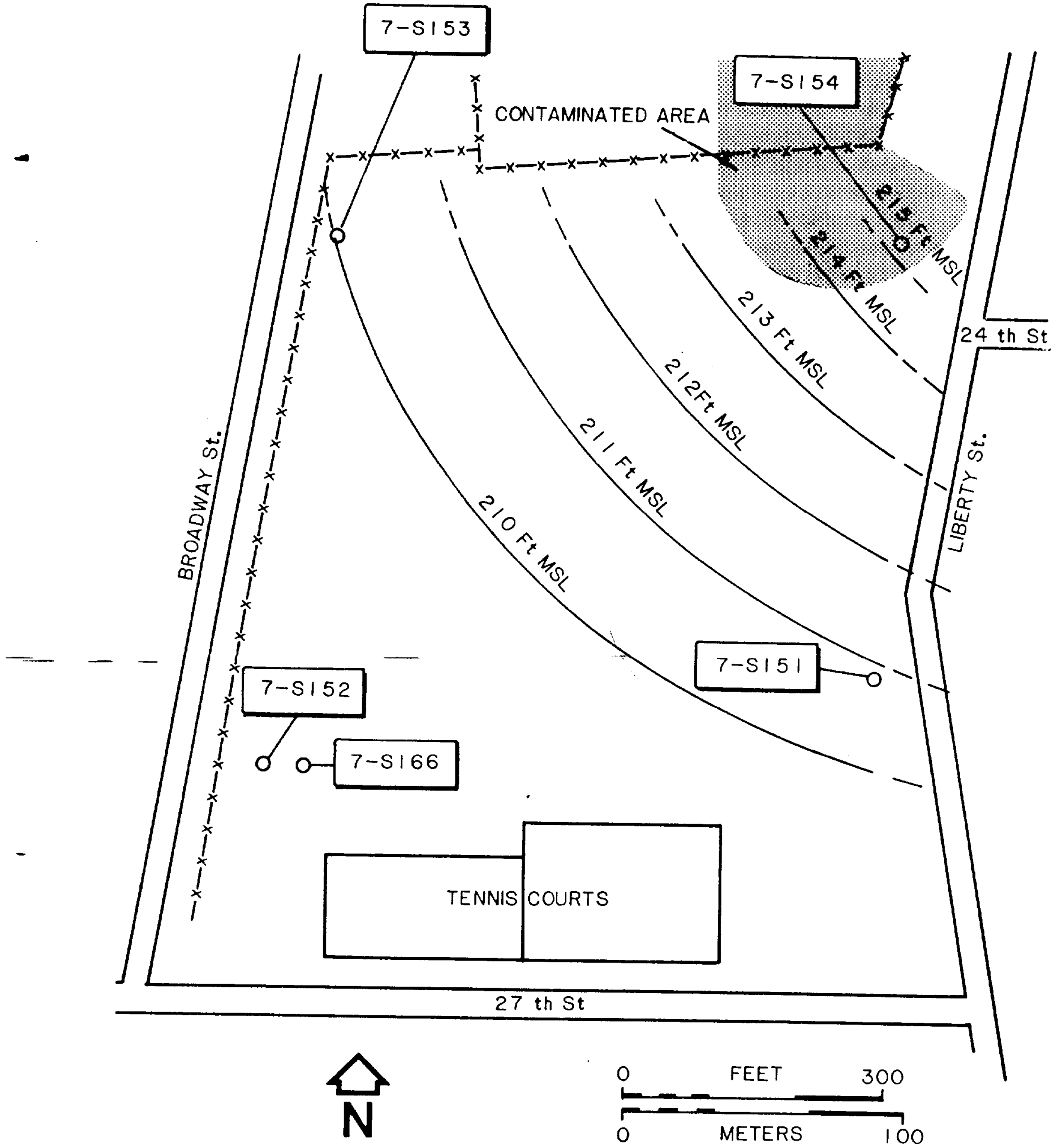

Figure 11. Hydraulic Gradient.

ANL-HP DWG. NO. 83-65

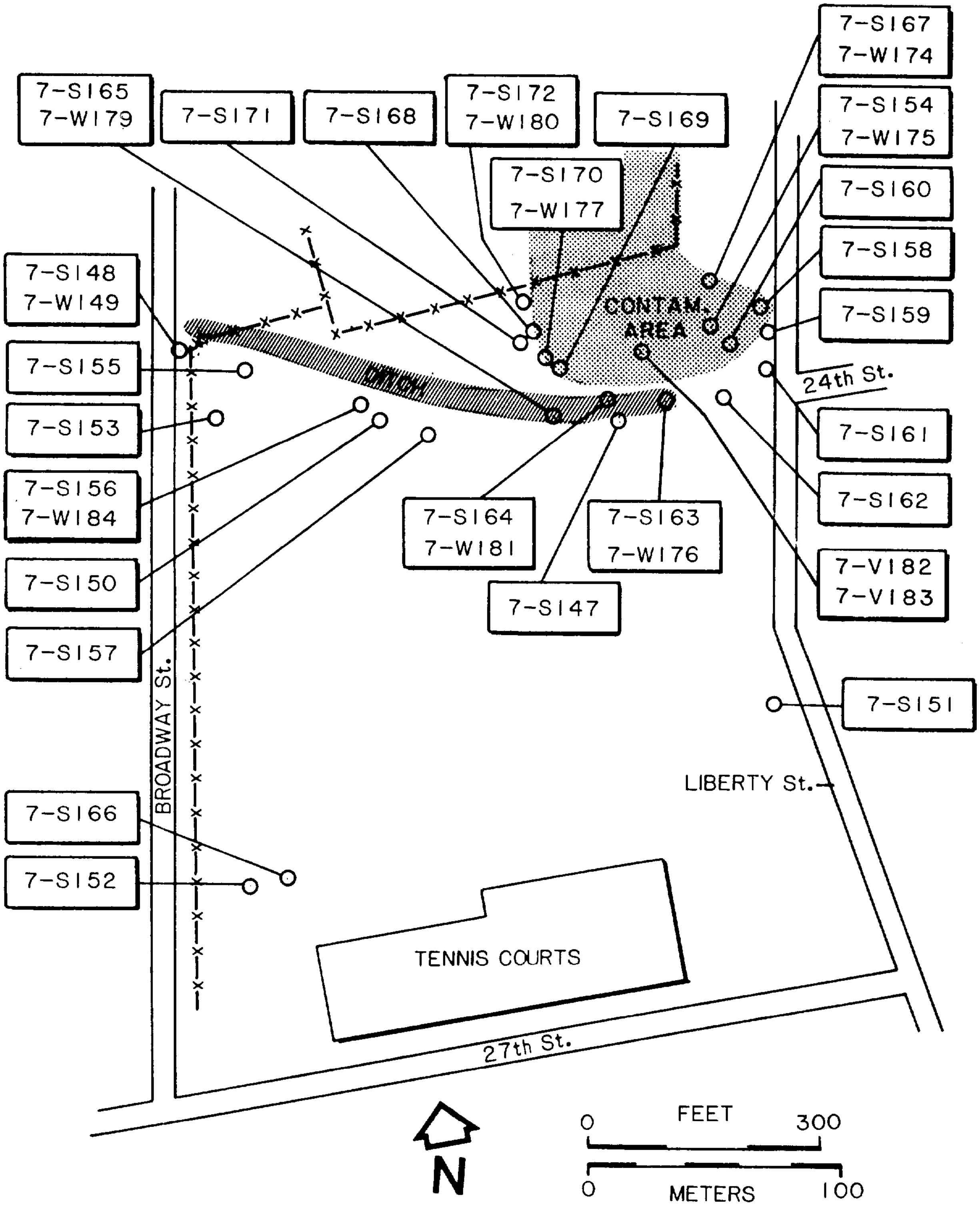

Figure 12. Sample Locations in the Back Forty Area.

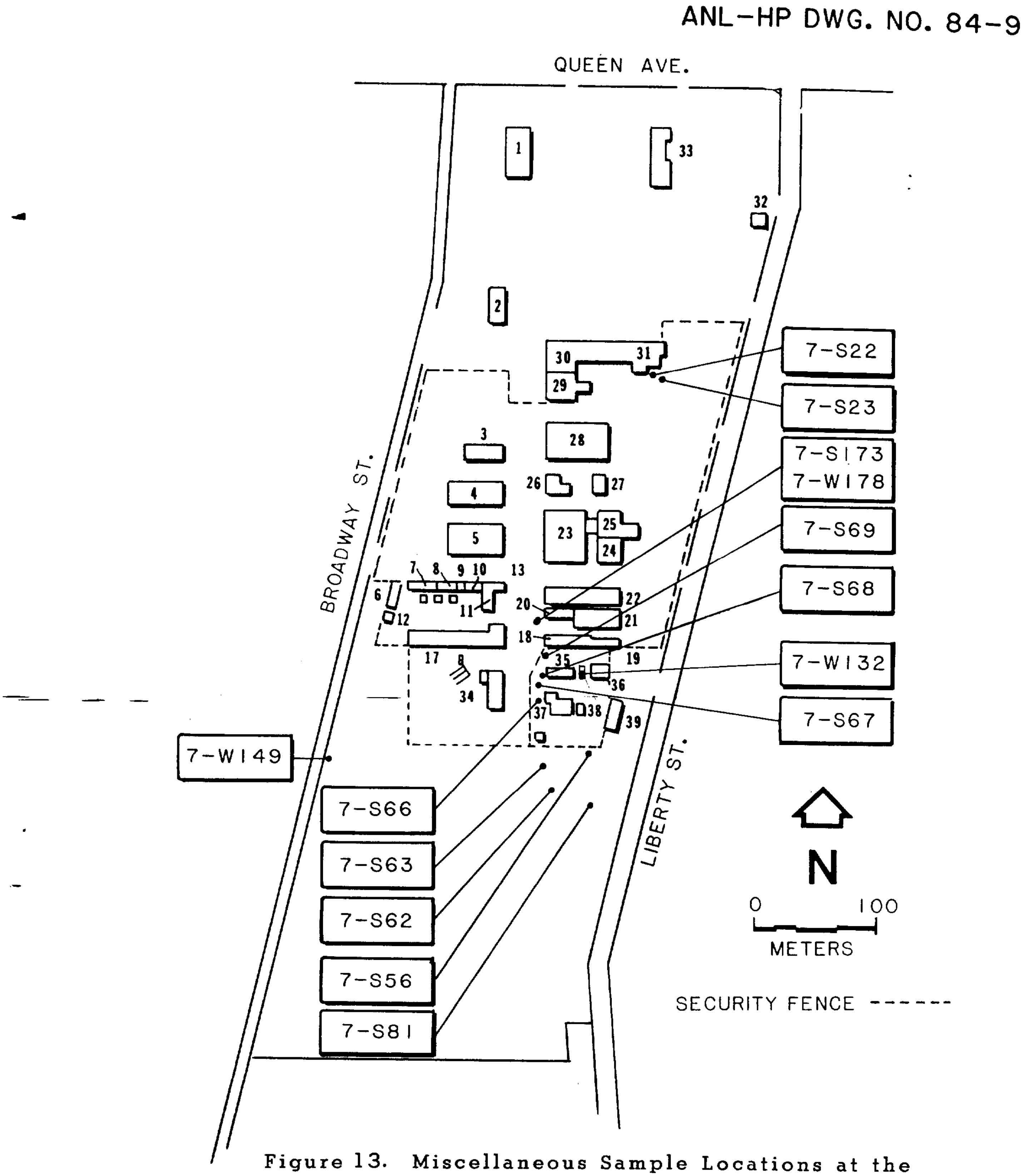

Figure 13. Miscellaneous Sample Locations at the Albany Research Center.

