DOE/EV-0005/4
DR. 219
375
7/3/78
Sdd + Spec.
E/H R Distr

MASTER

Formerly Utilized MED/AEC Si es Remedial Action Program

Radiological Survey of the Ashland Oil Company (Former Haist Property), Tonawanda, New York

May 1978

Final Report

Prepared for

U.S. Department of Energy
Assistant Secretary for Environment
Division of Environmental Control Technology
Washington, D.C. 20545

Under
Contract No. W-7405-ENG-26

DISTRIBUTION OF THIS DOCUMENT IS UNLIMITED

DISCLAIMER

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

DISCLAIMER

Portions of this document may be illegible in electronic image products. Images are produced from the best available original document.

DOE/EV-0005/4
UC-70

MASTER

Formerly Utilized MED/AEC Sites Remedial Action Program

Radiological Survey of the Ashland Oil Company (Former Haist Property), Tonawanda, New York

May 1978

Final Report

Prepared for

U.S. Department of Energy
Assistant Secretary for Environment
Division of Environmental Control Technology
Washington, D.C. 20545

Under
Contract No. W-7405-ENG-26

By
Oak Ridge National Laboratory
Oak Ridge, Tennessee 37830

DISTRIBUTION OF THIS DOCUMENT IS UNLIMITED

Available from:

National Technical Information Service (NTIS)
U.S. Department of Commerce
5285 Port Royal Road
Springfield, Virginia 22161

Price:

Printed Copy:	$ 5.25
Microfiche:	$ 3.00

PREFACE

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

This report contains the results of a radiological survey of the former Haist Property, now owned by the Ashland Oil Company, Tonawanda, New York. The survey was conducted in 1976 by the Energy Research and Development Administration (ERDA) a forerunner of the Department of Energy. Specific findings indicate the presence of low levels of radiation and contamination in soils on the property. Under current usage of the site there is no hazard to people working in this area. However, certain use conditions could arise in the future that would likely represent an unacceptable situation, hence, the DOE plans to conduct further engineering assessments of this site to identify the necessity and possible options for remedial action.

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

R. W. Leggett
F. F. Haywood
H. W. Dickson
D. L. Anderson
C. A. Golden
W. D. Cottrell
W. F. Fox

THIS PAGE

WAS INTENTIONALLY

LEFT BLANK

CONTENTS

LIST OF FIGURES

LIST OF TABLES

RADIOLOGICAL SURVEY OF THE ASHLAND OIL COMPANY (FORMERLY HAIST PROPERTY) TONAWANDA, NEW YORK

ABSTRACT

The results of a radiological survey of the former Haist property, Tonawanda, New York, are presented in this report. The property served as a repository for uranium ore tailings during the period 1944-46.

It was released for unrestricted use following a survey conducted in 1958 by the Health and Safety Laboratory (HASL), operated then by the Atomic Energy Commission. The property is now owned by Ashland Oil, Inc., and is used for oil refining operations. The survey was undertaken to determine whether the present radiological status of the property is consistent with current radiation protection guidelines and to determine the extent of movement of radioactive residues from the property via natural means such as surface run-off. The survey included measurement of external gamma and surface beta-gamma radiation levels on and near the site; radium and uranium concentrations in the soil on the site; concentrations of radium, uranium, and thorium in water samples collected on the site and in the drainage paths between the site and the

Niagara River; radium concentrations in mud samples taken from the drainage areas; and radon daughter levels in the only building on the site. The results indicate that the residues on the site do not pose an immediate health hazard, assuming that residues remain in place (except for normal drainage) and that the site continues to be used in the manner in which it is presently used. However, potential health hazards could result from some uses of the site. In particular, if buildings were to be constructed in certain areas on the site, significant concentrations of radon daughters could develop in these structures.

INTRODUCTION

At the request of the Department of Energy (DOE), (then Energy Research and Development Administration), a radiological survey was conducted in Tonawanda, New York, at the former Haist property. This 10-acre tract served as a disposal site for refinery residues generated by Linde Air Products (a Division of Union Carbide Corporation) in Tonawanda, New York, during their period of participation in the ore refinery operations program of the Manhattan Engineering District. The site, now owned by Ashland Oil, Inc., occupies a corner of the total Ashland property, the site of a large oil refining operation.

Residues comprised essentially of low-grade uranium-ore tailings were deposited on the Haist property during the period 1944-46. Records indicate that about 8000 tons of residues containing approximately 0.54% uranium were spread out over roughly two-thirds of the site to a depth of 1 to 5 ft. The approximate distribution of the residues as documented[1] in 1958 by the Department of Energy Environmental Measurements Laboratory (then Health and Safety Laboratory), is shown in Fig. 1.

In 1974, some of the residues (perhaps 30-40%) were moved to the adjacent Seaway Industrial Park in order to prepare the site for construction of two storage tanks. Some of the remaining residue has been relocated by earth-moving equipment and by natural run-off; and a large amount of clean fill dirt has been placed on the site.

The former Haist property is located in a large industrial area. Residences are found close by on two sides of the property. West of the site along the east bank of Grand Island, residences are found at a distance of approximately 0.5 mile. Residences in the city of Tonawanda also begin at a distance of 0.5 mile. In both cases, the dwellings are predominantly single family units comprising a low density population of approximately 2500 persons per square mile. The location of the Haist site with respect to the total Ashland property and the surrounding industrial area is shown in Fig. 2. There is one building, a fuel gas distribution center, on the site; it is occupied only a few hours each month. The only other active use being made of the property is as an electrical switch yard and oil storage area (see Fig. 3). A small area on the north end is being encroached upon by a storage yard located on adjoining property owned by Ashland Oil Company. Communications with Ashland management indicate no change in the usage of this property is anticipated for the foreseeable future.

Surface water drains from the property in small streams which merge and run off onto the Seaway Industrial Park, which borders the Haist property on the northeastern side. Normally the water drains through Seaway, continues north for nearly a mile through an industrial zone,

and then drains into the Niagara River. However, at present the run-off accumulates in a low part of the Seaway Industrial Park because drainage is impeded by incomplete culvert construction.

The last radiological survey of the site was conducted in 1958 by the Environmental Measurements Laboratory, which recommended that the property be released for unrestricted use without removal of the residues.[1] In 1960, the property was transferred to Ashland Oil, Inc., by the General Services Administration, which had control of the site since 1949.

The present survey was undertaken to characterize the existing radiological status of the property. It was conducted by five members of the Health and Safety Research Division, Oak Ridge National Laboratory (ORNL), during the period July 27-August 6, 1976. The survey consisted of: (1) measurement of external gamma radiation at the surface and at 1 m above the surface at the intersection of mutually perpendicular grid lines spaced 100 ft apart covering the property, and measurement of beta-gamma radiation 1 cm above the surface on the same grid; (2) collection of soil samples from the site for the determination of ^{226}Ra, ^{238}U, ^{232}Th, and ^{227}Ac concentrations; (3) collection of water and mud samples along the drainage paths between the site and the Niagara River; (4) measurement of gamma radiation at various depths in core holes dug throughout the site to determine the depth of the contamination in the soil; and (5) measurements of radon daughter concentrations in the National Fuel Gas (NFG) building on the site.

RADIOLOGICAL SURVEY TECHNIQUES

The entire site was divided into subsections by a 100-ft grid. The grid and several landmarks are shown in Fig. 3. Grid points are identified via lines A through E (running southeast to northwest) and lines 1 through 13 (running northeast to southwest). The former Haist property is represented in Fig. 3 by the area to the right of line 2. For convenience in reporting, the three sections of the site separated by two dikes (labelled dike 1 and dike 2) are referred to as section NW (for northwest), section M (for middle), and section SE (for southeast); dike 1 will be considered as part of section M, and section SE will include dike 2.

Measurement of External Gamma and Beta-Gamma Radiation Levels

External gamma radiation levels were measured at the surface and at 1 m above the surface with scintillation survey meters; these instruments are described in Appendix I. Measurements were taken at each point on a 100-ft grid (Fig. 3) covering the entire site and at additional points along drainage ditches, fences, and tailings piles. Readings at 1 m above the surface were also taken at several nearby offsite locations. Geiger-Muller survey meters, described in Appendix I, were used to measure beta-gamma radiation levels at the surface at each of the grid points.

Scintillation and Geiger-Muller (G-M) survey meter measurements are indicative of the instantaneous exposure rate at the point of measurement. Individual readings may be in error by ±30% or more due to the low radiation fields encountered over large areas and due to differences in

the geometric arrangement of environmental radiation sources and those used for calibration in the Laboratory. Percentagewise, largest errors for the G-M meter occur near background levels, at which the G-M meter typically shows readings of 0.01 to 0.04 mrad/hr. At this level, accuracy is increased substantially by averaging several readings. Since beta-gamma measurements on this site were near background levels at many points, readings are reported to the nearest hundredth of a millerad per hour for purposes of averaging and comparing.

Measurement of Radium in the Soil

Holes were drilled with a motorized drilling rig to depths of 6 to 12 ft at the locations shown in Fig. 4. An auger with a 5-in. inside diameter was used for the drilling. Gamma radiation was measured as a function of depth in the core holes by lowering a scintillation probe inside the auger. In some cases, additional measurements were made in the core hole after the auger was removed from the hole. This "logging" of the core holes was done as a first step in determining the depth of contamination in the soil.

Soil samples were collected, using a split-spoon sampler, at the 41 locations shown in Fig. 5. In addition to random samples taken throughout the site, extra samples were collected from closely spaced holes in areas which were thought to have the most-contaminated soils. The samples were packaged in plastic bags or bottles and shipped in steel cans. The samples were prepared for counting by the Bendix Field Engineering Corporation in Grand Junction, Colorado, where they were dried for 24 hr at 110°C and then pulverized to a particle size of -35

mesh (500 μm). Then the samples were returned to ORNL where aliquots from each sample were transferred to plastic petri dishes, weighed, and counted using a Ge(Li) detector. The spectra obtained were analyzed by computer techniques.

A description of the Ge(Li) detector and the soil counting procedure is given in Appendix II. Concentrations of ^{226}Ra, ^{232}Th, ^{227}Ac, and ^{40}K were determined using gamma ray spectroscopy. The concentrations of ^{238}U were determined for most samples utilizing a neutron irradiation technique developed by Dyer et al.[2] Mud samples were collected along the drainage area between the site and the Niagara River (see Figs. 6 and 7) and were packaged and returned to ORNL for determination of the concentration of radium and uranium.

Measurement of Radioactivity in Surface Water

Water samples were collected from the drainage areas for determination of radium, uranium, and thorium content. These samples were taken at the locations shown in Fig. 6. The samples were analyzed at ORNL using radiochemical techniques.

Radon Daughter Measurements

Radon daughter measurements were made in the NFG building, the only structure on the site other than storage tanks. Air was pumped for 5 min at approximately 12 liters per minute through a membrane filter with a maximum pore size of 0.45 μ. The filter was counted using an alpha spectrometry technique refined by Kerr.[3]

Background Radionuclide Concentrations in Soil

Six soil samples (NY-2 through NY-7) were collected in areas removed from the site far enough so as not to be influenced by conditions on the site. The locations of these samples are shown in Fig. 8. The average ^{226}Ra concentration in these background samples was observed to be 0.84 pCi/g.

SURVEY RESULTS

In the following discussion, unless otherwise specified, reported survey meter measurements represent gross readings; that is, background levels for the area have not been subtracted. Similarly, reported concentrations of radionuclides in environmental samples represent gross concentrations.

External Gamma and Beta-Gamma Radiation Levels

The average external gamma radiation reading at 1 m above the surface on the site was approximately 33 μR/hr. The highest readings were found in an area covering about one acre in section NW, and including grid points B5, C3, C4, C5, D3, and D4 (see Fig. 3). Readings from this specific area ranged from 60 μR/hr to 190 μR/hr and averaged approximately 120 μR/hr. Measurements averaged 48 μR/hr in section NW, 23 μR/hr in section M, and 17 μR/hr in section SE. Individual readings are given in Fig. 9; and those areas on and near the site with external gamma radiation levels above 20 μR/hr and 60 μR/hr, respectively, are shown in Fig. 10. Background readings taken in the Tonawanda area were in the range 8 to 14 μR/hr.

Continuous exposure to the highest gamma radiation measured, 190 μR/hr, would result in an integrated dose equivalent of approximately

1.6 rem/year. However, workers are on the site no more than 5% of the time; and the average external gamma radiation level on the site, 33 μR/hr, is only 3 times greater than the average background. These figures suggest that workers on the site receive, on the average, an integrated dose equivalent of less than 10 mrem/year from radiation contributed by the residues on the site (that is, from the average gamma radiation levels on the site minus the average background level for that area). Ten mrem per year is roughly 10% of the integrated dose equivalent which one receives over the period of a year from natural background radiation.