TABLE 1

SOIL-SAMPLE WEIGHTS
(grams)

Sample Number	Wet Weight	Dry Weight	Sieved Weight	Rocks and Dross
		SOIL		
7-SS141	3237	2425	1030	1373
7-SS143	1852	1081	532	542
7-SS144	1336	1021	732	284
7-SS146	2360	1565	710	846
7-SS147	1646	1349	561	774
7-SS148-A	2251	1997	485	1504
7-SS148-B	1962	1775	403	1364
7-S150-A	1440	1077	808	260
7-S150-B	1287	1008	774	229
7-S150-C	1389	1060	777	274
7-S151-1	443	356	337	10
7-S151-2	277	225	182	15
7-S151-3	552	421	360	53
7-S151-4	649	493	446	40
7-S151-5	662	488	455	22
7-S151-6	607	495	360	129
7-S151-7	550	415	389	4
7-S151-8	439	339	310	6
7-S151-9	834	652	636	10
7-S151-10	863	669	596	66
7-S151-11	647	496	423	65
7-S151-12	822	630	554	66
7-S151-13	762	593	519	68
7-S151-14	694	552	479	69
7-S151-15	710	588	439	147
7-S152-1	424	341	329	10
7-S152-2	600	479	437	35
7-S152-3	371	281	257	3
7-S152-4	593	446	430	11
7-S152-5	694	527	513	11
7-S152-6	690	560	546	11
7-S152-7	780	608	591	14
7-S152-8	569	435	409	19
7-S152-9	706	536	478	46
7-S152-10	677	517	428	82
7-S152-11	834	634	475	150
7-S152-12	715	547	392	142

TABLE 1
(cont'd.)

Sample Number	Wet Weight	Dry Weight	Sieved Weight	Rocks and Dross
		SOIL (cont'd.)		
7-S152-13	575	446	375	65
7-S152-14	278	224	142	28
7-S152-15	569	480	318	158
7-S152-16	481	427	242	183
7-S152-17	462	386	177	199
7-S152-18	205	177	99	68
7-S152-20	385	329	172	154
7-S152-21	627	528	230	293
7-S152-22	448	404	176	226
7-S152-23	481	414	127	276
7-S152-24	281	238	25	162
7-S152-25	497	416	142	263
7-S153-1	369	311	306	4
7-S153-2	498	406	390	13
7-S153-3	567	434	380	54
7-S153-4	625	477	418	55
7-S153-5	533	418	343	72
7-S153-6	715	568	474	90
7-S153-7	747	596	543	53
7-S153-8	584	482	388	93
7-S153-9	662	515	412	103
7-S153-10	877	678	568	110
7-S153-11	790	622	490	131
7-S153-12	378	291	249	40
7-S153-13	805	591	410	180
7-S153-14	678	494	375	118
7-S153-15	782	598	409	185
7-S154-1	332	285	199	74
7-S154-2	488	358	204	154
7-S154-3	447	341	109	228
7-S154-4	432	327	83	232
7-S154-5	539	440	226	204
7-S154-6	600	507	325	175
7-S154-7	520	460	243	206
7-S154-8	506	442	297	134
7-S154-9	557	475	264	203
7-S154-10	400	319	280	29
7-S155-1	501	401	347	43
7-S155-2	406	345	317	19
7-S155-3	491	385	184	192

TABLE 1
(cont'd.)

Sample Number	Wet Weight	Dry Weight	Sieved Weight	Rocks and Dross
SOIL (cont'd.)				
7-S155-4	427	331	227	95
7-S155-5	459	402	174	219
7-S155-6	438	360	160	191
7-S155-7	335	236	120	108
7-S155-8	1210	686	549	130
7-S155-9	763	582	476	104
7-S155-10	737	566	487	78
7-S156-1	432	348	329	9
7-S156-2	486	394	307	78
7-S156-3	405	313	209	79
7-S156-4	608	467	372	87
7-S156-5	675	517	432	79
7-S156-6	675	506	427	71
7-S156-7	556	418	371	38
7-S156-8	336	253	236	10
7-S156-9	700	540	305	228
7-S156-10	603	462	154	299
7-S157-1	393	318	274	39
7-S157-2	422	349	242	100
7-S157-3	524	426	169	248
7-S157-4	571	430	265	160
7-S157-5	622	482	451	29
7-S157-6	714	540	417	123
7-S157-7	724	535	469	65
7-S157-8	664	520	455	61
7-S157-9	700	574	460	113
7-S157-10	789	648	532	113
7-S158-1	335	250	215	29
7-S158-2	375	296	248	37
7-S158-3	472	359	81	255
7-S158-4	593	485	302	79
7-S158-5	577	431	421	4
7-S158-6	355	289	209	65
7-S158-7	570	463	406	42
7-S158-8	797	667	453	207
7-S158-9	738	605	521	80
7-S158-10	720	599	439	153
7-S159-1	398	297	195	100
7-S159-2	458	348	171	173

TABLE 1
(cont'd.)

Sample Number	Wet Weight	Dry Weight	Sieved Weight	Rocks and Dross
SOIL (cont'd.)				
7-S159-3	456	347	88	238
7-S159-4	637	504	338	160
7-S159-5	655	500	369	131
7-S159-6	364	294	222	66
7-S159-7	440	361	263	95
7-S159-8	354	294	163	129
7-S159-9	543	447	309	136
7-S159-11	729	594	416	175
7-S160-1	379	297	237	60
7-S160-2	475	372	251	118
7-S160-3	547	426	116	308
7-S160-4	604	482	209	271
7-S160-5	686	555	389	161
7-S160-6	614	498	381	115
7-S160-7	492	424	215	206
7-S160-8	432	366	152	213
7-S160-9	567	472	304	163
7-S160-10	553	451	347	100
7-S161-1	326	261	182	71
7-S161-2	393	309	224	79
7-S161-3	494	411	287	122
7-S161-4	650	511	325	181
7-S161-5	581	452	378	73
7-S161-6	729	564	481	79
7-S161-7	544	454	276	177
7-S161-8	521	443	230	212
7-S161-9	224	184	147	34
7-S161-10	415	332	284	46
7-S162-1	379	323	265	55
7-S162-2	356	286	114	160
7-S162-3	550	457	303	153
7-S162-4	676	542	446	91
7-S162-5	217	190	115	73
7-S162-6	541	467	221	246
7-S162-7	319	277	102	124
7-S162-8	624	512	330	177
7-S162-9	832	687	434	251
7-S162-10	786	647	442	202

TABLE 1
(cont'd.)

Sample Number	Wet Weight	Dry Weight	Sieved Weight	Rocks and Dross
		SOIL (cont'd.)		
7-S163-1	358	288	238	48
7-S163-2	339	265	72	190
7-S163-3	518	419	177	242
7-S163-4	540	440	330	110
7-S163-5	734	552	518	31
7-S163-6	733	588	403	184
7-S163-7	648	511	415	95
7-S163-8	736	573	521	50
7-S163-9	681	551	434	116
7-S163-10	938	783	536	247
7-S164-1	538	414	335	76
7-S164-2	421	324	276	45
7-S164-3	527	401	367	34
7-S164-4	690	560	388	170
7-S164-5	672	532	456	73
7-S164-6	726	572	489	81
7-S164-7	579	445	415	28
7-S164-8	811	631	535	93
7-S164-9	570	429	408	19
7-S164-10	671	539	388	150
7-S165-1	280	223	171	49
7-S165-2	433	361	248	110
7-S165-3	531	432	297	133
7-S165-4	622	512	310	202
7-S165-5	726	579	391	183
7-S165-6	747	566	517	39
7-S165-7	378	319	184	130
7-S165-8	301	243	170	67
7-S165-10	778	625	445	177
7-S166-1	395	336	309	21
7-S166-2	440	372	294	78
7-S166-3	296	240	169	37
7-S166-4	669	522	267	253
7-S166-5	695	526	327	197
7-S166-6	788	599	444	151
7-S166-7	646	502	376	124
7-S166-8	752	579	399	138
7-S166-9	611	486	380	103
7-S166-10	802	647	499	148

TABLE 1
(cont'd.)

Sample Number	Wet Weight	Dry Weight	Sieved Weight	Rocks and Dross
		SOIL (cont'd.)		
7-S166-11	774	619	325	293
7-S166-12	747	582	370	211
7-S166-13	723	578	435	140
7-S166-14	655	543	379	160
7-S166-15	624	539	345	194
7-S166-16	420	376	199	175
7-S166-17	395	358	173	184
7-S166-18	413	345	148	197
7-S166-19	374	369	170	196
7-S166-20	377	333	156	177
7-S166-21	523	458	190	268
7-S166-22	512	458	165	290
7-S166-23	427	388	148	237
7-S166-24	648	576	197	373
7-S166-25	465	402	134	263
7-S167-1	426	361	183	167
7-S167-2	533	432	142	287
7-S167-3	86	71	55	12
7-S167-4	464	385	225	157
7-S167-5	603	466	401	64
7-S167-6	696	566	282	284
7-S167-7	576	488	288	184
7-S167-8	568	487	187	294
7-S167-9	435	364	125	239
7-S167-10	76	64	50	12
7-S168-1	514	424	324	99
7-S168-2	531	443	360	80
7-S168-3	501	419	320	98
7-S168-4	618	488	380	107
7-S168-5	583	444	363	80
7-S168-6	775	598	373	221
7-S168-7	779	594	372	222
7-S168-8	319	235	219	12
7-S168-9	320	242	103	134
7-S168-10	476	378	217	161
7-S169-1	387	305	234	69
7-S169-2	526	420	285	135
7-S169-3	459	366	289	77
7-S169-4	434	346	274	68

TABLE 1
(cont'd.)

Sample Number	Wet Weight	Dry Weight	Sieved Weight	Rocks and Dross
SOIL (cont'd.)				
7-S169-5	576	428	380	48
7-S169-6	621	474	365	108
7-S169-7	259	199	171	19
7-S169-8	476	361	178	180
7-S169-9	610	440	266	170
7-S169-10	401	347	161	184
7-S170-1	309	250	207	36
7-S170-2	482	396	312	80
7-S170-3	321	272	184	52
7-S170-4	529	446	318	125
7-S170-5	619	491	443	44
7-S170-6	589	473	394	77
7-S170-7	628	489	373	112
7-S170-8	631	473	427	42
7-S170-9	687	502	416	83
7-S170-10	554	395	314	76
7-S171-1	358	300	256	41
7-S171-2	443	371	311	58
7-S171-3	372	318	231	78
7-S171-4	489	443	332	57
7-S171-5	347	270	230	17
7-S171-6	500	395	265	126
7-S171-7	533	431	259	167
7-S171-8	706	551	459	83
7-S171-9	516	375	299	73
7-S171-10	500	413	295	118
7-S172-1	368	310	245	65
7-S172-2	302	257	200	49
7-S172-3	444	369	286	80
7-S172-4	554	443	330	109
7-S172-5	548	435	379	49
7-S172-6	714	548	400	139
7-S172-7	630	476	363	113
7-S172-8	574	459	355	103
7-S172-9	437	349	282	66
7-S172-10	197	164	146	18
7-S173-1	321	267	176	87
7-S173-2	609	498	406	92

TABLE 1
(cont'd.)

Sample Number	Wet Weight	Dry Weight	Sieved Weight	Rocks and Dross
		SOIL (cont'd.)		
7-S173-3	556	445	318	127
7-S173-4	519	439	282	156
7-S173-5	311	260	199	60
7-S173-6	767	639	439	195
7-S173-7	603	498	411	85
7-S173-8	560	489	323	150
7-S173-9	808	666	428	233
7-S173-10	922	737	468	269
		VEGETATION		
7-V182	1656	45.1		
7-V183	633	30.8		

TABLE 2

WATER SAMPLE VOLUMES AND WEIGHTS

Sample Number	Volume (mℓ)	Total Solids(g)
7-W142	970	2.5
7-W145	1010	0.53
7-W149	1040	64.5
7-W174	1053	1.382
7-W175	1064	0.360
7-W176	1065	8.155
7-W177	1059	1.119
7-W178	1061	0.406
7-W179	1062	1.598
7-W180	1082	1.442
7-W181	1057	2.021
7-W184	1065	0.501

TABLE 3

GROUND AND WATER SURFACE ELEVATIONS IN THREE BOREHOLES IN THE BACK FORTY AREA

Bore Hole Number[a]	Ground Surface Elevation (ft MSL)	Water Surface Elevation (ft MSL)
7-S151	217.36	210.94
7-S153	216.79	209.95
7-S154	217.86	215.11

[a] See Figure 12 for locations.

TABLE 4

GAMMA-SPECTRAL AND URANIUM-FLUOROMETRIC ANALYSES OF SOIL SAMPLES

Sample Number	Gamma Spectra, pCi/g±σ[a]			Uranium Fluorometric	
	^{137}Cs	^{232}Th Decay Chain	^{226}Ra Decay Chain	μg/g±10%	pCi/g±10%[b]
7-S62-1	0.33±0.07	0.98±0.28	13.80± 0.20[c]	25.0 ± 1.0	77.2 ± 0.7
7-S63-1	0.59±0.08	5.70±0.29	12.90± 0.10[c]	50.0 ± 3.0	34.3 ± 2.1
7-SS141	0.10±0.03	0.94±0.09	1.09± 0.11	2.2 ± 0.2	1.5 ± 0.1
7-SS143	0.07±0.03	1.05±0.11	1.08± 0.11	1.5 ± 0.2	1.0 ± 0.1
7-SS144	0.16±0.03	0.87±0.09	1.26± 0.13	1.7 ± 0.2	1.2 ± 0.1
7-SS146	0.44±0.04	1.00±0.10	1.11± 0.11	1.7 ± 0.2	1.2 ± 0.1
7-S147	0.10±0.03	1.13±0.11	1.11± 0.11	1.9 ± 0.2	1.3 ± 0.1
7-S148-A	0.44±0.04	0.94±0.09	1.13± 0.11	1.5 ± 0.2	1.0 ± 0.1
7-S148-B	0.34±0.03	1.00±0.10	1.21± 0.12	1.5 ± 0.2	1.0 ± 0.1
7-S150-A	≤0.02	1.19±0.12	0.96± 0.10	1.3 ± 0.1	0.9 ± 0.1
7-S150-B	0.06±0.03	0.70±0.07	0.93± 0.09	1.4 ± 0.1	1.0 ± 0.1
7-S150-C	≤0.02	0.84±0.08	1.08± 0.11	1.4 ± 0.1	1.0 ± 0.1
7-S151-1	0.29±0.03	1.00±0.10	1.22± 0.12	1.7 ± 0.2	1.2 ± 0.1
7-S151-2	≤0.02	1.09±0.11	1.28± 0.13	1.6 ± 0.2	1.1 ± 0.1
7-S151-3	≤0.02	1.18±0.12	1.27± 0.13	1.4 ± 0.1	1.0 ± 0.1
7-S151-4	≤0.02	0.67±0.07	1.06± 0.11	1.3 ± 0.1	0.9 ± 0.1
7-S151-5	≤0.02	1.03±0.10	1.67± 0.17	1.4 ± 0.1	1.0 ± 0.1
7-S151-6	≤0.02	0.91±0.09	0.84± 0.08	1.4 ± 0.1	1.0 ± 0.1
7-S151-7	≤0.02	1.15±0.12	1.28± 0.13	1.4 ± 0.1	1.0 ± 0.1
7-S151-8	0.03±0.02	1.04±0.10	0.99± 0.10	1.4 ± 0.1	1.0 ± 0.1
7-S151-9	≤0.02	0.71±0.07	0.74± 0.07	1.3 ± 0.1	0.9 ± 0.1
7-S151-10	0.06±0.02	0.75±0.07	0.85± 0.09	1.3 ± 0.1	0.9 ± 0.1
7-S151-11	≤0.02	1.38±0.14	1.19± 0.12	1.5 ± 0.2	1.0 ± 0.1
7-S151-12	≤0.02	1.18±0.12	1.22± 0.12	1.4 ± 0.1	1.0 ± 0.1
7-S151-13	≤0.02	1.35±0.14	1.32± 0.13	1.5 ± 0.2	1.0 ± 0.1
7-S151-14	0.05±0.02	0.35±0.06	0.64± 0.06	1.2 ± 0.1	0.8 ± 0.1
7-S151-15	≤0.02	0.60±0.06	0.70± 0.07	1.3 ± 0.1	0.9 ± 0.1
7-S152-1	0.19±0.04	0.79±0.08	0.85± 0.09	1.5 ± 0.2	1.0 ± 0.1
7-S152-2	<0.02	1.27±0.13	1.14± 0.11	1.6 ± 0.2	1.1 ± 0.1
7-S152-3	0.05±0.02	1.35±0.14	1.08± 0.11	1.4 ± 0.1	1.0 ± 0.1
7-S152-4	<0.02	1.03±0.10	1.04± 0.10	1.5 ± 0.2	1.0 ± 0.1
7-S152-5	<0.02	0.92±0.09	<0.02	1.5 ± 0.2	1.0 ± 0.1
7-S152-6	<0.02	0.68±0.07	0.82± 0.08	1.4 ± 0.1	1.0 ± 0.1
7-S152-7	<0.02	1.06±0.11	0.80± 0.08	1.3 ± 0.1	0.9 ± 0.1

TABLE 4
(cont'd.)

Sample Number	Gamma Spectra, pCi/g±σ[a] ^{137}Cs	^{232}Th Decay Chain	^{226}Ra Decay Chain	Uranium Fluorometric[b] μg/g±10%	pCi/g±10%
7-S152-8	<0.02	1.03±0.10	1.17± 0.12	1.5 ± 0.2	1.0 ± 0.1
7-S152-9	<0.02	1.22±0.11	1.07± 0.11	1.5 ± 0.2	1.0 ± 0.1
7-S152-10	<0.02	0.73±0.07	1.05± 0.11	1.4 ± 0.1	1.0 ± 0.1
7-S152-11	<0.02	0.81±0.08	0.77± 0.08	1.4 ± 0.1	1.0 ± 0.1
7-S152-12	<0.02	0.69±0.07	0.81± 0.08	1.4 ± 0.1	1.0 ± 0.1
7-S152-13	<0.02	<0.04	0.55± 0.06	1.3 ± 0.1	0.9 ± 0.1
7-S152-14	<0.02	0.50±0.05	0.43± 0.04	1.3 ± 0.1	0.9 ± 0.1
7-S152-15	<0.02	0.16±0.05	0.38± 0.04	1.5 ± 0.2	1.0 ± 0.1
7-S152-16	0.02±0.02	0.46±0.07	0.58± 0.06	1.2 ± 0.1	0.8 ± 0.1
7-S152-17	<0.02	0.29±0.06	0.37± 0.04	1.4 ± 0.1	1.0 ± 0.1
7-S152-18	<0.02	0.29±0.06	0.62± 0.06	1.2 ± 0.1	0.8 ± 0.1
7-S152-20	<0.02	<0.04	0.55± 0.06	1.2 ± 0.1	0.8 ± 0.1
7-S152-21	<0.02	0.53±0.05	0.62± 0.06	1.1 ± 0.1	0.8 ± 0.1
7-S152-22	<0.02	0.64±0.06	0.71± 0.07	1.2 ± 0.1	0.8 ± 0.1
7-S152-23	<0.02	0.60±0.06	1.11± 0.11	1.1 ± 0.1	0.7 ± 0.1
7-S152-24	<0.02	0.67±0.07	1.62± 0.16	1.2 ± 0.1	0.8 ± 0.1
7-S152-25	<0.02	0.44±0.04	0.42± 0.04	1.2 ± 0.1	0.8 ± 0.1
7-S153-1	0.05±0.03	0.82±0.08	0.88± 0.09	1.5 ± 0.2	1.0 ± 0.1
7-S153-2	<0.02	1.17±0.12	0.62± 0.06	1.6 ± 0.2	1.1 ± 0.1
7-S153-3	<0.02	0.88±0.09	0.78± 0.08	1.4 ± 0.1	1.0 ± 0.1
7-S153-4	<0.02	1.03±0.10	0.88± 0.09	1.4 ± 0.1	1.0 ± 0.1
7-S153-5	<0.02	1.04±0.10	1.36± 0.14	1.4 ± 0.1	1.0 ± 0.1
7-S153-6	<0.02	1.34±0.13	1.09± 0.11	1.4 ± 0.1	1.0 ± 0.1
7-S153-7	<0.02	1.10±0.11	0.93± 0.09	1.3 ± 0.1	0.9 ± 0.
7-S153-8	<0.02	0.79±0.08	0.99± 0.10	1.4 ± 0.1	1.0 ± 0.
7-S153-9	0.03±0.02	1.08±0.11	0.69± 0.07	1.3 ± 0.1	0.9 ± 0.
7-S153-10	<0.02	1.11±0.11	1.03± 0.10	1.4 ± 0.1	1.0 ± 0.
7-S153-11	0.03±0.02	0.82±0.08	0.83± 0.08	1.4 ± 0.1	1.0 ± 0.
7-S153-12	<0.02	0.87±0.09	0.99± 0.10	1.4 ± 0.1	1.0 ± 0.
7-S153-13	<0.02	1.09±0.11	0.68± 0.07	1.4 ± 0.1	1.0 ± 0.
7-S153-14	<0.02	0.70±0.07	0.60± 0.06	1.3 ± 0.1	0.9 ± 0.
7-S153-15	<0.02	<0.04	0.39± 0.02	1.2 ± 0.1	0.8 ± 0.
7-S154-1	0.29±0.04	0.79±0.08	1.22± 0.12	3.2 ± 0.3	2.2 ± 0.
7-S154-2	0.18±0.04	11.00±1.00	1.50± 0.20	77.8 ± 7.8	53.1 ± 5.
7-S154-3	≤0.02	1.93±0.19	1.18± 0.12	9.2 ± 0.9	6.3 ± 0.
7-S154-4	≤0.02	1.41±0.14	1.18± 0.12	3.0 ± 0.3	2.0 ± 0.
7-S154-5	≤0.02	1.26±0.13	1.08± 0.11	1.5 ± 0.2	1.0 ± 0.
7-S154-6	≤0.02	1.08±0.11	1.05± 0.11	1.6 ± 0.2	1.1 ± 0.
7-S154-7	≤0.02	0.97±0.10	0.96± 0.10	1.5 ± 0.2	1.0 ± 0.
7-S154-8	0.03±0.02	0.66±0.07	0.88± 0.09	1.6 ± 0.2	1.1 ± 0.