Beta-gamma readings taken at the surface at the grid points are shown in Fig. 11. The distribution of the readings closely parallels the distribution of the external gamma radiation readings. Measurements averaged approximately 37 μrad/hr, with highest readings being found in section NW. The external gamma radiation measurements at the surface (see Fig. 12) averaged approximately 33 μR/hr.

Results of Water and Mud Sample Analyses

The concentration of radium in mud samples taken from the drainage paths leading from Ashland and Seaway to the Niagara River are given in Fig 7. Uranium concentrations are listed in Table 1 and locations are shown in Fig. 6. Background concentrations of ^{238}U and ^{226}Ra in the Tonawanda area are typically near 1 pCi/g. The highest concentrations of radium in surface samples (26.4 pCi/g and 16.1 pCi/g) were found near the material which was transported by the Ashland Oil Company to Seaway in 1974. In samples taken from the drainage paths between the former Haist property and the Niagara River, the highest concentration found

was 8.3 pCi/g, in a sample taken from point D (see Fig. 7), which also contains drainage from the residues on Seaway. All other samples taken from drainage paths leading from the former Haist property (and crossing the Seaway property) showed less than 4 pCi/g radium, and the radium concentration in samples collected within 800 ft of the boundary of the site averaged about 2 pCi/g. Since most of the drainage from the former Haist property is carried northward toward the Niagara River, it appears that only small quantities of radium are carried from the site in surface run-off.

A concentration of natural uranium of approximately 25 pCi/g was found in a mud sample taken near the Haist property (M9) and in a sample taken in a drainage path (M8) over 2000 m from the center of the Haist site (see Table 1 and Fig. 6). The highest uranium concentration found in the mud samples (32.5 pCi/g) was from a sample (M5) taken near the residues toward the east boundary of the Industrial Park.

The concentration of uranium, radium, and thorium in water samples from Ashland and Seaway and from drainage paths leading to the Niagara River is given in Table 2, which also shows the concentration guide for each isotope considered. Locations at which the samples were collected are shown in Fig. 6. In every water sample, the concentration of each isotope considered was at least an order of magnitude below the CG_w.[4]

Concentrations of Radionuclides in the Soil

Concentrations of radionuclides in soil samples from core holes collected on the site are listed in Table 3; locations are shown in Fig. 5. In Table 3, the part of the sample number preceding the dash gives the location; for example, sample 15-C is from core hole 15. Gamma radiation

levels in core holes are listed as a function of depth in Table 4 for core-hole locations at which no soil samples were taken. These scintillation probe readings are used only to give an approximation of the depth of contamination in the soil.

The average concentration of radium in soil samples taken from section NW was approximately 13 pCi/g. Highest radium concentrations in section NW were found near the surface at location 66 (137 pCi/g) and in a region including locations 47, 48, and 49, where there appears to be tailings extending from the surface to a depth of 4 or 5 ft. The concentration of uranium at location 49 is 0.24% by weight between 3 and 4 ft deep. At location 66, the uranium content near the surface was 0.08% by weight or 2.57 pCi/g. The average concentration of radium in samples taken at depths of 0-4 ft at locations 47, 48, and 49 was about 37 pCi/g.

It appears that most of the residues have been removed from Section M. Radium concentrations in the 50 samples collected from this section averaged approximately 18 pCi/g; however, in hole 42, the soil between a depth of 4 and 5 ft contains 1.2% uranium. Most of these samples were taken from dike 1 which was built using soil from the site. The remaining samples were taken from locations 40, 42, and 43. Some samples from several feet below the surface at locations 40 and 42 showed radium concentrations of 50 to 160 pCi/g.

Radium concentrations in soil samples from section SE averaged approximately 35 pCi/g and were as high as 508 pCi/g. Highest concentrations were in a nearly rectangular area estimated to be about 200 ft

by 50 ft and including locations 1, 2, 3, 4, 6, 18, 19, and 37 (see Figs. 4 and 5). In this same area, the concentration of uranium was found to range from normal terrestrial concentrations to 2900 pCi/g or 0.83% by weight. The depth of contamination ranged to approximately 7 ft. Records indicate that sludges from uranium ore processing were dumped in this area (see Fig. 1). According to soil sample analyses (Table 3) and core-hole loggings (Table 4), at least part of the sludge remains; it is covered by 2 or 3 ft of relatively uncontaminated soil and extends to a depth of 6 to 7 ft in most places. Samples from several other parts of section SE contained over 100 pCi/g radium; these samples were usually taken from depths of 4 to 8 ft. The NFG building is near the edge of a tailings or sludge pile which has been covered with clean fill dirt.

Radium concentrations as high as 259 pCi/g (at location 27 at a depth of 2 to 3 ft) were found near the building.

Radon Emanation

The average radon emanation at the surface near locations at which soil samples were taken can be estimated from data in Tables 3 and 5 and Fig. 13. As an illustration, the radon emanation from a tailings pile containing locations 47, 48, and 49 was estimated. In this area, the contamination is, for the most part, from the surface to a depth of 4 or 5 ft. The average concentration of radium found at locations 47, 48, and 49 at depths of 0 to 4 ft was about 37 pCi/g. Assuming that the tailings are moist for most of the year, it may be seen from Fig. 13 that a 4-ft layer of these tailings would release radon at the rate of

approximately 19 pCi/m^2 per second. If a building were constructed over these tailings, the tailings would probably become reasonably dry and, according to Fig. 13, radon would be released at the rate of approximately 26 pCi/m^2 per second.

As a second example, the average radon emanation from a circular area with its center at location 3 and with a radius of 25 ft was estimated. This area includes locations 1, 2, 3, 4, and 6 (see Fig. 5). The top 2 ft of soil in this area are relatively uncontaminated and appear to be composed mostly of clay. The average radium concentration at a depth of 2-6 ft in the region was about 140 pCi/g. From Fig. 13, 4 ft of moist tailings with this concentration of radium would release radon at the rate of approximately 70 pCi/m^2 per second; and from Table 5, 2 ft of clay topsoil would reduce the radon emanation by about 75%. Hence, radon in this area would emanate at the rate of approximately 18 pCi/m^2 per second. For simplicity, the slight radon contribution from the top 2 ft of soil, which showed only scattered contamination, was neglected.

Figure 13 is based on a differential equation which describes the diffusion of radioactive gases through soils (see, for example, ref. 5). Hence, ideal conditions are assumed. Furthermore, errors are introduced in assumptions regarding soil type, moisture content,[6] uniformity of radium in the soil, and uniformity of the depth of contamination.

At the Middlesex Sampling Plant in Middlesex, New Jersey, actual radon emanation measurements were made,[7] and results were compared with estimates based on Fig. 13. It appears from this comparison that

estimates based on Fig. 13 would be expected to be in error by a factor of 5 or more for some individual locations on the Haist property; however, the average of estimates for several locations is expected to reflect the actual annual average radon emanation rate within a factor of 2.

Conservative estimates of radon emanations from the entire site were made using this same method. The results are shown in Fig. 14, and assumptions regarding each estimate are described in Appendix III. Integrating the radon emanation function (defined by Fig. 14) over the entire site and dividing by the area of the site yields an average of about 7 pCi/m^2 per second for the site. The average world-wide background emanation rate is reported to be 0.43 pCi/m^2 per second.[8] Hence, the radon emanation from the 10-acre site is roughly equivalent to the radon emanation from 150 acres of land which has the natural abundance of radium.

The radon concentration C in the first story of a building which is built on contaminated soil can be estimated from the equation[9]

$$C = \frac{J}{(\lambda_R + \lambda_V)\, h} \quad ,$$

where J is the emanation rate of the radon from the soil, h is the height of the ceiling, $\lambda_R = 2.1 \times 10^{-6}\ s^{-1}$ (the radioactive decay constant for ^{222}Rn), and λ_V is the air exchange rate in the building. It is assumed in the equation that the floor is not a barrier to radon; hence, this is a "worse-case" situation. For floors which act as barriers, the value of J should be adjusted accordingly. For example, as little as

10% of the radon might diffuse through a 2-in. concrete slab;[10] however, radon will diffuse readily through some materials. If we assume that the emanation rate, J, is 7 pCi/m^2 per second (the estimated average for the entire site), that ceiling height, h, is 3 m, and that there is one air exchange per hour in the building, then

$$C = \frac{7\ pCi/m^2\text{-}s}{(2.1 \times 10^{-6}\ s^{-1} + 2.8 \times 10^{-4}\ s^{-1})\ 3\ m}$$

$$\simeq 8.3 \times 10^3\ pCi/m^3 \simeq 8\ pCi/liter.$$

At the rate of one air exchange per hour, 1.0 pCi/liter of radon would produce a radon daughter concentration of approximately 0.005 WL* at steady-state conditions. Hence, a radon emanation rate of 7 pCi/m^2 per second might lead to a radon daughter concentration of about 0.04 WL. The maximum emanation rate on the site was estimated to be about 26 pCi/m^2 per second, assuming that the tailings are dry. If dwellings were to be constructed on the surface in the areas of highest radon emanation, radon daughter concentrations of 0.15 WL or greater could occur in these structures assuming no attenuation of the radon from the building materials. If there were a basement in the building, then significantly higher radon daughter concentrations could occur in the basement.

---

*A working level (WL) is defined as any combination of short-lived radon daughters in one liter of air that will result in the ultimate emission of 1.3×10^5MeV of alpha particle energy.

Radon Daughter Concentration in the NFG Building

The alpha spectroscopy technique revealed a radon daughter concentration of only 0.002 WL in the NFG building. This is well below guidelines[11] for remedial action suggested by the Surgeon General for dwellings in Grand Junction, Colorado, constructed on or with uranium mill tailings.

The NFG building is occupied only a few hours each month and is the only building on the site. It is poorly ventilated and is near (but not on) a tailings pile which is covered with several feet of relatively uncontaminated soil.

SUMMARY

Soil sample analyses indicate that the highest concentrations of radium in the soil are in the southeastern part of the site, near the switchyard (see Fig. 3). Several samples taken from depths of 2 to 6 ft in that area contained 200 to 500 pCi/g of radium. The average radium concentration in soil samples taken from the southeastern third of the site was approximately 35 pCi/g. The radium concentration in samples taken from the northwestern third of the site was generally below 50 pCi/g and averaged about 13 pCi/g; however, contamination in that area is near the surface in many places, and the external gamma radiation levels and the radon emanation rate appear to be higher than in other parts of the site. In the area between the two dikes, much of the residue has been removed, and most of that which remains is covered with several feet of relatively clean soil. The uranium concentration ranged from near the normal terrestrial level to as much as 1.2% by weight

(location 42, section M, 4-5 ft deep). Residual uranium is not distributed evenly, and most of the material can be found to depths of 7 ft in the SE section, original disposal site. The uranium concentration was found to exceed the source material level (0.05% wt as stated in 10 CFR 40) in 18 of the core holes.

Water samples taken on the site and in the drainage paths between the site and the Niagara River showed only low concentrations of uranium, thorium, and radium. In every sample, the concentration of each isotope tested was well below the CG_w for that isotope.

Mud samples taken from the drainage paths between the site and the Niagara River contained between 1.2 and 8.3 pCi/g of radium. The sample containing 8.3 pCi/g was taken at the intersection of two drains, one of these leads from the area on Seaway containing the residue which was deposited there in 1974, and the other leads from the former Haist property and crosses Seaway. It is reasonable to assume that most of the radium at the intersection of the two drains came from the Seaway residue, and it appears that only small amounts of radium are carried more than a few yards from the former Haist property by surface run-off. At present much of the run-off accumulates on Seaway near the boundary of the former Haist property because of incomplete culvert construction.

The highest concentration of uranium in mud samples was 32.5 pCi/g, in a sample taken near the residue on Seaway. In mud samples taken from the drainage paths between the former Haist property and the Niagara River, the highest concentration of uranium was 26 pCi/g, in a sample taken over one-half mile from the Haist property.

The external gamma radiation level on the site varied from the background level up to 190 μR/hr. Highest levels were measured in the northwestern third of the site; in one area covering more than an acre, external gamma radiation measurements averaged approximately 120 μR/hr. The average external gamma radiation reading for the entire site was approximately 33 μR/hr. The average reading in the area between the two dikes was about 23 μR/hr, and the average in the southeastern third of the site was about 17 μR/hr. Outside the perimeter of the site, the external gamma radiation level was near the background level except in spots near the northern boundary, where readings of 30 μR/hr or more were observed.