TABLE 4
(cont'd.)

Sample Number	Gamma Spectra, pCi/g±σ[a]			Uranium Fluorometric[b]	
	^{137}Cs	^{232}Th Decay Chain	^{226}Ra Decay Chain	μg/g±10%	pCi/g±10%
7-S154-9	≤0.02	0.64±0.06	0.57± 0.06	1.5 ± 0.2	1.0 ± 0.1
7-S154-10	≤0.02	0.35±0.07	0.82± 0.08	1.4 ± 0.1	1.0 ± 0.1
7-S155-1	0.13±0.04	1.17±0.12	0.18± 0.03	1.6 ± 0.2	1.1 ± 0.1
7-S155-2	≤0.02	1.58±0.16	1.40± 0.14	1.7 ± 0.2	1.2 ± 0.1
7-S155-3	≤0.02	0.96±0.10	1.25± 0.13	1.5 ± 0.2	1.0 ± 0.1
7-S155-4	≤0.02	1.32±0.13	1.22± 0.12	1.5 ± 0.2	1.0 ± 0.1
7-S155-5	≤0.02	0.86±0.09	0.90± 0.09	1.4 ± 0.1	1.0 ± 0.1
7-S155-6	≤0.02	0.74±0.07	0.82± 0.03	1.5 ± 0.2	1.0 ± 0.1
7-S155-7	≤0.02	0.99±0.10	0.97± 0.10	1.5 ± 0.2	1.0 ± 0.1
7-S155-8	≤0.02	1.18±0.12	0.82± 0.08	1.6 ± 0.2	1.1 ± 0.1
7-S155-9	≤0.02	1.16±0.12	0.98± 0.10	1.4 ± 0.1	1.0 ± 0.1
7-S155-10	≤0.02	1.29±0.13	1.21± 0.12	1.4 ± 0.1	1.0 ± 0.1
7-S156-1	0.11±0.03	0.90±0.09	0.93± 0.09	1.6 ± 0.2	1.1 ± 0.1
7-S156-2	≤0.02	0.97±0.10	0.98± 0.10	1.6 ± 0.2	1.1 ± 0.1
7-S156-3	≤0.02	1.03±0.10	0.94± 0.09	1.4 ± 0.1	1.0 ± 0.1
7-S156-4	≤0.02	1.13±0.11	0.81± 0.08	1.4 ± 0.1	1.0 ± 0.1
7-S156-5	0.06±0.03	0.66±0.07	0.95± 0.10	1.4 ± 0.1	1.0 ± 0.1
7-S156-6	≤0.02	1.21±0.12	1.08± 0.11	1.4 ± 0.1	1.0 ± 0.1
7-S156-7	≤0.02	0.81±0.08	1.12± 0.11	1.4 ± 0.1	1.0 ± 0.1
7-S156-8	≤0.02	1.13±0.11	0.73± 0.07	1.4 ± 0.1	1.0 ± 0.1
7-S156-9	0.04±0.02	1.16±0.12	1.15± 0.12	1.4 ± 0.1	1.0 ± 0.1
7-S156-10	0.04±0.02	0.75±0.08	1.04± 0.10	1.6 ± 0.2	1.1 ± 0.1
7-S157-1	0.03±0.02	0.68±0.07	1.20± 0.12	1.5 ± 0.2	1.0 ± 0.1
7-S157-2	≤0.02	1.20±0.12	1.32± 0.13	1.6 ± 0.2	1.1 ± 0.1
7-S157-3	≤0.02	0.65±0.07	0.77± 0.08	1.5 ± 0.2	1.0 ± 0.1
7-S157-4	≤0.02	0.86±0.09	1.16± 0.12	1.3 ± 0.1	0.9 ± 0.1
7-S157-5	≤0.02	1.02±0.10	1.05± 0.11	1.3 ± 0.1	0.9 ± 0.1
7-S157-6	≤0.02	0.57±0.06	1.22± 0.12	1.4 ± 0.1	1.0 ± 0.1
7-S157-7	≤0.02	1.13±0.11	1.00± 0.10	1.4 ± 0.1	1.0 ± 0.1
7-S157-8	≤0.02	1.19±0.12	0.99± 0.10	1.3 ± 0.1	0.9 ± 0.1
7-S157-9	≤0.02	0.89±0.09	0.89± 0.09	1.3 ± 0.1	0.9 ± 0.1
7-S157-10	≤0.02	0.80±0.08	0.95± 0.10	1.1 ± 0.1	0.8 ± 0.1
7-S158-1	0.24±0.03	1.91±0.19	1.28± 0.13	6.0 ± 0.6	5.2 ± 0.5[d]
7-S158-2	≤0.02	1.38±0.14	1.01± 0.10	2.0 ± 0.2	1.4 ± 0.1
7-S158-3	≤0.02	0.71±0.07	1.33± 0.13	1.7 ± 0.2	1.2 ± 0.1
7-S158-4	≤0.02	0.67±0.07	0.87± 0.09	1.6 ± 0.2	1.1 ± 0.1
7-S158-5	≤0.02	0.75±0.08	0.99± 0.10	1.4 ± 0.1	1.0 ± 0.1
7-S158-6	0.06±0.03	1.14±0.11	1.04± 0.10	1.5 ± 0.2	1.0 ± 0.1

TABLE 4
(cont'd.)

Sample Number	Gamma Spectra, pCi/g±σ^a			Uranium Fluoromet	
	^{137}Cs	^{232}Th Decay Chain	^{226}Ra Decay Chain	µg/g±10%	pCi/g±
7-S158-7	<0.02	1.24±0.12	1.30± 0.13	1.6 ± 0.2	1.1 ±
7-S158-8	0.04±0.02	0.89±0.09	1.03± 0.10	1.4 ± 0.1	1.0 ±
7-S158-9	≤0.02	0.86±0.09	0.87± 0.09	1.3 ± 0.1	0.9 ±
7-S158-10	≤0.02	0.88±0.09	0.79± 0.08	1.4 ± 0.1	1.0 ±
7-S159-1	0.12±0.03	0.99±0.10	0.99± 0.10	2.7 ± 0.3	1.8 ±
7-S159-2	<0.02	0.75±0.08	0.90± 0.09	1.7 ± 0.2	1.2 ±
7-S159-3	<0.02	1.03±0.10	1.10± 0.11	1.7 ± 0.2	1.2 ±
7-S159-4	<0.02	0.60±0.06	0.76± 0.08	1.5 ± 0.1	1.0 ±
7-S159-5	0.02±0.02	1.11±0.11	0.89± 0.09	1.3 ± 0.1	0.9 ±
7-S159-6	<0.02	1.28±0.13	1.20± 0.12	1.3 ± 0.1	0.9 ±
7-S159-7	<0.02	1.11±0.11	1.14± 0.11	1.4 ± 0.1	1.0 ±
7-S159-8	<0.02	0.71±0.07	1.03± 0.10	1.5 ± 0.2	1.0 ±
7-S159-9	<0.02	0.94±0.09	1.01± 0.10	1.4 ± 0.1	1.0 ±
7-S159-11	<0.02	0.93±0.09	1.02± 0.10	1.4 ± 0.1	1.0 ±
7-S160-1	0.35±0.04	2.92±0.29	1.13± 0.11	18.0 ± 1.8	12.3 ±
7-S160-2	<0.02	1.67±0.17	1.18± 0.12	5.3 ± 0.5	3.6 ±
7-S160-3	0.03±0.02	1.35±0.14	0.95± 0.10	4.5 ± 0.5	3.1 ±
7-S160-4	<0.02	0.66±0.07	0.74± 0.07	1.8 ± 0.2	1.2 ±
7-S160-5	<0.02	0.96±0.10	0.85± 0.09	1.4 ± 0.1	1.0 ±
7-S160-6	<0.02	1.04±0.10	1.07± 0.11	1.4 ± 0.1	1.0 ±
7-S160-7	<0.02	1.06±0.11	0.90± 0.09	1.6 ± 0.2	1.1 ±
7-S160-8	<0.02	0.95±0.10	0.72± 0.07	1.6 ± 0.2	1.1 ±
7-S160-9	<0.02	0.52±0.05	0.89± 0.09	1.4 ± 0.1	1.0 ±
7-S160-10	<0.02	0.71±0.07	0.62± 0.06	1.5 ± 0.2	1.0 ±
7-S161-1	0.08±0.03	1.00±0.10	1.01± 0.10	1.7 ± 0.2	1.2 ±
7-S161-2	<0.02	1.14±0.11	1.01± 0.10	2.2 ± 0.2	1.5 ±
7-S161-3	<0.02	0.88±0.09	1.04± 0.10	1.6 ± 0.2	1.1 ±
7-S161-4	<0.02	1.00±0.10	0.57± 0.06	1.6 ± 0.2	1.1 ± 0
7-S161-5	<0.02	1.10±0.11	0.77± 0.08	1.6 ± 0.2	1.1 ± 0
7-S161-6	0.04±0.02	1.08±0.11	0.65± 0.07	1.4 ± 0.1	1.0 ± 0
7-S161-7	<0.02	0.87±0.09	0.62± 0.06	1.4 ± 0.1	1.0 ± 0
7-S161-8	<0.02	0.59±0.06	0.63± 0.06	1.4 ± 0.1	1.0 ± 0
7-S161-9	<0.02	0.85±0.09	0.77± 0.08	1.5 ± 0.2	1.0 ± 0
7-S161-10	<0.02	0.53±0.05	0.40± 0.04	2.7 ± 0.3	1.8 ± 0
7-S162-1	0.04±0.02	1.22±0.12	0.94± 0.09	2.8 ± 0.3	1.9 ± 0
7-S162-2	<0.02	0.58±0.06	0.82± 0.08	1.7 ± 0.2	1.2 ± 0
7-S162-3	<0.02	0.70±0.07	0.66± 0.07	1.5 ± 0.2	1.0 ± 0
7-S162-4	<0.02	0.93±0.09	0.76± 0.08	1.4 ± 0.1	1.0 ± 0

TABLE 4
(cont'd.)