The National Fuel Gas building, in the northeast corner of the site, is occupied at most a few hours each week. The building is located near the edge of a tailings pile which is covered by two or more feet of earth in most places. Although the building is poorly ventilated, it does not appear that much radon is entering the structure. A spot sample taken in the building revealed a radon daughter concentration of only 0.002 WL. This is well below the Surgeon General's guideline for remedial action for dwellings built on or with uranium tailings; however for a more definite estimate of the annual average radon daughter concentration it would be necessary to sample for six periods throughout the year. Each of these sampling periods should be 100 hr minimum duration and separated by at least 4 weeks.

The residues on the site do not appear to pose any health hazards, assuming that the residues will remain in place and that the site will

continue to be used in the manner in which it is now being used. It is estimated that workers on the site currently receive an integrated dose equivalent from external gamma radiation which is less than 10% of the dose equivalent received from natural background radiation. The radon daughter concentration in the only on the site building is close to background level. Furthermore, only small quantities of radium or uranium are carried from the site in surface run-off. Since the average radon emanation from the site is probably less than 15 times the average world-wide background level, and since the property covers 10 acres, the radon emanation from the site is roughly equivalent to the radon emanation from 150 acres of land at background levels. Being in an industrial area, the population density surrounding the site is very low and thus there are few people at risk. Hence, it appears that there are no distinct health hazards which result from atmospheric transport of radon from the site.

On the other hand, potential health hazards could result from some uses of the site and the residues. For example, if a building were to be built on some parts of the property, radon concentrations of 0.15 WL or more could occur in the building. Furthermore, exposure for 40 hr per week to the highest gamma radiation level measured on the site would result in an integrated dose equivalent of roughly 4 times the dose equivalent which an average individual in the United States receives from natural background radiation. Finally, if the residues should be removed from the site for use near dwellings, potential health hazards could result from external gamma radiation, ingestion of radioactive material, and inhalation of radon daughters in the dwellings.

REFERENCES

1. Health and Safety Laboratory Report of Haist Property to General Services Administration, 1958.
2. F. F. Dyer, J. F. Emery, and G. W. Leddicotte, Comprehensive Study of the Neutron Activation Analysis of Uranium by Delayed Neutron Counting, ORNL-3342 (October 1962).
3. G. D. Kerr, Measurement of Radon Progeny Concentrations in Air by Alpha-Particle Spectroscopy, ORNL-TM-4924 (1975).
4. Energy Research and Development Administration, ERDA Manual Chapter 0524, Part I, C., p. 2 (April 8, 1975).
5. M. V. J. Culot, H. G. Olson, and K. J. Schiager, Radon Progeny Control in Buildings, COO-2273-1, Colorado State University, Fort Collins (May 1973).
6. J. A. Auxier, "Respiratory Exposure in Buildings Due to Radon Progeny," *Health Phys.* 31, 119-25 (1976).
7. H. W. Dickson, R. W. Leggett, F. F. Haywood, W. A. Goldsmith, W. D. Cottrell, and W. F. Fox, Radiological Survey of the Middlesex Sampling Plant, Middlesex, New Jersey, DOE/EV-0005/1, (November 1977).
8. M. H. Wilkening, W. E. Clements, and D. Stanley, "Radon-222 Flux Measurements in Widely Separated Regions," pp. 717-30 of The Natural Radiation Environment II, CONF-720805-P2 (1972).
9. W. A. Goldsmith, F. F. Haywood, and D. G. Jacobs, "Guidelines for Cleanup of Uranium Tailings from Inactive Mills," Proceedings

REFERENCES (continued)

of the Ninth Annual Health Physics Society Topical Symposium, 735-41 (1976).

10. K. J. Schiager, "Analysis of Exposures on or near Uranium Mill Tailings Piles," Radiat. Data and Rep. 15, 411-25 (1974).

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

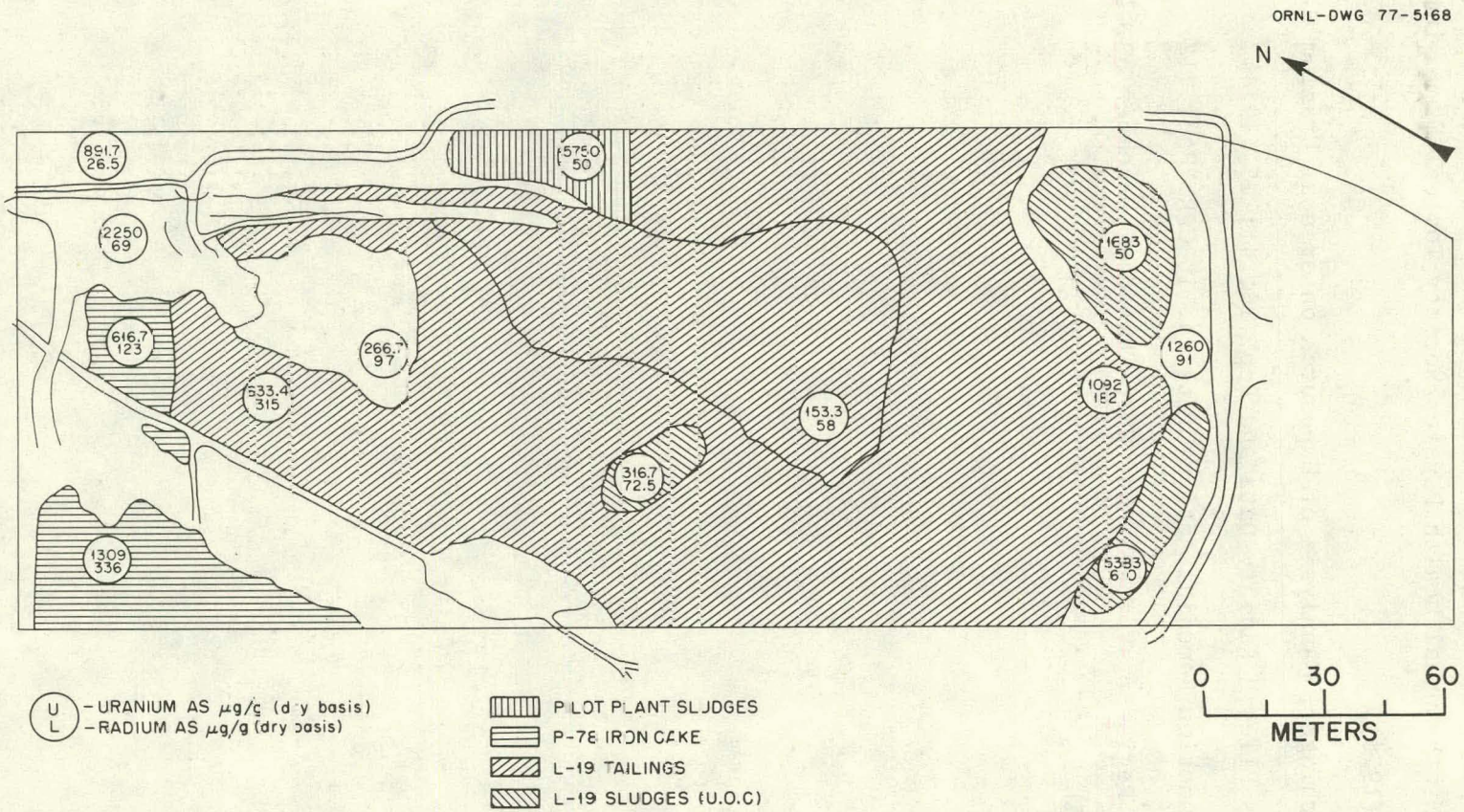

Fig. 1. Approximate distribution of tailings on Haist property in 1958. Source: Health and Safety Laboratory Report on Haist Property to General Services Administration, 1958.

Fig. 2. Aerial view of Ashland and surrounding area.

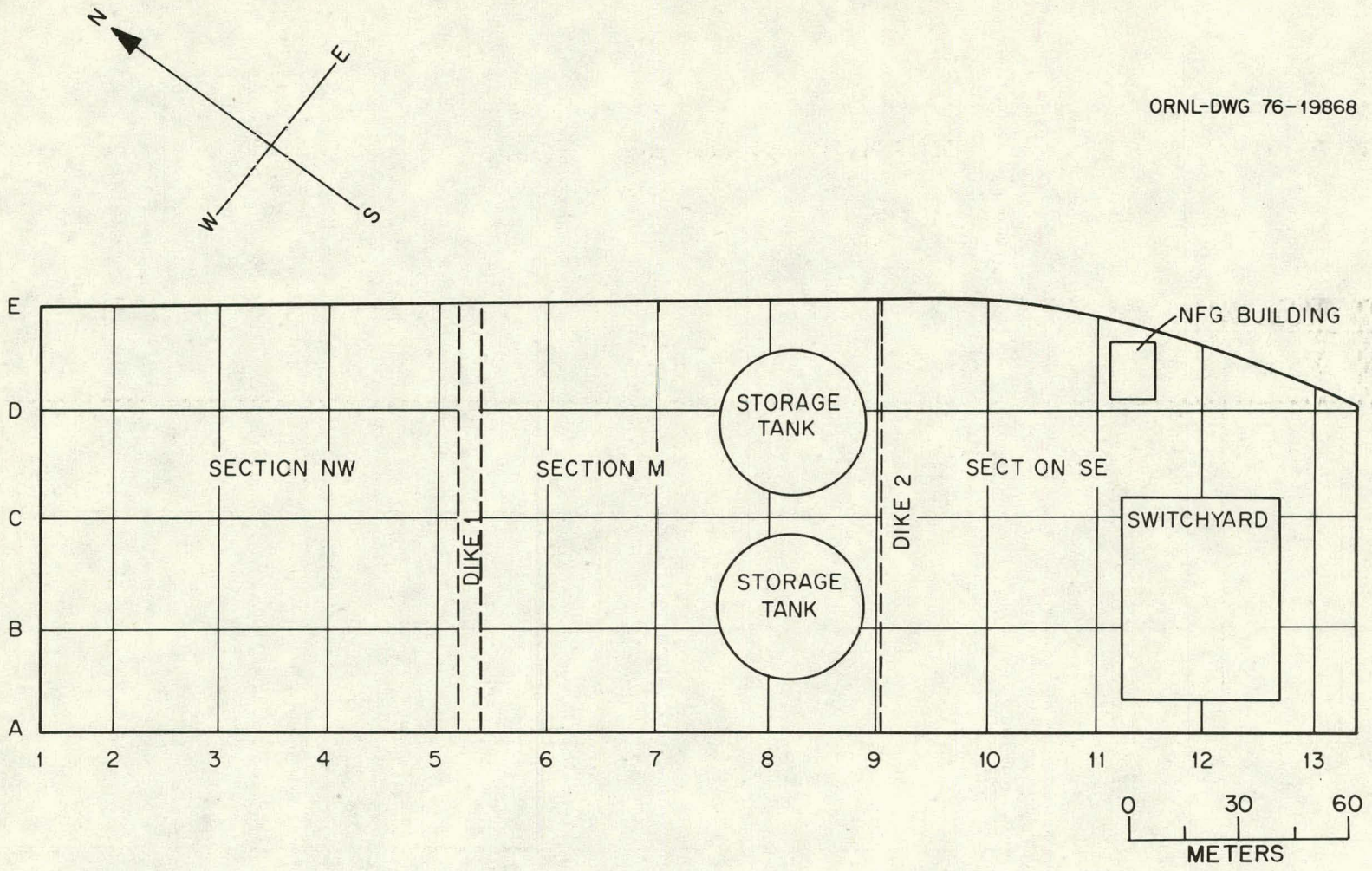

Fig. 3. Grid points and landmarks.

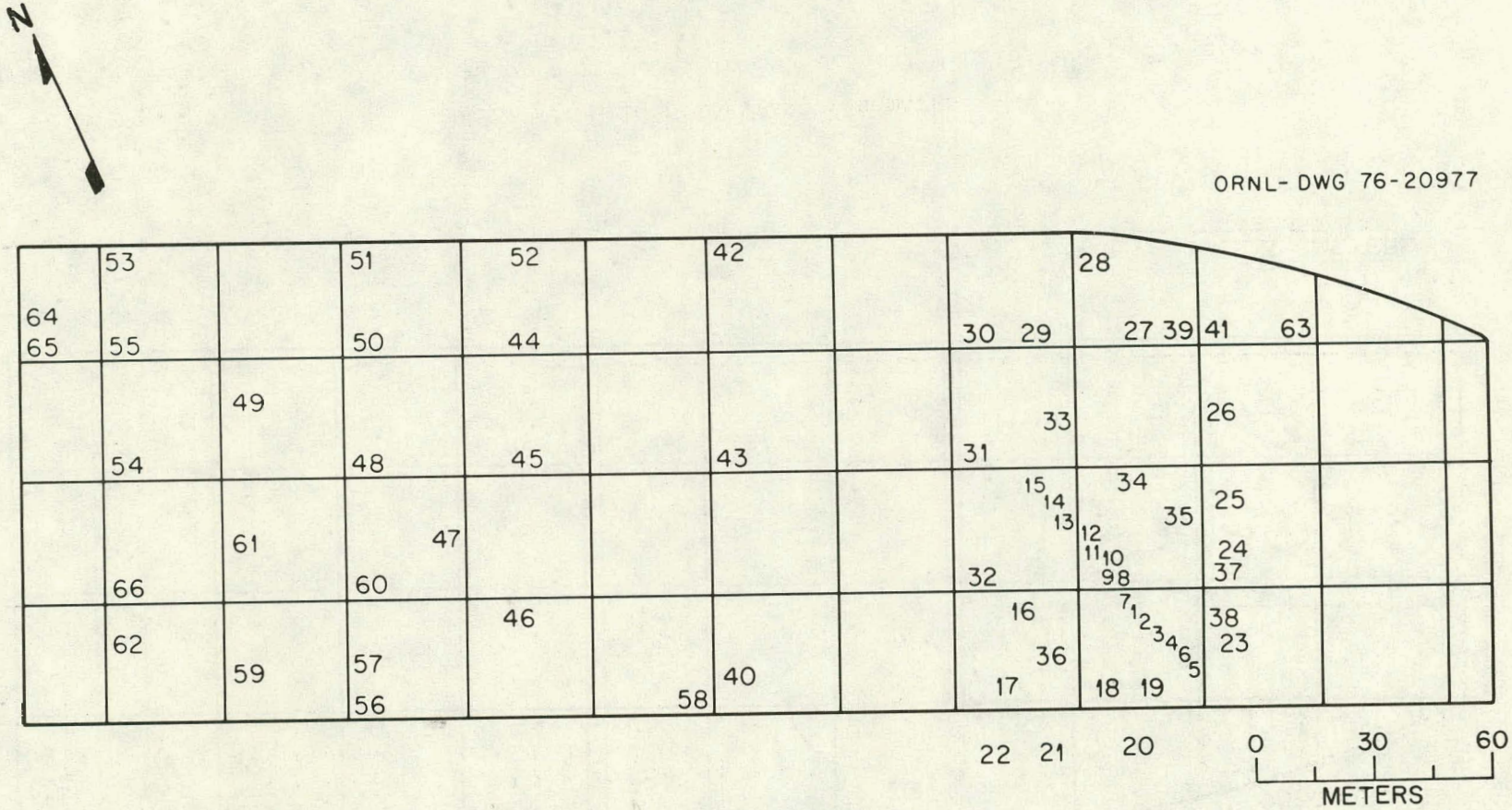

Fig. 4. Locations of core holes.

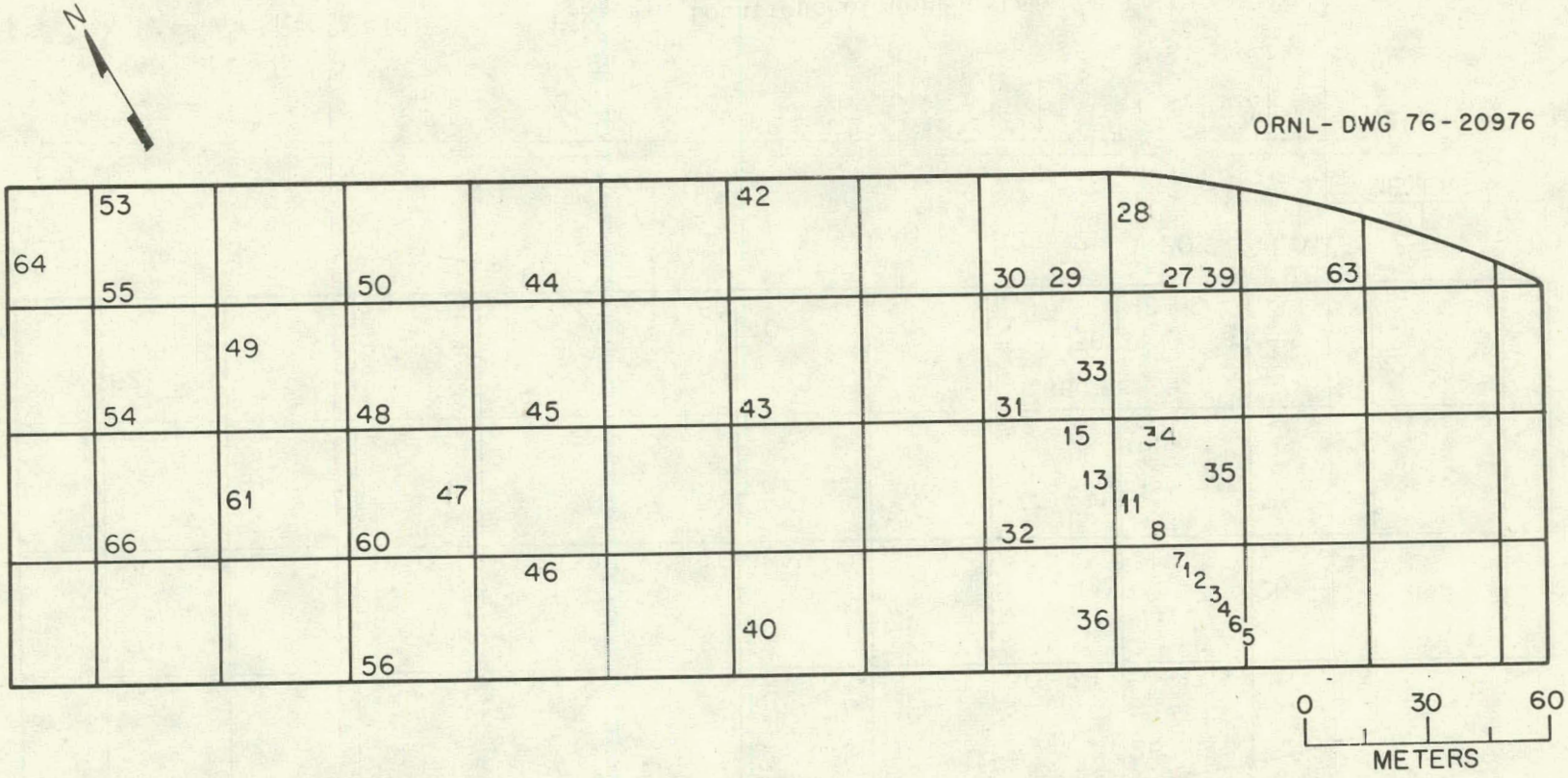

Fig. 5. Locations of core holes for which soil samples were collected.

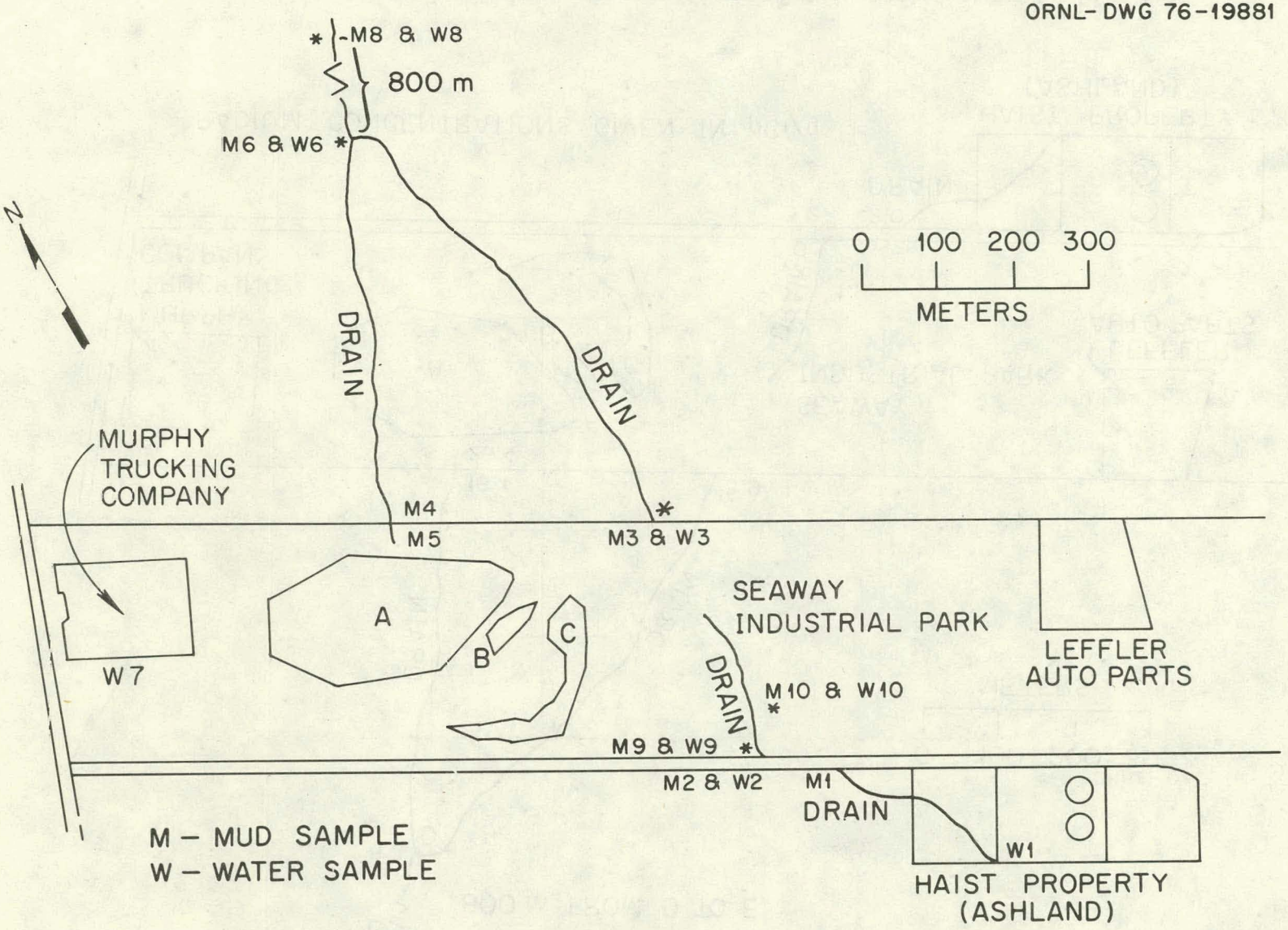

Fig. 6. Locations of water and mud samples.