Sample Number	Gamma Spectra, pCi/g±σ[a]			Uranium Fluorometric	
	^{137}Cs	^{232}Th Decay Chain	^{226}Ra Decay Chain	Uranium Fluorometric µg/g±10%	Uranium Fluorometric pCi/g±10%[b]
7-S162-5	<0.02	0.92±0.09	0.97± 0.10	1.5 ± 0.2	1.0 ± 0.1
7-S162-6	<0.02	0.86±0.09	0.70± 0.07	1.4 ± 0.1	1.0 ± 0.1
7-S162-7	<0.02	0.69±0.07	0.46± 0.05	1.4 ± 0.1	1.0 ± 0.1
7-S162-8	<0.02	1.04±0.10	0.92± 0.09	1.4 ± 0.1	1.0 ± 0.1
7-S162-9	0.03±0.02	0.54±0.05	0.85± 0.09	1.4 ± 0.1	1.0 ± 0.1
7-S162-10	<0.02	0.86±0.09	0.69± 0.07	1.4 ± 0.1	1.0 ± 0.1
7-S163-1	0.56±0.06	0.92±0.09	0.84± 0.08	3.9 ± 0.4	2.7 ± 0.3
7-S163-2	<0.02	1.19±0.12	0.55± 0.06	2.6 ± 0.3	1.8 ± 0.2
7-S163-3	<0.02	0.84±0.08	0.67± 0.07	1.8 ± 0.2	1.2 ± 0.1
7-S163-4	<0.02	0.94±0.09	0.74± 0.07	1.4 ± 0.1	1.0 ± 0.1
7-S163-5	0.02±0.02	1.20±0.12	0.83± 0.08	1.6 ± 0.2	1.1 ± 0.1
7-S163-6	<0.02	1.26±0.13	1.22± 0.12	1.6 ± 0.2	1.1 ± 0.1
7-S163-7	<0.02	1.14±0.11	0.98± 0.10	1.5 ± 0.2	1.0 ± 0.1
7-S163-8	<0.02	1.13±0.11	1.07± 0.11	1.5 ± 0.2	1.0 ± 0.1
7-S163-9	<0.02	0.76±0.08	0.75± 0.08	1.4 ± 0.1	1.0 ± 0.1
7-S163-10	<0.02	0.68±0.07	0.74± 0.07	1.4 ± 0.1	1.0 ± 0.1
7-S164-1	0.12±0.04	0.86±0.09	0.99± 0.10	2.4 ± 0.2	1.6 ± 0.2
7-S164-2	0.10±0.10	0.66±0.07	1.09± 0.11	2.2 ± 0.2	1.5 ± 0.2
7-S164-3	0.04±0.02	1.01±0.10	0.96± 0.10	1.8 ± 0.2	1.2 ± 0.1
7-S164-4	<0.02	0.87±0.09	0.79± 0.08	1.6 ± 0.2	1.1 ± 0.1
7-S164-5	<0.02	1.07±0.11	0.67± 0.07	1.4 ± 0.1	1.0 ± 0.1
7-S164-6	<0.02	0.79±0.08	0.74± 0.07	1.4 ± 0.1	1.0 ± 0.1
7-S164-7	<0.02	1.13±0.11	0.70± 0.07	1.5 ± 0.2	1.0 ± 0.1
7-S164-8	<0.02	1.14±0.11	0.91± 0.09	1.4 ± 0.1	1.0 ± 0.1
7-S164-9	<0.02	1.33±0.13	0.93± 0.09	1.5 ± 0.2	1.0 ± 0.1
7-S164-10	<0.02	0.74±0.07	0.70± 0.07	1.7 ± 0.2	1.2 ± 0.1
7-S165-1	0.10±0.03	0.92±0.09	0.88± 0.09	2.4 ± 0.2	1.6 ± 0.2
7-S165-2	<0.02	0.82±0.08	0.88± 0.09	2.0 ± 0.2	1.4 ± 0.1
7-S165-3	<0.02	0.71±0.07	0.71± 0.07	1.7 ± 0.2	1.2 ± 0.1
7-S165-4	<0.02	0.82±0.08	0.47± 0.05	1.4 ± 0.1	1.0 ± 0.1
7-S165-5	<0.02	0.95±0.10	0.79± 0.08	1.4 ± 0.1	1.0 ± 0.1
7-S165-6	<0.02	1.08±0.11	1.40± 0.14	1.4 ± 0.1	1.0 ± 0.1
7-S165-7	<0.02	0.94±0.09	0.89± 0.09	1.4 ± 0.1	1.0 ± 0.1
7-S165-8	<0.02	0.77±0.08	0.69± 0.07	1.4 ± 0.1	1.0 ± 0.1
7-S165-10	<0.02	0.91±0.09	0.97± 0.10	1.6 ± 0.2	1.1 ± 0.1
7-S166-1	0.23±0.03	0.99±0.10	1.00± 0.10	1.6 ± 0.2	1.1 ± 0.1
7-S166-2	0.07±0.03	1.08±0.11	0.82± 0.08	1.8 ± 0.2	1.2 ± 0.1

TABLE 4
(cont'd.)

Sample Number	Gamma Spectra, pCi/g±σ^a			Uranium·Fluorome	
	^{137}Cs	^{232}Th Decay Chain	^{226}Ra Decay Chain	µg/g±10%	pCi/
7-S166-3	<0.02	1.02±0.10	0.98± 0.10	1.6 ± 0.2	1.1
7-S166-4	<0.02	1.01±0.10	1.11± 0.11	1.4 ± 0.1	1.0
7-S166-5	<0.02	1.17±0.12	1.22± 0.12	1.6 ± 0.2	1.1
7-S166-6	<0.02	1.34±0.13	1.02± 0.10	1.4 ± 0.1	1.0
7-S166-7	<0.02	0.66±0.07	0.73± 0.07	1.4 ± 0.1	1.0
7-S166-8	<0.02	0.97±0.10	0.81± 0.08	1.4 ± 0.1	1.0
7-S166-9	<0.02	0.81±0.08	0.89± 0.09	1.5 ± 0.2	1.0
7-S166-10	<0.02	0.95±0.10	0.67± 0.07	1.3 ± 0.1	0.9
7-S166-11	<0.02	1.04±0.10	1.26± 0.13	1.4 ± 0.1	1.0
7-S166-12	<0.02	0.67±0.07	0.73± 0.07	1.3 ± 0.1	0.9
7-S166-13	<0.02	0.64±0.06	0.59± 0.06	1.2 ± 0.1	0.8
7-S166-14	<0.02	0.58±0.06	0.67± 0.07	1.3 ± 0.1	0.9
7-S166-15	<0.02	<0.04	0.34± 0.03	1.2 ± 0.1	0.8
7-S166-16	<0.02	0.33±0.06	0.38± 0.04	1.2 ± 0.1	0.8
7-S166-17	<0.02	0.57±0.06	0.44± 0.04	1.2 ± 0.1	0.8
7-S166-18	0.02±0.01	0.45±0.06	0.60± 0.06	1.1 ± 0.1	0.8
7-S166-19	<0.02	0.34±0.06	0.55± 0.06	1.2 ± 0.1	0.8
7-S166-20	<0.02	0.43±0.06	0.42± 0.04	1.0 ± 0.1	0.7
7-S166-21	<0.02	0.31±0.06	0.51± 0.05	1.2 ± 0.1	0.8
7-S166-22	<0.02	0.50±0.05	0.68± 0.07	1.1 ± 0.1	0.8
7-S166-23	0.05±0.02	0.20±0.06	0.34± 0.03	1.0 ± 0.1	0.7
7-S166-24	<0.~~02~~	0.19±0.06	0.36± 0.04	1.1 ± 0.1	0.8
7-S166-25	<0.02	0.51±0.05	0.44± 0.04	1.0 ± 0.1	0.7
7-S167-1	0.11±0.03	0.89±0.09	1.03± 0.10	3.0 ± 0.3	2.0
7-S167-2	<0.02	1.58±0.16	0.93± 0.09	3.6 ± 0.4	2.5
7-S167-3	0.04±0.02	1.49±0.15	1.43± 0.14	3.1 ± 0.3	2.1
7-S167-4	<0.02	0.88±0.09	0.69± 0.07	1.5 ± 0.2	1.0 ±
7-S167-5	<0.02	1.03±0.10	0.82± 0.08	1.4 ± 0.1	1.0 ±
7-S167-6	<0.02	0.88±0.09	0.87± 0.09	1.4 ± 0.1	1.0 ±
7-S167-7	<0.02	0.83±0.08	0.63± 0.06	1.5 ± 0.2	1.0 ±
7-S167-8	0.07±0.03	0.49±0.05	0.61± 0.06	1.5 ± 0.2	1.0 ±
7-S167-9	<0.02	0.86±0.09	0.66± 0.07	1.5 ± 0.2	1.0 ±
7-S167-10	<0.02	0.73±0.07	0.83± 0.08	1.5 ± 0.2	1.0 ±
7-S168-1	0.21±0.03	3.86±0.39	1.80± 0.18	8.6 ± 0.9	5.9 ±
7-S168-2	0.10±0.03	2.45±0.25	0.74± 0.07	6.0 ± 0.6	4.1 ±
7-S168-3	<0.02	1.59±0.16	0.87± 0.09	3.6 ± 0.4	2.5 ±
7-S168-4	<0.02	1.18±0.12	1.16± 0.12	2.0 ± 0.2	1.4 ±
7-S168-5	<0.02	0.97±0.10	1.16± 0.12	1.6 ± 0.2	1.1 ±
7-S168-6	<0.02	1.28±0.13	0.92± 0.09	1.7 ± 0.2	1.2 ±
7-S168-7	<0.02	1.16±0.12	0.48± 0.05	1.3 ± 0.1	0.9 ±

TABLE 4
(cont'd.)