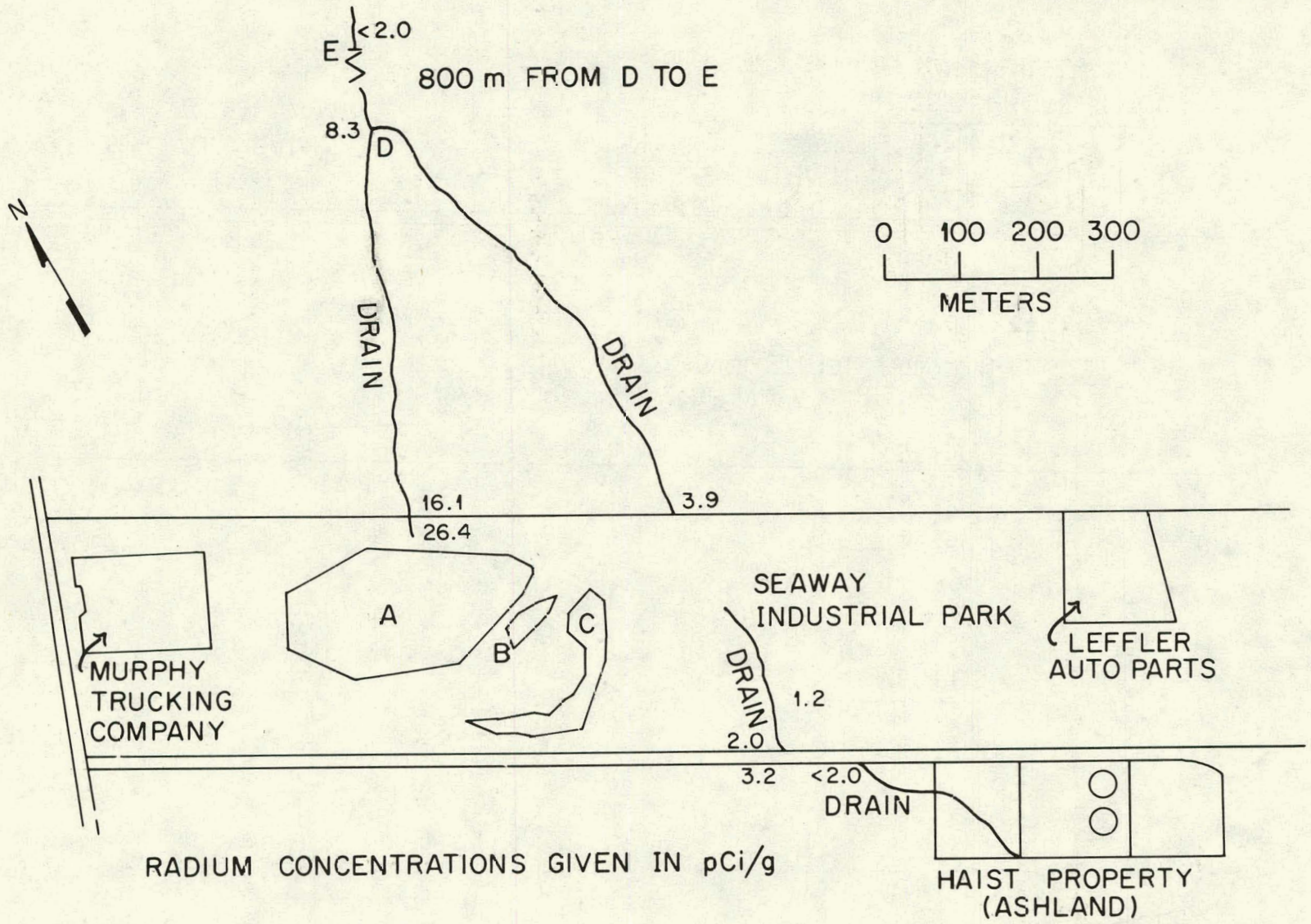

Fig. 7. Radium concentrations of mud samples shown in Fig. 6.

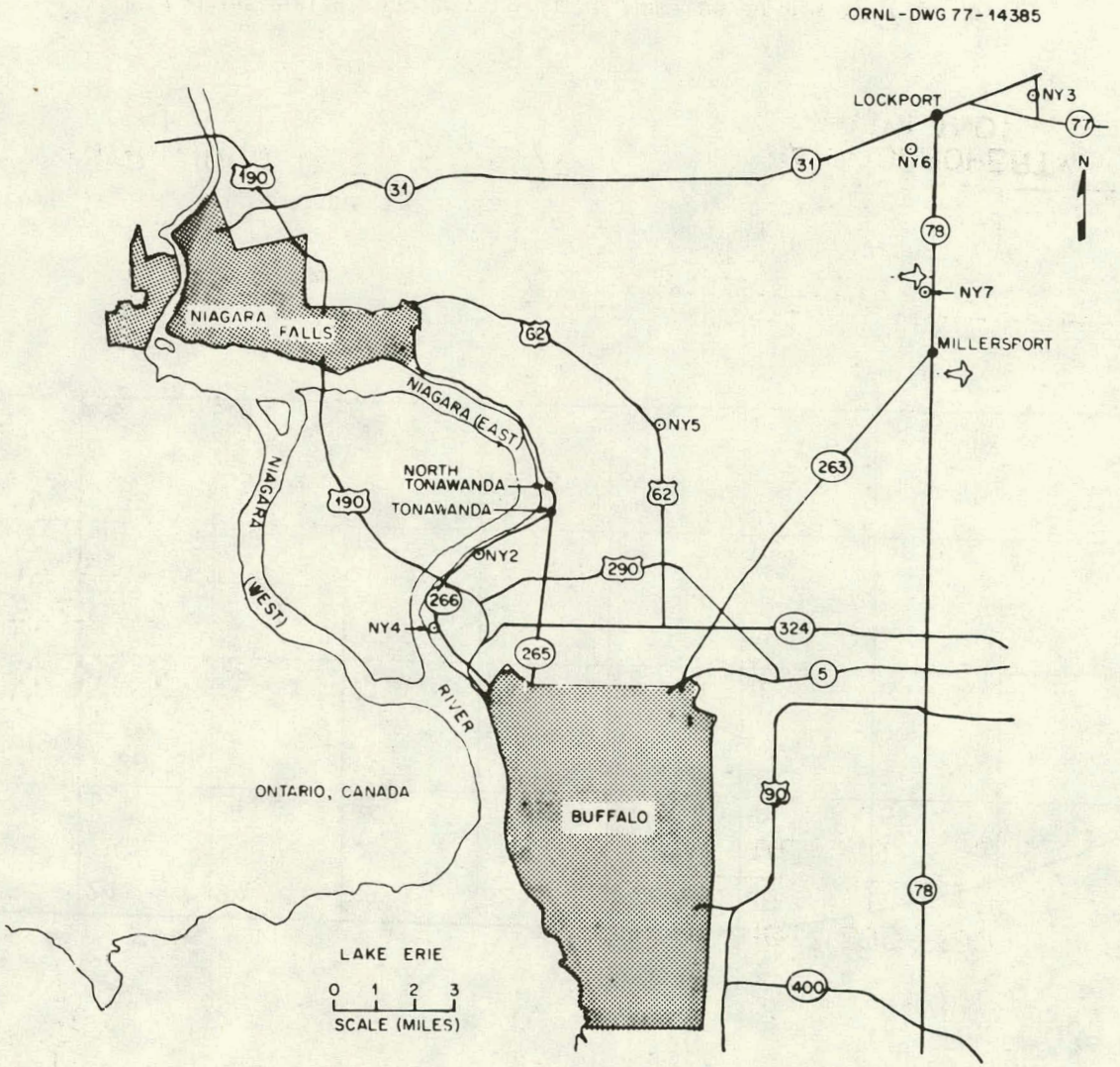

Fig. 8. Locations of background soil samples (NY-2 through NY-7) collected in the vicinity of Tonawanda, New York.

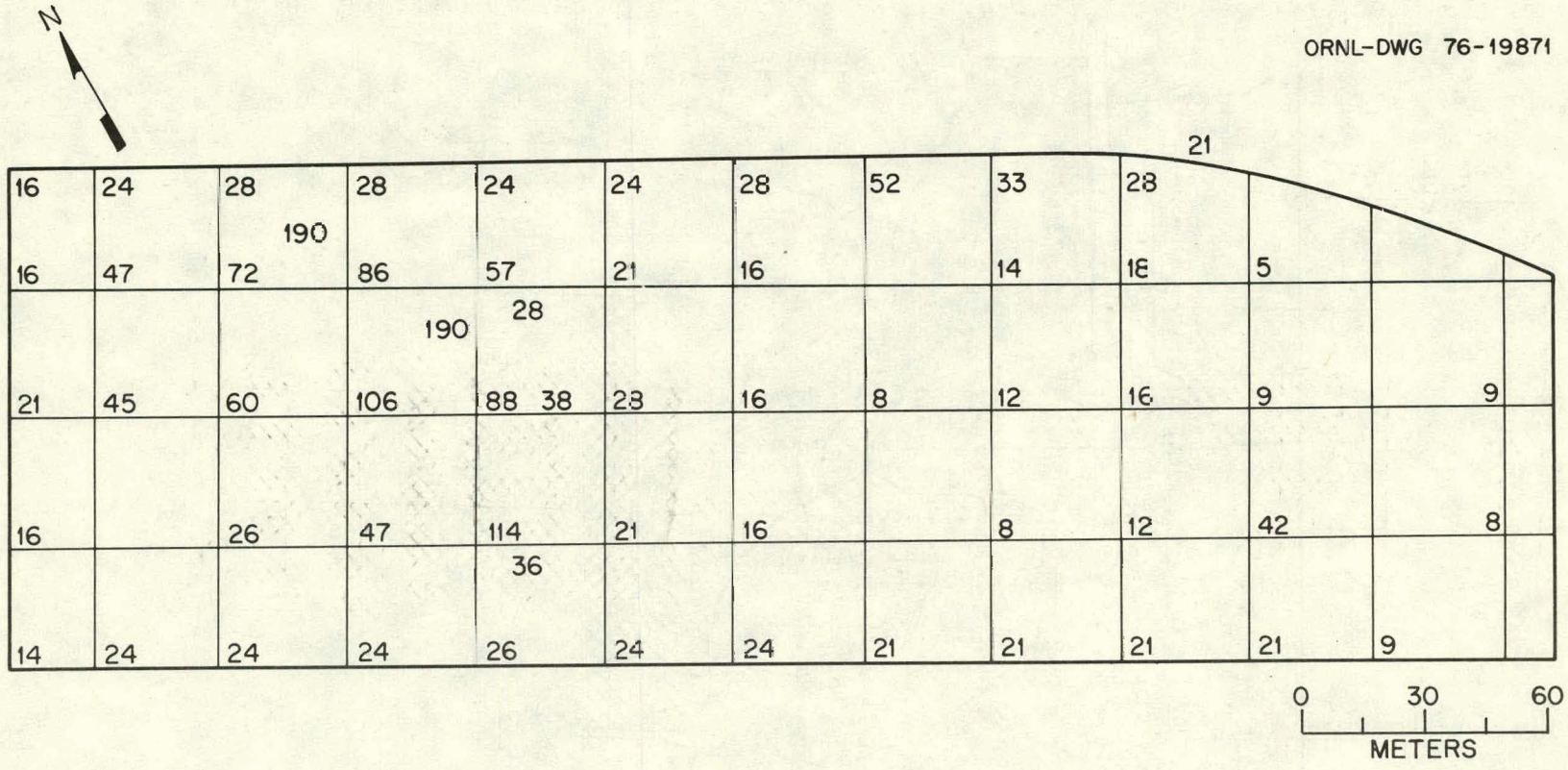

Fig. 9. External gamma radiation (in μR/hr) at 1 m above surface.

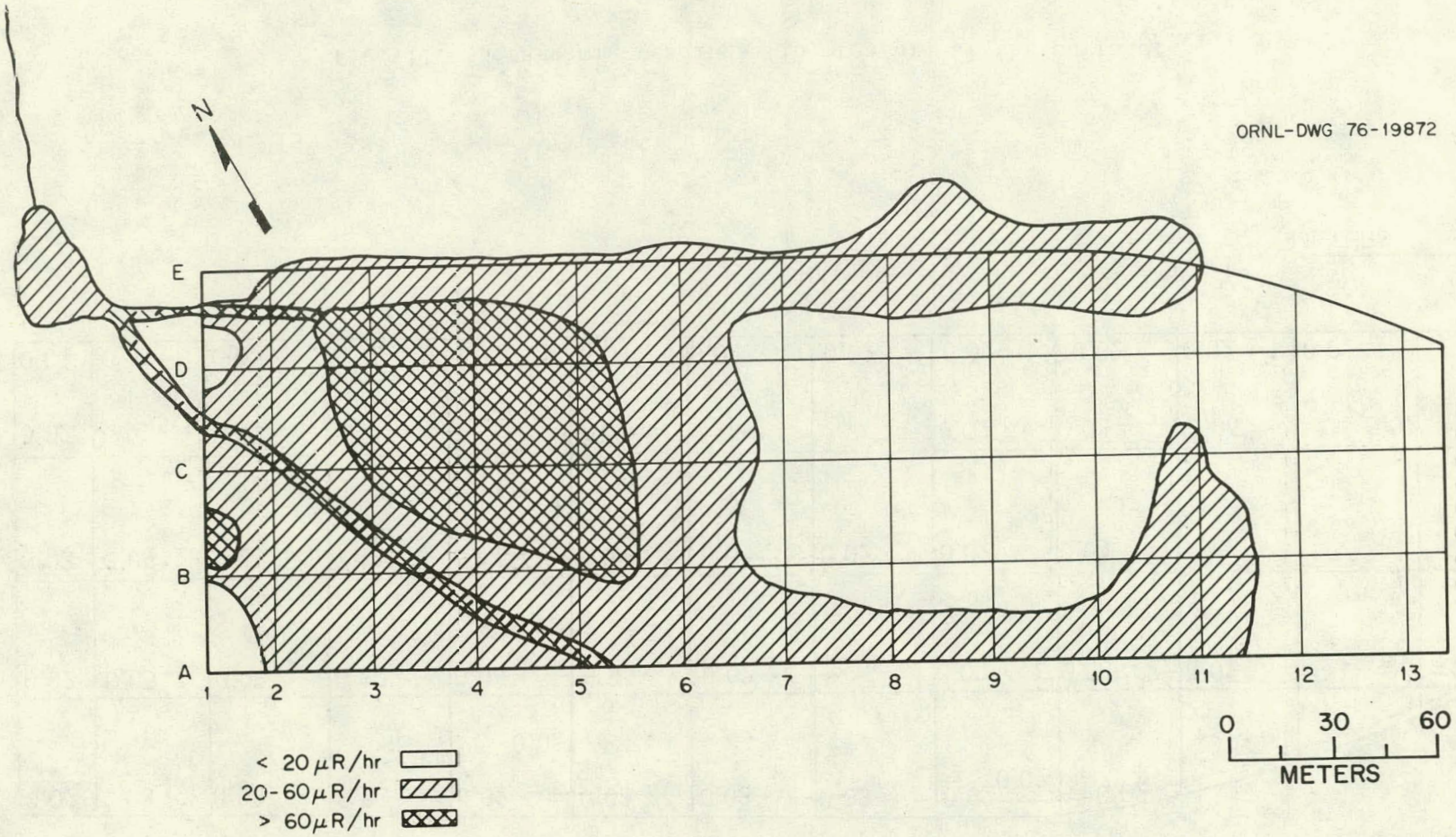

Fig. 10. External gamma radiation profile of the former Haist property and adjacent areas.