	Gamma Spectra, pCi/g±σ[a]			Uranium Fluorometric	
Sample Number	^{137}Cs	^{232}Th Decay Chain	^{226}Ra Decay Chain	µg/g±10%	pCi/g±10%[b]
7-S168-8	<0.02	0.88±0.09	0.67± 0.07	1.3 ± 0.1	0.9 ± 0.1
7-S168-9	<0.02	1.21±0.12	0.97± 0.10	1.3 ± 0.1	0.9 ± 0.1
7-S168-10	0.04±0.02	0.81±0.08	0.68± 0.07	1.3 ± 0.1	0.9 ± 0.1
7-S169-1	0.17±0.03	0.73±0.07	0.64± 0.06	1.6 ± 0.2	1.1 ± 0.1
7-S169-2	0.06±0.02	0.98±0.10	0.68± 0.07	1.7 ± 0.2	1.2 ± 0.1
7-S169-3	0.04±0.02	0.57±0.06	0.68± 0.07	1.7 ± 0.2	1.2 ± 0.1
7-S169-4	<0.02	0.88±0.09	0.71± 0.07	1.5 ± 0.2	1.0 ± 0.1
7-S169-5	<0.02	0.79±0.08	0.85± 0.09	1.4 ± 0.1	1.0 ± 0.1
7-S169-6	<0.02	0.73±0.07	0.61± 0.06	1.4 ± 0.1	1.0 ± 0.1
7-S169-7	<0.02	0.89±0.09	0.89± 0.09	1.4 ± 0.1	1.0 ± 0.1
7-S169-8	<0.02	1.18±0.12	0.64± 0.06	1.4 ± 0.1	1.0 ± 0.1
7-S169-9	<0.02	0.83±0.08	1.12± 0.11	1.6 ± 0.2	1.1 ± 0.1
7-S169-10	<0.02	0.49±0.05	0.45± 0.05	1.4 ± 0.1	1.0 ± 0.1
7-S170-1	0.15±0.03	0.84±0.08	0.90± 0.09	3.2 ± 0.3	2.2 ± 0.2
7-S170-2	<0.02	1.00±0.10	0.99± 0.10	3.1 ± 0.3	2.1 ± 0.2
7-S170-3	<0.02	0.98±0.10	0.93± 0.09	3.7 ± 0.4	2.5 ± 0.3
7-S170-4	<0.02	0.92±0.09	0.76± 0.08	3.1 ± 0.3	2.1 ± 0.2
7-S170-5	<0.02	0.63±0.06	0.88± 0.09	1.4 ± 0.1	1.0 ± 0.1
7-S170-6	<0.02	0.77±0.08	0.60± 0.06	1.3 ± 0.1	0.9 ± 0.1
7-S170-7	<0.02	1.07±0.11	0.83± 0.08	1.3 ± 0.1	0.9 ± 0.1
7-S170-8	0.02±0.02	0.98±0.10	0.57± 0.06	1.4 ± 0.1	1.0 ± 0.1
7-S170-9	0.05±0.02	0.85±0.09	0.55± 0.06	1.4 ± 0.1	1.0 ± 0.1
7-S170-10	<0.02	1.54±0.15	1.17± 0.12	1.6 ± 0.2	1.1 ± 0.1
7-S171-1	0.59±0.06	0.65±0.06	0.87± 0.09	2.1 ± 0.2	1.4 ± 0.1
7-S171-2	<0.02	0.76±0.08	1.02± 0.10	1.8 ± 0.2	1.2 ± 0.1
7-S171-3	<0.02	0.46±0.07	1.15± 0.12	1.8 ± 0.2	1.2 ± 0.1
7-S171-4	0.08±0.03	1.02±0.10	1.11± 0.11	1.5 ± 0.2	1.0 ± 0.1
7-S171-5	<0.02	1.14±0.11	0.65± 0.07	1.4 ± 0.1	1.0 ± 0.1
7-S171-6	<0.02	1.18±0.12	1.24± 0.12	1.4 ± 0.1	1.0 ± 0.1
7-S171-7	<0.02	0.88±0.09	0.98± 0.10	1.4 ± 0.1	1.0 ± 0.1
7-S171-8	<0.02	1.21±0.12	1.04± 0.10	1.4 ± 0.1	1.0 ± 0.1
7-S171-9	<0.02	1.19±0.12	1.02± 0.10	1.4 ± 0.1	1.0 ± 0.1
7-S171-10	<0.02	1.04±0.10	1.00± 0.10	1.4 ± 0.1	1.0 ± 0.1
7-S172-1	0.28±0.03	0.79±0.08	0.89± 0.09	1.8 ± 0.2	1.2 ± 0.1
7-S172-2	0.03±0.02	0.93±0.09	0.68± 0.07	1.7 ± 0.2	1.2 ± 0.1
7-S172-3	0.04±0.02	0.47±0.07	0.86± 0.09	1.8 ± 0.2	1.2 ± 0.1
7-S172-4	<0.02	1.01±0.10	1.08± 0.11	1.6 ± 0.2	1.1 ± 0.1

TABLE 4
(cont'd.)

Sample Number	Gamma Spectra, pCi/g±σ[a] ^{137}Cs	^{232}Th Decay Chain	^{226}Ra Decay Chain	Uranium Fluorometric μg/g±10%	pCi/g±10%
7-S172-5	<0.02	1.06±0.11	0.06± 0.02	1.5 ± 0.2	1.0 ± 0.
7-S172-6	0.06±0.02	0.85±0.09	0.81± 0.08	1.4 ± 0.1	1.0 ± 0.
7-S172-7	<0.02	0.89±0.09	0.85± 0.09	1.4 ± 0.1	1.0 ± 0.
7-S172-8	<0.02	0.98±0.10	1.02± 0.10	1.4 ± 0.1	1.0 ± 0.
7-S172-9	<0.02	1.04±0.10	0.86± 0.09	1.5 ± 0.2	1.0 ± 0.
7-S172-10	<0.02	0.61±0.06	0.73± 0.07	1.5 ± 0.2	1.0 ± 0.
7-S173-1	<0.02	0.88±0.09	0.96± 0.10	1.6 ± 0.2	1.1 ± 0.
7-S173-2	0.06±0.02	1.07±0.11	0.85± 0.09	1.7 ± 0.2	1.2 ± 0.
7-S173-3	0.04±0.02	0.87±0.09	0.78± 0.08	1.5 ± 0.2	1.0 ± 0.
7-S173-4	<0.02	1.01±0.10	0.80± 0.08	1.4 ± 0.1	1.0 ± 0.
7-S173-5	<0.02	0.78±0.08	0.90± 0.09	1.3 ± 0.1	0.9 ± 0.
7-S173-6	<0.02	0.82±0.08	1.10± 0.11	1.3 ± 0.1	0.9 ± 0.
7-S173-7	<0.02	0.94±0.09	0.76± 0.08	1.2 ± 0.1	0.8 ± 0.
7-S173-8	<0.02	0.37±0.08	0.55± 0.06	1.2 ± 0.1	0.8 ± 0.
7-S173-9	<0.02	0.24±0.07	0.59± 0.06	1.3 ± 0.1	0.9 ± 0.
7-S173-10	0.02±0.02	0.82±0.08	0.60± 0.06	1.2 ± 0.1	0.8 ± 0.

[a] One standard deviation due to counting statistics.

[b] ANL conversion from Appendix 5.

[c] These samples are listed here since they were reported erroneously in DOE/EV-0005/39.

[d] The conversion factor is 0.86 pCi/g for sample 7-S158-1 because of the presence of U-233 as shown in Table 7 and calculated in Appendix 5.

TABLE 5

GAMMA-SPECTRAL AND URANIUM-FLUOROMETRIC ANALYSES OF MISCELLANEOUS SAMPLES

Sample Number	Gamma Spectra			Uranium Fluorometric	
	^{137}Cs	^{232}Th Decay Chain	^{226}Ra Decay Chain		
		Water-Dissolved Solids			
		pCi/ℓ ± 1σ		μg/ℓ±10%	pCi/ℓ±10%[a]
7-W142	4.6 ±0.5	9.4 ±0.9	<0.02	0.41± 0.04	0.28± 0.03
7-W145	<0.02	<0.04	3.4 ±0.3	<0.1	<0.07
7-W149	<0.02	BDL[b]	<0.02	0.18± 0.02	0.12± 0.01
7-W174	≤0.02	≤0.04	11.00±1.0	1.4 ± 0.14	0.96± 0.10
7-W175	1.00±0.1	≤0.04	≤0.02	<0.2	<0.1
7-W176	≤0.02	≤0.04	≤0.02	6.9 ± 0.7	4.7 ± 0.5
7-W177	≤0.02	≤0.04	1.0 ±0.1	<0.2	<0.1
7-W178	≤0.02	≤0.04	≤0.02	<0.2	<0.1
7-W179	≤0.02	≤0.04	1.60±0.2	1.1 ± 0.1	0.75± 0.08
7-W180	3.00±0.3	9.00±0.9	10.00±1.0	<0.2	<0.1
7-W181	≤0.02	≤0.04	7.00±0.7	<0.2	<0.1
7-W184	5.00±0.5	≤0.04	≤0.02	<0.2	<0.1
		Water-Suspended Solids			
		pCi/g ± 1σ		μg/g±10%	pCi/g±10%[a]
7-W142	<0.03	1.46±0.15	0.55±0.06	3.4 ± 0.3	2.3 ± 0.2
7-W145	<0.03	<0.04	11.00±1.00	4.0 ± 0.4	2.7 ± 0.3
7-W149[c]	0.49±0.05	0.96±0.10	0.68±0.07	2.1 ± 0.2	1.4 ± 0.1
7-W174	0.12±0.04	≤0.04	≤0.02	1.6 ± 0.2	1.1 ± 0.1
7-W175	≤0.02	≤0.04	22.00±2.00	1.9 ± 0.2	1.3 ± 0.1
7-W176	0.05±0.02	1.42±0.14	1.70±0.17	1.8 ± 0.2	1.2 ± 0.1
7-W177	≤0.02	0.91±0.09	2.37±0.24	1.5 ± 0.2	1.0 ± 0.1
7-W178	≤0.02	22.00±2.00	≤0.02	1.5 ± 0.2	1.0 ± 0.1
7W-179	2.32±0.23	≤0.04	7.68±0.77	1.4 ± 0.1	1.0 ± 0.1
7W-180	≤0.02	4.11±0.41	3.31±0.33	1.3 ± 0.1	0.9 ± 0.1
7W-181	0.12±0.04	3.00±0.30	≤0.02	1.1 ± 0.1	0.8 ± 0.1
7W-184	0.28±0.03	≤0.04	≤0.02	1.7 ± 0.2	1.2 ± 0.1

TABLE 5
(cont'd.)

Sample Number	Gamma Spectra, pCi/g±σ			Uranium Fluorometric	
	^{137}Cs	^{232}Th Decay Chain	^{226}Ra Decay Chain	μg/g±σ	pCi/g±σ
			Vegetation		
7-V182	0.08±0.03	BDL	0.68±0.07	0.046±0.022	0.031±0.015
7-V183	0.04±0.03	BDL	1.07±0.10	0.095±0.033	0.064±0.022
Grass[d]	<0.05	0.001±0.001		0.074±0.015	0.050±0.010

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[a] ANL conversion from Appendix 5.

[b] BDL = Below Detectable Levels

[c] Ag-110m was measured at 2.1 ± 0.6 pCi/g in the suspended solids of 7-W149 on August 9, 1983.

[d] Listed for comparison from "Environmental Monitoring at Argonne National Laboratory: Annual Report for 1982" (ANL-83-26) by N. W. Golchert, T. L. Duffy and J. Sedlet.

TABLE 6

CHEMICAL SEPARATION AND ALPHA-SPECTROMETRIC ANALYSIS OF SOIL SAMPLES

(fCi/g ± σ)

Sample Number	^{239}Pu	^{238}Pu
7-S56-3	10 ± 5	2 ± 2
7-S68-3	2 ± 2	2 ± 2
7-S69-3	2 ± 2	2 ± 2
7-S81-2	6 ± 3	2 ± 2
7-S148A	10 ± 3	2 ± 2
7-S148B	13 ± 6	10 ± 5

TABLE 7

URANIUM MASS SPECTROMETRIC ANALYSES

Sample Number	Atom % U 233	 234	 235	 236	 238
	(±0.0003)	(±0.0003)	(±0.001)	(±0.0003)	(±0.0
7-S22-A	<0.0003	0.0010	0.268	0.0028	99.7
7-S23-A	<0.0003	0.0008	0.233	0.0031	99.7
7-S56-3	<0.0003	0.0057	0.727	0.0005	99.2
7-S62-1	<0.0003	0.0055	0.718	<0.0003	99.27
7-S63-1	<0.0003	0.0052	0.719	<0.0003	99.27
7-S66-1	<0.0003	0.0062	0.731	0.0007	99.2
7-S67-3	<0.0003	0.0054	0.720	<0.0003	99.27
7-S68-3	<0.0003	0.0058	0.736	<0.0003	99.25
7-S69-3	<0.0003	0.0056	0.729	<0.0003	99.26
7-S148A	<0.0005	0.0053	0.7186	<0.0005	99.27
7-S148B	<0.0005	0.0055	0.7193	<0.0005	99.27
7-S154-2	<0.0003	0.0055	0.7280	0.0005	99.26
7-S158-1	0.0012	0.0064	0.7233	0.0007	99.26
7-S160-1	<0.0003	0.0055	0.726	<0.0003	99.26
7-S168-1	<0.0003	0.0058	0.740	<0.0003	99.25

APPENDICES

Appendices 1 through 5 and 7 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 8 contains a generic discussion of the nature and sources of radiation, its potential danger to humans, and methods utilized to evaluate radiation exposures.