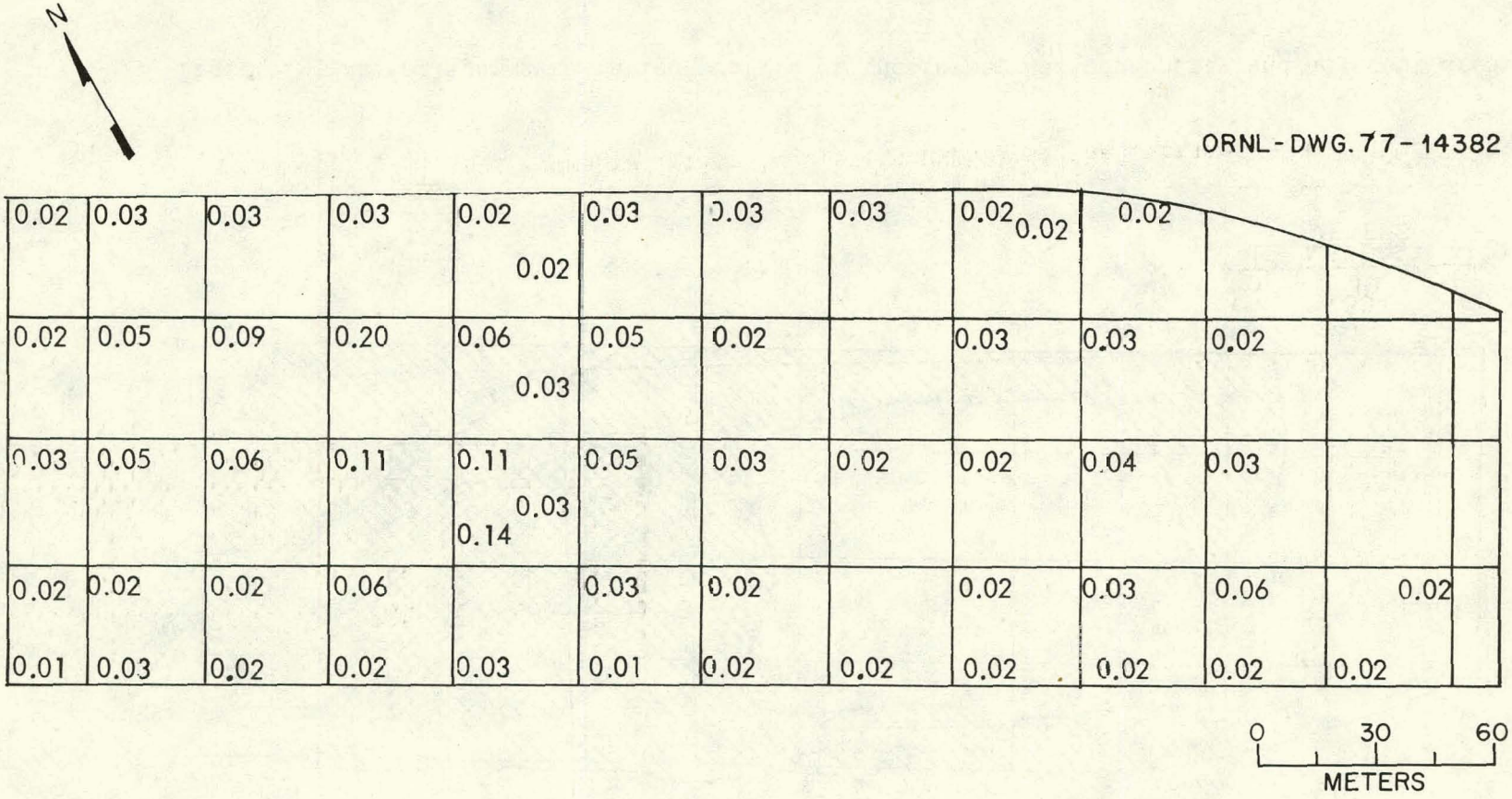

Fig. 11. Beta-gamma readings (in mrad/hr) at the surface.

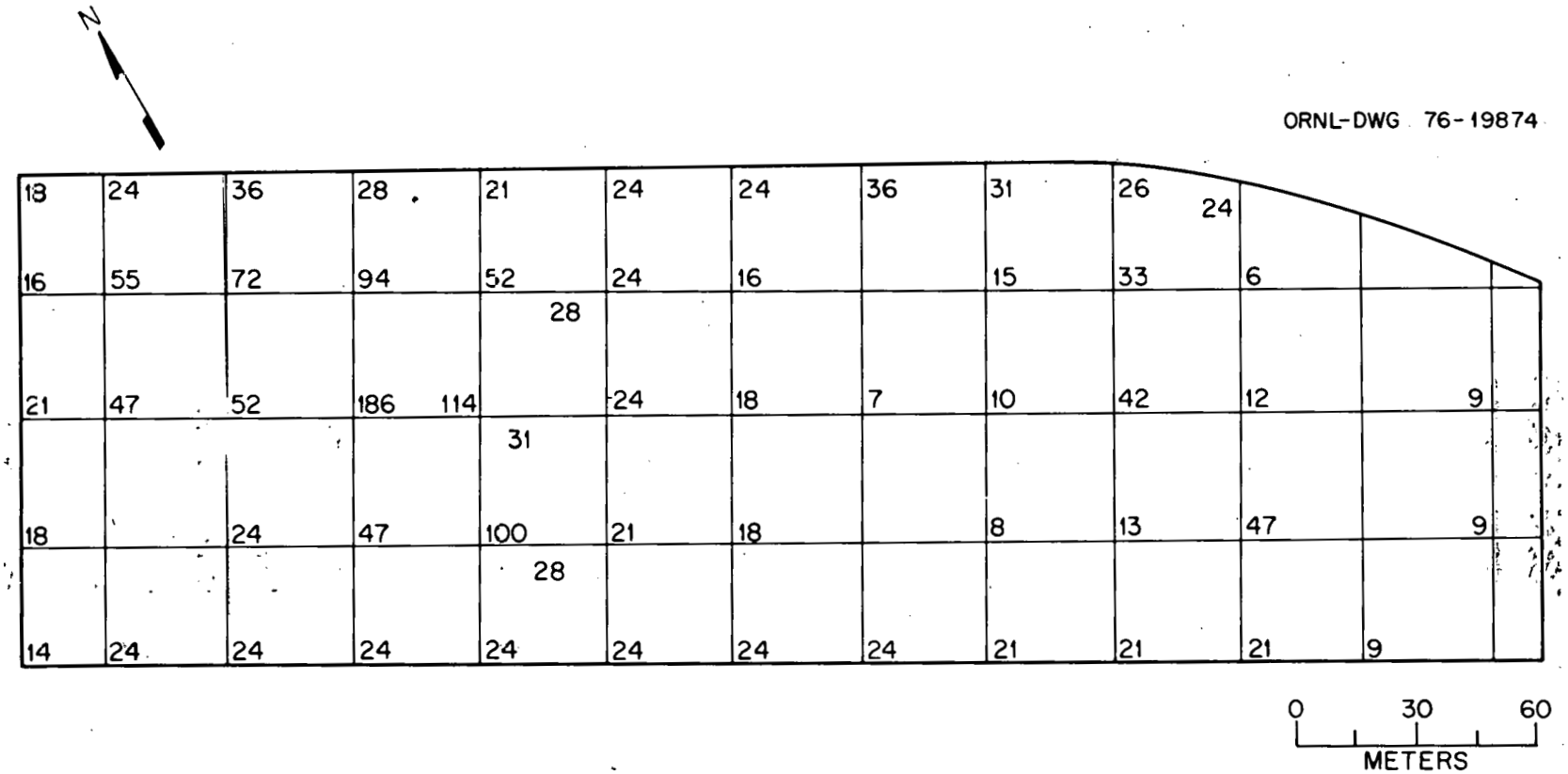

Fig. 12. External gamma radiation levels (in μR/hr) at the surface.

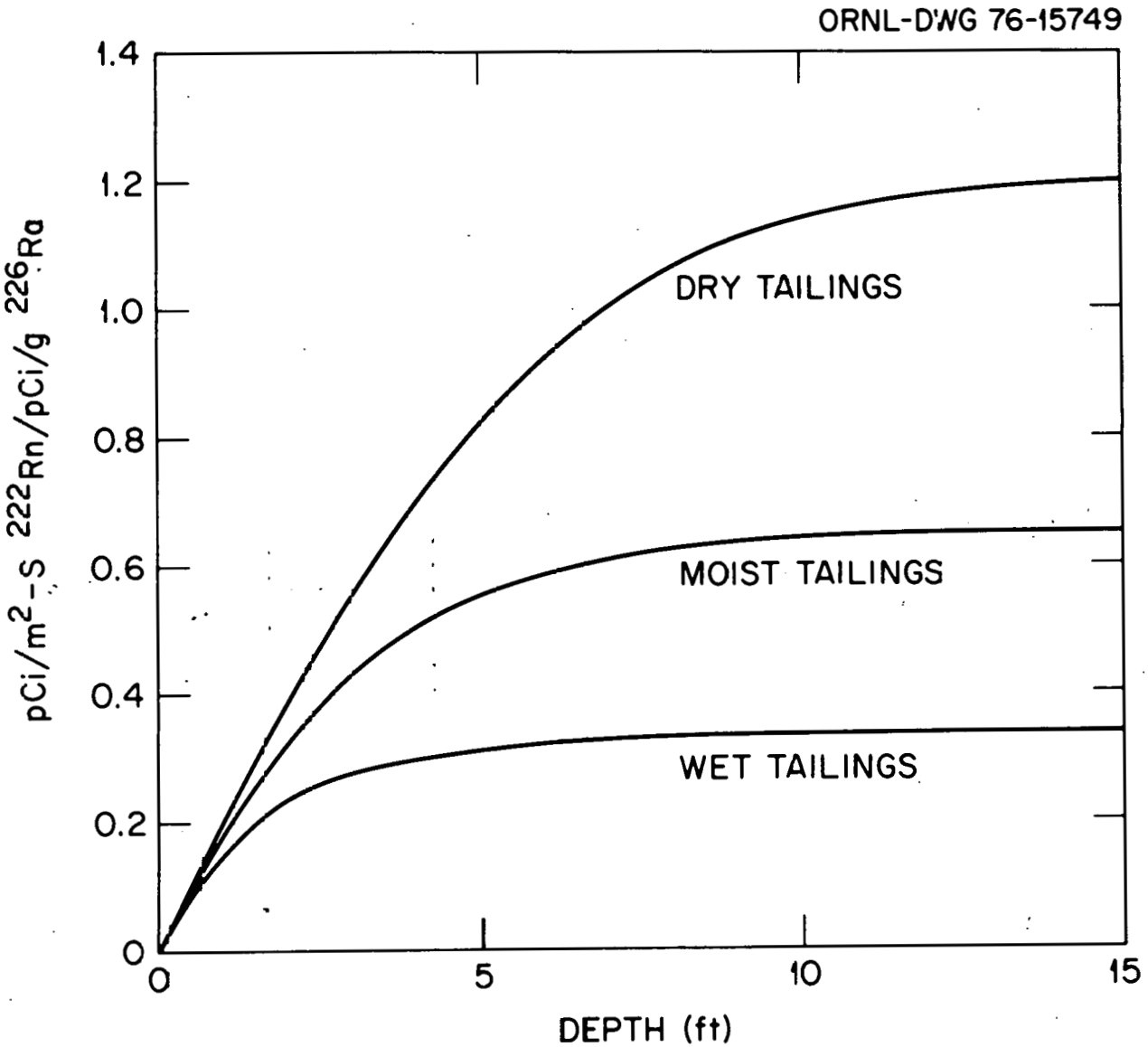

Fig. 13. Relationship of radium concentration and radon emanation.