APPENDIX 1

INSTRUMENTATION

I. PORTABLE RADIATION SURVEY METERS

A. Gas-Flow Proportional Survey Meters

The Eberline PAC-4G-3 was the primary instrument used for surveying. This instrument is a gas-flow proportional counter which utilizes a propane gas-proportional detector, 51 cm^2 (AC-21), 100 cm^2, or 325 cm^2 (AC-22) in area, with a thin double-aluminized Mylar window ($\sim$ 0.85 mg/cm^2).

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

B. Beta-Gamma End Window Survey Meter

When an area of contamination was found with a PAC instrument, a reading was taken 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 densit approximately 7 mg/cm^2. At this density, the instrument is not sensitive t the majority of alpha emissions. A maximum reading is obtained with th probe placed in contact with the area of contamination. In this position the response (in mR/h) to gamma radiation is generally conservative relativ to a determination of mrad/h at 1 cm. This instrument is calibrated in mR/ with a ^{226}Ra standard.

C. Low-Energy Gamma Scintillation Survey Meter

An Eberline Model PRM-5-3 with a PG-2 gamma scintillation detector wa used to determine low-energy x and gamma radiation. The PG-2 detecto consists of a thin NaI(Tℓ) scintillation crystal 5 cm (2 in.) in diameter b 2 mm thick. This instrument is calibrated on three separate discriminator for three energy regions using ^{239}Pu (17 keV), ^{241}Am (59.5 keV), and ^{23} (185.7 keV) sources. This instrument can be operated in either a diffe ential (to discriminate between different energy regions) or integral mod

APPENDIX 1
(cont'd.)

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

An Eberline Micro "R" meter model PRM-7 was used to detect high-energy gamma radiation. This instrument contains an internally mounted NaI(Tℓ) scintillation crystal 2.5 cm (1 in.) in diameter by 2.5 cm (1 in.) thick and can be used to measure fields of low-level radiation between 10 μR/h and 5000 μR/h. This instrument is used to survey ambient background radiation. It is held 1 m (3 ft.) from the surface during the survey. This instrument is also calibrated with a standard ^{226}Ra source.

E. Integrating Radiation Meter

In addition to the PRM-7, a pressurized ion chamber (Reuter Stokes Model RSS-111) was 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 (~ 1 m) above the surface and has a uniform energy response from about 0.2 MeV to about 4 MeV. A 3-h period of operation is usually sufficient to obtain significant data.

II. SMEAR-COUNTING INSTRUMENTATION

An ANL-designed gas-flow proportional detector connected to an Eberline Mini Scaler Model MS-2 was 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.

Any smear taken from a contaminated area was 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 non-conducting 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.

The PC counters are 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.

III. AIR-SAMPLING DEVICE

Air samples were collected using a commercially available (ANL-modified Filter Queen) vacuum cleaner identified as the "Princess Model."

APPENDIX 1
(cont'd.)

Air was drawn through a filter medium at a flow rate of 40 m^3/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-μm particles is about 99.9%.

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 μm) filter paper for about one hour. An alpha 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.

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 Bicron 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 withstand 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.

APPENDIX 2

CONVERSION FACTORS

I. INSTRUMENTATION

The factors used to convert the instrument readings to units of disintegrations per minute per 100 cm^2 (dis/min-100 cm^2) and the derivation of those factors are listed below.

A. Conversion Factors

	PAC-4G-3		Floor Monitor (FM-4G)	
	Alpha	Beta	Alpha	Beta
To 100 cm^2	1.96	1.96	0.31	0.31
cts/min to dis/min for ^{90}Sr-^{90}Y	-	2	-	2
cts/min to dis/min for ^{239}Pu	2	-	2	-
cts/min to dis/min for normal U	3.5	2.7	3.0	2.5
cts/min to dis/min ^{226}Ra plus daughters	1.7	1.7	1.7	1.8

B. Derivation of Conversion Factors

- Floor Monitor

Window Area: ~ 325 cm^2
Conversion to 100 cm^2 = 0.31 times Floor Monitor readings

- PAC-4G-3

Window Area: ~ 51 cm^2
Conversion to 100 cm^2 = 1.96 times PAC reading

- 2π Internal Gas-Flow Counter, PC counter

Geometry: Solid Steel Spun Top - 0.50

Geometry: Mylar Spun Top - 0.43
Mylar spun top counting {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.

APPENDIX 2
(cont'd.)

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 in x 1.25 in. x 0.005 in. (3.2 cm x 3.2 cm x 0.013 cm) 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 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:

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[a] 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 x bf x sa x waf is 0.51.

APPENDIX 2
(cont'd.)

A. Conversion Equation (Alpha)

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

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 the 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 (0.713) is used.

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

B. Conversion Equation (Beta)

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

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

A backscatter factor (bf) of 1.1 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 3

RADON-DETERMINATION CALCULATIONS

Calculations for determining radon concentrations in air samples collected with an Argonne National Laboratory-designed air sampler using HV-70 or LB5211 filter media are summarized in this appendix; the basic assumptions and calculations used to derive the air concentrations also are included.

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 adhered to airborne particulates (i.e., unattached fraction) and, therefore, is not collected on the filter media.

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 the 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 α emissions and 16% decays by 6.28 MeV α 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

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

where: A_o = 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 $\simeq$ 100 minutes)

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

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

Concentration is determined by the equation:

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

where: C = concentration (dis/min-m^3)

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

f = sampling rate (m^3/min = m^3/h x 1 h/60 minutes)

t_s = length of sampling time (minutes)

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

$t_{\frac{1}{2}}$ = half-life of isotope or controlling parent (minutes).

III. ACTINON CORRECTION

Since the actinon (^{219}Rn) progeny (AcA, AcB & AcC) decays at t
half-life of 36 minutes, it cannot be distinguished from the radon (
progeny using standard air sampling with HV-70 or LB5211 filter medi
standard alpha-counting techniques. A positive displacement pump is us
collect a sample on Millipore membrane (0.5 to 0.8 μm) filter media.
sample rate is approximately 20 liters/minute for a sampling time
least 90 minutes. The center portion of the sample is removed and c

APPENDIX 3
(cont'd.)

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:

Data $f = 40\ m^3/60\ min$ $t_s = 40\ min$
at $t = 100\ min$ $A = 2000\ dis/min$
at $t = 360\ min$ $A = 140\ dis/min$
at $t = 7\ days$ $A = 5\ dis/min$

For long-lived activity:

$$A_o = A = 5\ dis/min$$

$$C(L) = A_o/fxt_s = \frac{5}{40/60x40} = 0.19\ dis/min\text{-}m^3.$$

APPENDIX 3
(cont'd.)

For thoron:

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

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

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

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

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

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

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

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

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

For 6.62 MeV peak: 44 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 Me alpha emissions are 100% of the total.

APPENDIX 3
(cont'd.)

$B_1 = 44$

$B_1/0.84 = 52$ counts

$B_2 = 601$ counts

Actinon = 52/653 = 0.08

Radon = 601/653 = 0.92

C(Rn) = C(36) x Radon% = 669.7 x 0.92 = 616.1 dis/min-m^3

C = C(36) x Actinon% = 669.7 x 0.08 = 53.6 dis/min-m^3.

Since we assume that on the average half of the progeny is not adhered to the airborne particulates, the above concentrations are then doubled to determine actual concentrations. 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 dis/min-m^3

C(Tn) = 7.6 dis/min-m^3 x 2 = 15.2 dis/min-m^3

C(An) = 53.6 dis/min-m^3 x 2 = 107.2 dis/min-m^3

C(Rn) = 616 dis/min-m^3 x 2 = 1232 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 x 10^3:

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

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

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

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

APPENDIX 4

SAMPLE PREPARATION AND ANALYSIS, GENERIC PROTOCOL

I. SOIL-SAMPLE PREPARATION

Soil samples are acquired as previously described. These bagged and identified at the collection site and returned to ANL. is an indication of radioactive contamination, the sample is seal Nalgene jar. At ANL, the soil samples are logged into the soil- book, and each sample is weighed (on a tared balance scale) and th is marked on the container. This weight is recorded in the soil b "wet weight."

After all samples are marked, weighed, and recorded, they are Each sample is placed in a pyrex beaker marked with the sample id cation number. If more than one beaker is necessary, additional (e.g., 1-3, 2-3, 3-3) are used. The original containers are sav repackaging the dried samples. The beaker is set in an 80°C oven un soil is dry (approximatley 48 hours). The sample is returned original container and reweighed using a tared balance scale. This is also marked on the container and in the soil-sample book, where referred to as a "dry weight."

After all the samples are returned to their original container milling process is started. Each dried sample is transferred to gallon ceramic mill jar containing mill balls (1¼" x 1¼" Burundum ders). The mill jar number is marked on the original container. Th are sealed and the samples are milled for two hours or until suff material is produced to obtain 100 g and 5 g samples for analyses. samples are milled six at a time. A second set of six jars is pr while the milling of the first set is proceeding. After each sampl milled, the mill balls are removed with tongs and placed in a tray. A plastic bag is inverted over the mill jar. Both are inverted and until all the soil is transferred to the bag. If the soil plates the of the mill jar, a small paint brush is used to loosen the soil before jar is inverted. A separate brush is used for each jar to prevent c contamination of the soil samples.

After milling, each sample is sieved through a number 30 st testing sieve (600 µ mesh) and transferred to a 12" x 12" ziplock Rocks and dross are bagged separately from the sieved material. The are marked with the sample number, the sieve number and R(rocks) or S(The balance is tared and the weights of the soil (or rocks) are measured recorded in the soil-sample book. A 100-g sample of the sieved material transferred to a 4-oz. Nalgene bottle. These samples are analyzed by able analytical techniques, including, as a minimum, gamma spectro (GeLi). A 5-g sample of the sieved material is transferred to a Nalgene bottle. One gram of this sample is used for the determinati uranium by laser fluorometry; 100 grams of this are needed for radioch analysis for Pu, Am, and Th if these analyses are required. The bo containing these weighed samples are marked with sample number and date,

APPENDIX 4
(cont'd.)

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 which is attached to a fume hood or specially constructed drying box.

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

III. WATER AND SLUDGE

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

APPENDIX 4
(cont'd.)

pended 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 (~ 40 min to reach temperature and ~ 80 min heating at temperature). Helium is used as a flow-gas through the tube during heating, and the tritium is collected in two traps on the downstream side of the furnace. The first trap is immersed in an ordinary ice bath (0°C); the second trap is immersed in a CO_2-Freon bath (-57°C). The collected tritiated water from both traps is combined, made up to a known volume, and an aliquot taken for liquid scintillation counting of the tritium.