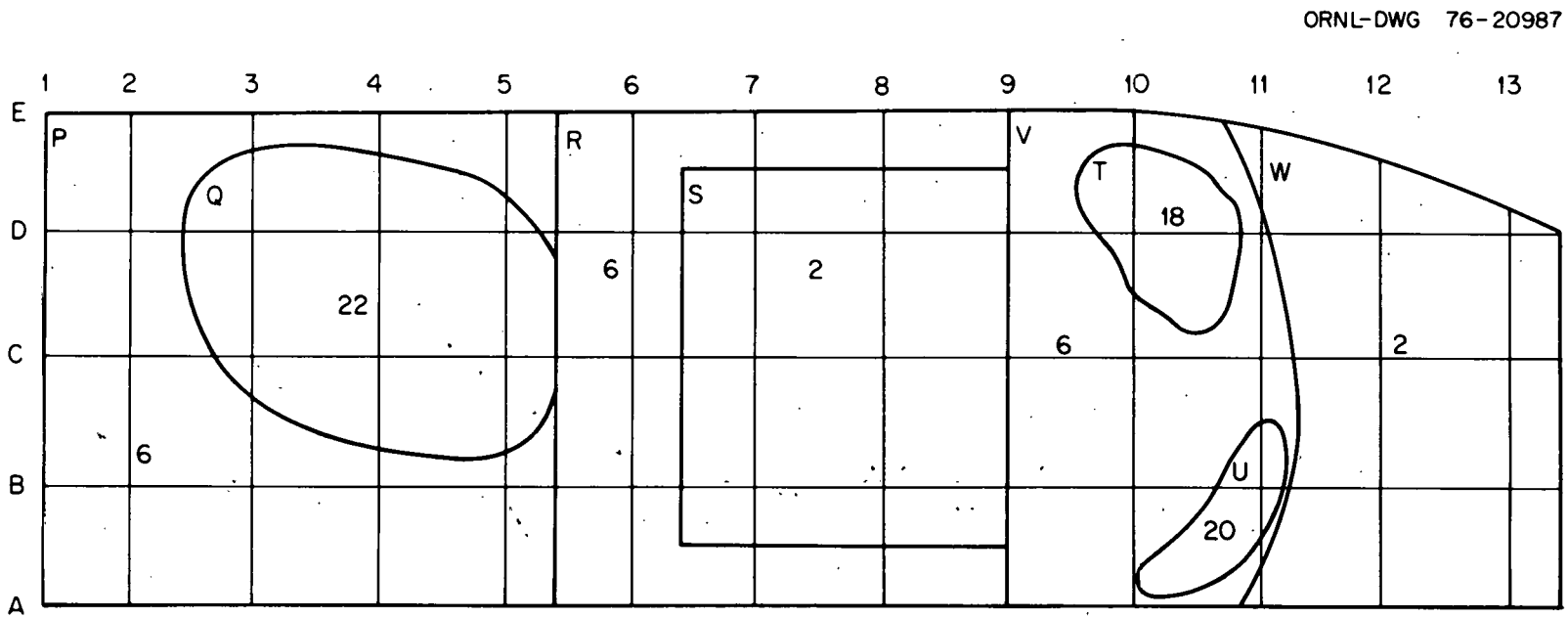

Fig. 14. Estimates for radon emanations (in pCi/m^2-s) from the soil.

Table 1. Concentrations of ^{238}U in mud samples

Samples[a]	pCi/g
M1	3.9
M2	11.0
M3	3.0
M4	19.8
M5	32.5
M6	15.4
M8	26.0
M9	24.7
M10	1.4

[a]See Fig. 6.

Table 2. Radionuclide concentrations in water samples (measurements given in pCi/ml)

Sample	^{226}Ra	^{234}U	^{235}U	^{238}U	^{228}Th	^{230}Th	^{232}Th
W1	4.0×10^{-4}	2.8×10^{-2}	1.5×10^{-3}	2.8×10^{-2}	3.9×10^{-4}	1.8×10^{-4}	7.2×10^{-5}
W2	1.0×10^{-3}	2.0×10^{-2}	1.0×10^{-3}	2.0×10^{-2}	3.7×10^{-4}	9.0×10^{-5}	$\leq 4.0\times10^{-5}$
W3	6.3×10^{-4}	4.1×10^{-3}	3.4×10^{-4}	4.2×10^{-3}	3.6×10^{-4}	7.6×10^{-5}	1.1×10^{-4}
W6	1.6×10^{-3}	4.1×10^{-2}	1.3×10^{-2}	5.3×10^{-2}	3.2×10^{-4}	9.0×10^{-4}	6.8×10^{-5}
W7	9.0×10^{-4}	1.0×10^{-2}	4.4×10^{-4}	1.0×10^{-2}	3.0×10^{-4}	1.4×10^{-4}	$\leq 3.0\times10^{-5}$
W8	5.8×10^{-4}	4.0×10^{-2}	1.4×10^{-3}	3.9×10^{-2}	3.7×10^{-4}	1.1×10^{-4}	4.1×10^{-5}
W9	8.0×10^{-4}	5.0×10^{-2}	2.1×10^{-3}	5.0×10^{-2}	3.2×10^{-4}	8.6×10^{-5}	$\leq 3.0\times10^{-5}$
W10	1.1×10^{-3}	1.4×10^{-2}	7.6×10^{-4}	1.1×10^{-2}	3.2×10^{-4}	7.2×10^{-5}	$\leq 3.0\times10^{-5}$
CG_w (Soluble)	3×10^{-2}	30	30	40	7	2	2

Table 3. Concentration of ^{226}Ra, ^{232}Th, ^{238}U, ^{227}Ac, and ^{40}K in core hole samples

Sample	Depth (ft)	^{226}Ra (pCi/g)	^{232}Th (pCi/g)	^{238}U (pCi/g)	^{227}Ac (pCi/g)	^{40}K (pCi/g)
1A	0 - 0.5	1.3	ND[a]	ND	ND	ND
1B	0.5 - 1.5	1.0	1.0	2.5	ND	12
1C	1.5 - 2.5	1.4	ND	ND	ND	ND
1D	2.5 - 3.5	15	ND	ND	ND	ND
1E	3.5 - 5.0	55	6.6	890	130	ND
1F	5.0 - 6.0	130	ND	ND	ND	ND
1G	6.0 - 7.0	82	ND	ND	ND	ND
2A	0 - 1.0	1.2	0.8	2.9	0.5	11
2B	1.0 - 2.0	1.3	0.9	ND	1.5	16
2C	2.0 - 3.0	140	ND	ND	ND	ND
2D	3.0 - 4.0	280	6.8	2,100	120	ND
2E	4.0 - 5.0	100	ND	ND	ND	ND
2F	5.0 - 6.0	130	ND	ND	ND	ND
2G	6.0 - 7.0	81	ND	ND	ND	ND
3A	0 - 1.0	3.2	0.9	ND	<0.1	11
3B	1.0 - 2.0	1.5	0.7	ND	ND	15
3C	2.0 - 3.0	16	1.2	44	ND	18
3D	3.0 - 4.0	100	5.8	710	120	ND
3E	4.0 - 5.0	21	ND	130	ND	23
3F	5.0 - 6.0	50	ND	150	0.5	19
3G	6.0 - 7.0	5.0	1.0	20	1.7	21
3H	7.0 - 8.0	1.0	ND	ND	ND	ND
4A	0 - 1.0	1.7	0.8	ND	ND	44
4B	1.0 - 2.0	1.7	0.9	3.3	ND	ND
4C	2.0 - 3.0	210	ND	ND	0.1	ND
4D	3.0 - 4.0	210	ND	230	ND	ND
4E	4.0 - 5.0	180	ND	1,200	ND	ND
4F	5.0 - 6.0	530	55	2,900	1,500	ND
4G	6.0 - 7.0	3.6	1.5	40	3.5	21
4H	7.0 - 8.0	1.0	1.1	26	0.4	19
5A	0 - 1.0	1.5	0.7	2.6	0.6	4.0
5B	1.0 - 2.0	1.4	1.0	2.4	ND	17
5C	2.0 - 3.0	1.5	0.9	ND	ND	20
5D	3.0 - 4.0	1.9	ND	ND	2.3	21
5E	4.0 - 5.0	1.7	1.1	4.4	ND	21
5F	5.0 - 6.0	1.3	1.0	ND	ND	23
5G	6.0 - 7.0	1.7	0.9	ND	ND	20
6A	0 - 1.0	1.7	0.8	ND	ND	ND
6B	1.0 - 2.0	6.5	0.8	28	11	16
6C	2.0 - 3.0	9.2	1.2	21	ND	20
6D	3.0 - 4.0	86	ND	ND	ND	ND
6E	4.0 - 5.0	220	12	1,100	390	ND
6F	5.0 - 6.0	160	10	820	260	ND
6G	6.0 - 7.0	13	ND	ND	0.2	ND
6H	7.0 - 8.0	1.2	1.0	13	0.6	21

Table 3. (cont'd.) Concentration of ^{226}Ra, ^{232}Th, ^{238}U, ^{227}Ac, and ^{40}K in core hole samples

Sample	Depth (ft)	^{226}Ra (pCi/g)	^{232}Th (pCi/g)	^{238}U (pCi/g)	^{227}Ac (pCi/g)	^{40}K (pCi/g)
7A	0 - 1.0	1.6	0.3	6.8	ND	17
7B	1.0 - 2.0	--	--	--	--	--
7C	2.0 - 3.0	1.5	0.9	4.4	2.3	11
7D	3.0 - 4.0	4.5	0.9	ND	0.1	17
7E	4.0 - 5.0	13	ND	ND	ND	ND
7F	5.0 - 6.0	19	1.2	58	30	18
7G	6.0 - 7.0	23	ND	85	33	16
7H	7.0 - 8.0	1.2	1.0	11	ND	23
8A	0 - 1.0	3.9	1.6	6.5	4.2	ND
8B	1.0 - 2.0	1.8	0.9	ND	ND	16
8C	2.0 - 3.0	1.5	1.1	ND	ND	16
8D	3.0 - 4.0	30	2.9	170	45	ND
8E	4.0 - 5.0	90	4.4	370	160	ND
8F	5.0 - 6.0	29	ND	170	52	14
8G	6.0 - 7.0	0.9	ND	ND	ND	ND
11A	0 - 1.0	2.0	ND	ND	ND	ND
11B	1.0 - 2.0	2.2	ND	ND	ND	ND
11C	2.0 - 3.0	1.4	1.0	2.3	ND	16
11D	3.0 - 4.0	2.3	0.7	ND	ND	14
11E	4.0 - 5.0	23	1.2	7.3	31	15
11F	5.0 - 6.0	25	4.7	38	ND	16
11G	6.0 - 7.0	3.7	ND	ND	ND	ND
11H	7.0 - 8.0	1.2	ND	13	ND	19
11I	8.0 - 9.0	6.4	0.9	27	ND	18
11J	9.0 - 10.0	1.0	0.9	ND	ND	21
13A	0 - 1.0	1.3	ND	ND	ND	ND
13B	1.0 - 2.0	1.6	1.1	3.1	ND	15
13C	2.0 - 3.0	0.8	0.9	1.5	ND	17
13D	3.0 - 4.0	2.4	ND	ND	ND	ND
13E	4.0 - 5.0	83	5.5	210	ND	ND
13F	5.0 - 6.0	64	ND	ND	ND	ND
13G	6.0 - 7.0	45	3.7	150	87	ND
13H	7.0 - 8.0	2.2	ND	ND	ND	ND
13I	8.0 - 9.0	1.7	ND	ND	ND	ND
13J	9.0 - 10.0	0.9	0.9	25	ND	18
15A	0 - 1.0	1.2	1.1	2.8	ND	18
15B	1.0 - 2.0	1.1	0.7	ND	ND	14
15C	2.0 - 3.0	2.1	1.1	ND	ND	17
15D	3.0 - 4.0	150	7.9	370	120	ND
15E	4.0 - 5.0	72	ND	ND	ND	ND
15F	5.0 - 6.0	25	ND	ND	ND	ND
15G	6.0 - 7.0	72	ND	ND	ND	ND
15H	7.0 - 8.0	3.5	ND	ND	ND	20
15I	8.0 - 9.0	1.0	ND	ND	ND	ND
15J	9.0 - 10.0	1.1	ND	ND	ND	ND