VI. ANALYSIS PROCEDURES

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

The total uranium (elemental) present in the 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

APPENDIX 4
(cont'd.)

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}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-μg)	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	0.711
^{238}U	0.746	4.4683×10^{9}	99.2746	238.0508	99.284
			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:

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

or (1.515 dis/min-μg)/(2.22 dis/min-pCi) = 0.683 pCi/μg

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

Note that 2.25% of the total activity is due to ^{235}U and 48.87% each is due to ^{234}U and ^{238}U.

Calculation of the specific activity of other than normal mixtures of uranium isotopes are 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.)

$0.99278 \times 0.746 = 0.7406$ dis/min-μg from ^{238}U
$0.000007 \times 1.436 \times 10^2 = 0.0010$ dis/min-μg from ^{236}U*
$0.007142 \times 4.798 = 0.0343$ dis/min-μg from ^{235}U
$0.000063 \times 1.387 \times 10^4 = 0.8738$ dis/min-μg from ^{234}U
$0.000012 \times 2.140 \times 10^4 = \underline{0.2568}$ dis/min-μg from ^{233}U**
1.9065 dis/min-μg U total

corresponding to:

(1.9065 dis/min-μg)/(2.22 dis/min-pCi) = 0.859 pCi/μg U

*The half-life for ^{236}U (2.342×10^7 yr) and the corresponding specific activity (1.436×10^2 dis/min-μg) 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-μg) 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

Excerpts From

I. DRAFT AMERICAN NATIONAL STANDARD

N13.12

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

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

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

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

APPENDIX 6
(cont'd.)

TABLE 1

SURFACE CONTAMINATION LIMITS*

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

APPENDIX 6
(cont'd.)

SURFACE CONTAMINATION LIMITS

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

+Disintegrations per minute per square decimeter.

NOTES:

(1) Values presented here are obtained from the Code of Federal Regulations, Title 10, Part 20, April 30, 1975. The most limiting of all given MPC values (for example, soluble versus insoluble) are to be used. In the event of the occurrence of mixtures of radionuclides, the fraction contributed by each constituent of its own limit shall be determined and the sum of the fraction shall be less than 1.

(2) Maximum permissible concentration in air applicable to continuous exposure of members of the public as published by or derived from an authoritative source such as the National Committee on Radiation Protection and Measurements (NCRP), the International Commission on Radiological Protection (ICRP), or the Nuclear Regulatory Commission (NRC). From the Code of Federal Regulations, Title 10, Part 20, Appendix B, Table 2, Column 1.

(3) The instrument utilized for this measurement shall be calibrated to measure at least 100 pCi of any Group 1 contaminants uniformly spread over 100 cm^2.

(4) Maximum permissible concentration in water applicable to members of the public.

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

APPENDIX 6
(cont'd.)

ALTERNATE SURFACE CONTAMINATION LIMITS

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

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

APPENDIX 6
(cont'd.)

ALTERNATE SURFACE CONTAMINATION LIMITS

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

+Disintegrations per minute per square decimeter.

NOTES:

(1) U_{nat} and decay products.

(2) The instrument utilized for this measurement shall be calibrated to measure at least 100 pCi of any Group 1 contaminants uniformly spread over 100 cm^2.

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

APPENDIX 6
(Cont'd.)

II.

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

APPENDIX 6
(cont'd.)

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.

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(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 (nuclides with decay modes other than alpha emission or spontaneous fission) except ^{90}Sr and others noted above.	5000 dis/min-100 cm^{2} $\beta\gamma$	15,000 dis/min-100 cm^{2} $\beta\gamma$	1000 dis/min-100 cm^{2} $\beta\gamma$

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 cm^2.

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

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

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(cont'd.)

III. 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.

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(cont'd.)

Division of Safety, Standards, and Compliance, U.S. Department of Energy, Washington, D.C. 20545.

712.6 General radiation exposure level criteria for remedial action.

The basis for undertaking remedial action shall be the applicable guidelines published by the Surgeon General of the United States. These guidelines recommended the following graded action levels for remedial action in terms of 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.

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

(1) For dwellings and schoolrooms:

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(cont'd.)

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

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

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

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

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

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

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

(n) "Working :eve;" (WL) means any combination of short-lived radon daughter products in 1 liter of air that will result in the ultimate emission of 1.3 x 10^5 MeV of potential alpha energy.

712.4 Interpretations

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

712.5 Communications

Except where otherwise specified in this part, all communications concerning the regulations in this part should be addressed to the Director,

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(cont'd.)

(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.

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(cont'd.)

IV. 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.

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

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(cont'd.)

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

192.12 Standards

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

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

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

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

(b) in any occupied or habitable building---

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

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

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

"Interim Soil Limits for D&D Projects"

TABLE XXIII. Recommended Soil Limits[a,b] (in pCi/g)

		Ingestion			
	Inhalation	Home Gardener	Full Diet	External Radiation	All Pathways[c]
^{231}Pa	50	740	150	250	40
^{227}Ac	200[d]	4,900	1,000	300	120[d]
^{232}Th	45	670	140	40	20
^{228}Th	1,000	37,000	7,800	55	50
^{230}Th (No Daught.)	300	4,400	940	36,000	280
^{238}U-^{234}U	750	44	8	6,000	40
^{90}Sr	2×10^6	100	19	-	100
^{137}Cs	7×10^6	800	1	90	80

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

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

[c] Based on a diet of a home gardener.

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

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VI. DOE 5480.1 Chg. 6, Chapter XI

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.

   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.

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

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(cont'd.)

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 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 1, Table I, Column 2.

2 The radiation protection standards in paragraph (1), above, are not exceeded.

(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

			Table I Controlled Area		Table II Uncontrolled Area	
Element (atomic number)	Isotope soluble (S) insolube (I)		Column 1 Air (pCi/ℓ)	Column 2 Water (pCi/ℓ)	Column 1 Air (pCi/ℓ)	Column 2 Water (pCi/ℓ)
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
Radon (86)	Rn 220	S	300		10	
	Rn 222	I	100		3	
Radium (88)	Ra 226	S	0.05	400	0.003	30
		I	0.05	9×10^5	0.002	3×10^4

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(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, Change 6, 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 mutiplied 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, Change 6, 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

ESTIMATED EXTENT OF CONTAMINATION

Estimates of the extent of the contamination at the assessed site are based on the total volume, mass, and quantity of radioactive material in the contaminated area. The volume is the product of the surface area and the depth of the contamination. The mass is the product of the volume and the density of the material. A density of 1.5 g/cm^3 is used for soil. The concentration (pCi/g) of the specific radioisotope is determined by radiochemical analysis of the soil. The total quantity of radioactive material is the product of the concentration of the specific radioisotope and the total mass of material.

Often there is more than one contaminant in the soil (or contaminated material) and the contaminants are not uniformly distributed throughout the material. In these cases, it is necessary to estimate the fraction of the material containing each contaminant in order to assess the total quantity of the radioactive material. This estimate of the fraction of the material containing each contaminant is based on the radiochemical analysis of randomly selected samples.

Estimates of the extent of contamination are usually determined for averaged (Option 1) and maximum or worst-case (Option 2) conditions. Sample calculations for the extent of contamination in the Back Forty area of the Albany, Oregon Bureau of Mines Site are as follows:

Volume (average) = 34,800 ft^2 (area) x 3.6 ft (avg. depth) = 125,000 ft^3
= 3,550 m^3

Volume (maximum) = 34,800 ft^2 (area) x 9 ft (max. depth) = 314,000 ft^3
= 8,880 m^3

Mass (average) = 3,550 m^3 x 1,500 kg/m^3 = 5.33 x 10^6 kg
Mass (maximum) = 8,880 m^3 x 1,500 kg/m^3 = 1.33 x 10^7 kg

Estimated Total Activity for ^{226}Ra (chain)

Average: 5.33 x 10^6 kg x 14 x 10^{-12} Ci/g x 10^3 g/kg x .05 (fraction)*
= 0.004 Ci

Maximum: 1.33 x 10^7 kg x 16 x 10^{-12} Ci/g x 10^3 g/kg x .05 (fraction)*
= 0.011 Ci.

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*This represents the estimated fraction of the total mass contaminated with the ^{226}Ra chain.

APPENDIX 8

EVALUATION OF RADIATION EXPOSURES

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 that of the alpha particle and the gamma-ray, causing fewer ionizations per unit path length than an alpha particle.

B. Sources of Radiation

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

Most atoms of the elements in our environment remain structurally stable. With time, an atom of potassium, for instance, may change its association with other atoms in chemical reactions and become part of other

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(cont'd.)

compounds, but it will always remain a potassium atom. Radioactive atoms, on the other hand, are not stable and will spontaneously emit radiation in order to achieve a more stable state. Because of this spontaneous transformation, the ratio of protons and neutrons in 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 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.

BACKGROUND RADIATION DOSES

Background radiation doses are comprised 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 effects as one rem from medical x-rays or one rem from the radiations emitted by naturally occurring or man-made radioactive materials.

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

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overall population-weighted external dose for the U.S. population as a whole has been estimated to be 26 mrem per year.

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

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 soft tissue doses arise primarily from the beta and gamma emissions from potassium-40. The total internal dose from inhaled plus incorporated radioactivity is about 28 mrem per year to the gonads (or whole-body dose), about 125 mrem per year to the lung, about 25 mrem per year to the bone marrow, and about 117 mrem per year to the bone (osteocytes).

The total natural background radiation dose is the sum of the external and internal components. The population-weighted dose for the U.S. population as a whole is about 82 mrem per year to the gonads or whole body,

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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).

Besides the natural background radiation, background radiation doses include contributions from man-made or technologically enhanced sources of radiation. By far, the most significant source 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.

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.

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

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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 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

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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.

DOSE DETERMINATION CALCULATION

External Exposure

External penetrating radiation dose rates are measured on contact with an end-window beta-gamma Geiger-Mueller (GM) detector (7 mg/cm^2 window), and at 1 meter with a NaI crystal detector (1 in diameter by 1 in thick) manufactured by Eberline Corporation (PRM-7 μR 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:

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

For the purposes of this example it is assumed that one milliRoentgen 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 non-occupationally exposed.(1)

Internal Exposure

The internal radiological hazard from inhalation/ingestion of contamination 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 m^3/working day and a soil density of 1.5 g/cm^3, are used. This means 4.39 g (1 ft x 0.305 m/ft x 1.5 g/cm^3 x 10^6 cm^3/m^3 x 10^{-6} m^{-1} x 9.6 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.

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The adult inhalation and ingestion dose commitment factors for the bone, lung and total body from ^{238}U, ^{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: 6.5×10^{-2} mrem/pCi x 5 pCi/g x 100 g = 32.5 mrem
Total Body: 5.5×10^{-3} mrem/pCi x 5 pCi/g x 100 g = 2.75 mrem.

Inhalation (rototilling and breathing ensuing aerosol):

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

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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^{-4}
^{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}

[a] Data taken from Reference 2.

[b] Nuclides in the chain that contribute negligibly (e.g., $<10^{-6}$ mrem) have not been included.

APPENDIX 8
(cont'd.)

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2. D. E. Dunning, 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.

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