Table 3. (cont'd.) Concentration of ^{226}Ra, ^{232}Th, ^{238}U, ^{227}Ac, and ^{40}K in core hole samples

Sample	Depth (ft)	^{226}Ra (pCi/g)	^{232}Th (pCi/g)	^{238}U (pCi/g)	^{227}Ac (pCi/g)	^{40}K (pCi/g)
27A	0 - 1.0	1.7	1.1	20	ND	17
27B	1.0 - 2.0	2.6	1.0	6.5	2.4	21
27C	2.0 - 3.0	79	ND	ND	ND	ND
27D	3.0 - 4.0	260	ND	ND	ND	ND
27E	4.0 - 5.0	73	ND	510	66	17
27F	5.0 - 6.0	120	ND	ND	ND	ND
27G	6.0 - 7.0	100	ND	550	91	13
27H	7.0 - 8.0	1.4	1.0	14	ND	21
27I	8.0 - 9.0	1.3	1.0	ND	ND	21
27J	9.0 - 10.0	1.0	1.0	2.4	ND	21
28A	0 - 1.0	2.2	1.0	ND	ND	ND
28B	1.0 - 2.0	1.6	1.0	5.4	ND	19
28C	2.0 - 3.0	1.0	1.1	ND	ND	20
28D	3.0 - 4.0	1.0	1.0	ND	ND	20
28E	4.0 - 5.0	1.0	ND	ND	ND	ND
28F	5.0 - 6.0	29.0	ND	68	49	18
28G	6.0 - 7.0	42	1.2	89	ND	ND
28H	7.0 - 8.0	4.6	ND	ND	ND	ND
28I	8.0 - 9.0	1.6	1.1	10	ND	22
28J	9.0 - 10.0	1.0	1.0	ND	ND	20
29A	0 - 1.0	2.1	0.9	7.4	ND	19
29B	1.0 - 2.0	1.2	0.7	ND	ND	16
29C	2.0 - 3.0	2.0	ND	ND	ND	ND
29D	3.0 - 4.0	37	ND	70	50	17
29E	4.0 - 5.0	40	ND	ND	ND	ND
29F	5.0 - 6.0	1.0	1.1	5.4	ND	19
29G	6.0 - 7.0	1.4	ND	ND	ND	ND
29H	7.0 - 8.0	1.2	1.0	ND	ND	20
30A	0 - 1.0	1.8	ND	ND	ND	ND
30B	1.0 - 2.0	2.2	ND	ND	ND	ND
30C	2.0 - 3.0	9.0	1.0	21	3.4	19
30D	3.0 - 4.0	1.4	ND	ND	ND	ND
30E	4.0 - 5.0	71	3.9	210	92	ND
30F	5.0 - 6.0	143	8.2	230	190	ND
30G	6.0 - 7.0	42	ND	100	ND	17
30H	7.0 - 8.0	2.0	1.0	11	1.3	19
31A	0 - 1.0	1.9	1.0	3.6	ND	17
31B	1.0 - 2.0	2.3	0.8	ND	4.5	16
31C	2.0 - 3.0	1.3	1.0	ND	ND	16
31D	3.0 - 4.0	1.3	ND	ND	ND	ND
31E	4.0 - 5.0	24	1.1	32	20	13
31F	5.0 - 6.0	160	5.4	200	122	ND
31G	6.0 - 7.0	31	2.4	81	31	16
31H	7.0 - 8.0	3.0	ND	ND	ND	ND
31I	8.0 - 9.0	1.1	1.0	2.6	ND	20
31J	9.0 - 10.0	1.0	0.9	1.4	ND	21

Table 3. (cont'd.) Concentration of ^{226}Ra, ^{232}Th, ^{238}U, ^{227}Ac, and ^{40}K in core hole samples

Sample	Depth (ft)	^{226}Ra (pCi/g)	^{232}Th (pCi/g)	^{238}U (pCi/g)	^{227}Ac (pCi/g)	^{40}K (pCi/g)
32A	0 - 1.0	1.4	0.9	ND	ND	20
32B	1.0 - 2.0	1.0	0.9	2.4	ND	ND
32C	2.0 - 3.0	1.7	0.9	ND	ND	ND
32D	3.0 - 4.0	1.5	ND	ND	ND	ND
32E	4.0 - 5.0	1.5	1.1	ND	ND	18
32F	5.0 - 6.0	2.7	0.9	1.5	ND	11
32G	6.0 - 7.0	20	ND	ND	ND	ND
32H	7.0 - 8.0	160	5.7	200	100	ND
32I	8.0 - 9.0	130	ND	210	81	ND
32J	9.0 - 10.0	2.7	1.1	ND	ND	21
32K	10.0 - 11.0	11	ND	ND	ND	ND
32L	11.0 - 12.0	1.6	ND	ND	ND	ND
33A	0 - 1.0	1.0	0.9	2.0	ND	16
33C	2.0 - 3.0	76	ND	ND	ND	ND
33D	3.0 - 4.0	58	5.0	290	100	ND
33E	4.0 - 5.0	39	ND	ND	ND	ND
33F	5.0 - 6.0	5.7	ND	ND	ND	ND
33G	6.0 - 7.0	1.3	1.0	6.7	0.7	ND
33H	7.0 - 8.0	1.1	ND	ND	ND	ND
34A	0 - 1.0	1.4	1.2	8.1	0.5	15
34B	1.0 - 2.0	1.4	ND	ND	ND	ND
34C	2.0 - 3.0	1.6	0.9	4.3	ND	20
34D	3.0 - 4.0	52	ND	120	94	14
34E	4.0 - 5.0	110	ND	ND	ND	ND
34F	5.0 - 6.0	21	0.6	ND	31	ND
34G	6.0 - 7.0	7.0	ND	32	11	21
34H	7.0 - 8.0	1.0	ND	ND	ND	ND
35A	0 - 1.0	1.5	ND	ND	ND	ND
35C	2.0 - 3.0	9.3	ND	ND	ND	ND
35D	3.0 - 4.0	1.5	ND	ND	ND	ND
35E	4.0 - 5.0	11	ND	ND	ND	ND
35F	5.0 - 6.0	92	7.6	330	160	ND
35G	6.0 - 7.0	1.2	1.0	ND	ND	21
35H	7.0 - 8.0	9.1	ND	ND	ND	ND
36A	0 - 1.0	1.1	1.0	ND	ND	19
36B	1.0 - 2.0	1.2	1.0	ND	ND	17
36C	2.0 - 3.0	1.3	1.1	ND	ND	19
36D	3.0 - 4.0	1.7	ND	ND	ND	ND
36E	4.0 - 5.0	1.5	0.9	ND	ND	13
36F	5.0 - 6.0	7.2	ND	ND	ND	ND
36G	6.0 - 7.0	36	ND	ND	ND	ND
36H	7.0 - 8.0	66	ND	ND	ND	ND
36I	8.0 - 9.0	9.6	ND	338	ND	15
36J	9.0 - 10.0	13	1.6	ND	16	15
39A	0 - 1.0	1.2	ND	ND	ND	ND
39B	1.0 - 2.0	0.9	1.0	2.7	ND	18

Table 3. (cont'd.) Concentration of ^{226}Ra, ^{232}Th, ^{238}U, ^{227}Ac, and ^{40}K in core hole samples

Sample	Depth (ft)	^{226}Ra (pCi/g)	^{232}Th (pCi/g)	^{238}U (pCi/g)	^{227}Ac (pCi/g)	^{40}K (pCi/g)
39C	2.0 - 3.0	0.9	1.1	2.4	ND	21
39D	3.0 - 4.0	1.1	1.1	ND	1.7	21
39E	4.0 - 5.0	1.1	1.0	3.4	2.0	20
39F	5.0 - 6.0	1.3	0.9	2.7	ND	ND
39G	6.0 - 7.0	150	7.7	960	190	ND
39H	7.0 - 8.0	3.0	1.1	ND	<0.1	20
39I	8.0 - 9.0	1.9	1.1	25	ND	22
39J	9.0 - 10.0	1.1	0.9	6.2	ND	21
39K	10.0 - 11.0	1.0	1.0	3.3	ND	19
39L	11.0 - 12.0	1.2	1.0	ND	ND	20
40A	0 - 1.0	1.2	1.0	ND	ND	17
40B	1.0 - 2.0	20	1.5	580	25	ND
40E	4.0 - 5.0	1.6	0.9	ND	ND	17
40F	5.0 - 6.0	1.0	1.0	ND	ND	20
40G	6.0 - 7.0	57	ND	ND	ND	ND
40H	7.0 - 8.0	200	20	ND	380	ND
40I	8.0 - 9.0	48	1.4	90	77	ND
40J	9.0 - 10.0	14	ND	39	16	22
40K	10.0 - 11.0	1.3	ND	ND	ND	ND
40L	11.0 - 12.0	1.0	1.0	2.3	ND	21
42B	1.0 - 2.0	1.6	ND	ND	ND	ND
42C	2.0 - 3.0	2.6	1.3	6.0	1.4	14
42D	3.0 - 4.0	4.5	1.8	ND	2.6	29
42E	4.0 - 5.0	130	5.6	4,300	110	ND
42F	5.0 - 6.0	31	0.7	1,300	18	ND
42G	6.0 - 7.0	1.3	ND	ND	ND	ND
42H	7.0 - 8.0	26	1.2	560	19	15
43A	0 - 1.0	5.6	1.0	18	4.0	19
43B	1.0 - 2.0	1.1	1.0	9.0	ND	21
43C	2.0 - 3.0	1.0	ND	ND	ND	ND
43D	3.0 - 4.0	1.1	ND	ND	ND	ND
43E	4.0 - 5.0	1.0	ND	ND	ND	ND
43F	5.0 - 6.0	1.1	1.0	ND	ND	22
44A	0 - 1.0	2.6	1.0	7.6	ND	18
44B	1.0 - 2.0	5.6	1.3	11	4.5	ND
44C	2.0 - 3.0	2.5	ND	ND	ND	ND
44D	3.0 - 4.0	10	ND	ND	ND	ND
44E	4.0 - 5.0	15	ND	48	23	15
44F	5.0 - 6.0	11	ND	ND	ND	ND
44G	6.0 - 7.0	6.6	ND	ND	ND	ND
44H	7.0 - 8.0	16	ND	ND	ND	ND
44I	8.0 - 9.0	7.3	1.1	27	5.4	19
44J	9.0 - 10.0	0.9	ND	ND	ND	ND
45A	0 - 1.0	6.5	ND	ND	ND	ND
45B	1.0 - 2.0	5.7	ND	ND	ND	ND
45C	2.0 - 3.0	7.5	ND	ND	ND	ND
45D	3.0 - 4.0	33.6	ND	ND	ND	ND

Table 3. (cont'd.) Concentration of ^{226}Ra, ^{232}Th, ^{238}U, ^{227}Ac, and ^{40}K in core hole samples

Sample	Depth (ft)	^{226}Ra (pCi/g)	^{232}Th (pCi/g)	^{238}U (pCi/g)	^{227}Ac (pCi/g)	^{40}K (pCi/g)
45E	4.0 - 5.0	47	ND	ND	13	15
45F	5.0 - 6.0	1.3	ND	ND	ND	ND
45G	6.0 - 7.0	13	1.1	9.7	4.2	18
45H	7.0 - 8.0	5.6	ND	ND	ND	ND
45I	8.0 - 9.0	13	ND	40	ND	ND
45J	9.0 - 10.0	1.1	1.0	11	ND	22
46A	0 - 1.0	12	0.9	6.1	2.2	ND
46B	1.0 - 2.0	3.0	ND	ND	ND	ND
46C	2.0 - 3.0	3.3	ND	ND	ND	ND
46D	3.0 - 4.0	4.4	ND	ND	ND	ND
46E	4.0 - 5.0	1.8	1.0	4.6	0.8	ND
46F	5.0 - 6.0	3.5	1.1	ND	1.9	18
46G	6.0 - 7.0	2.6	1.2	5.4	ND	17
46H	7.0 - 8.0	1.7	ND	ND	ND	ND
46I	8.0 - 9.0	88	1.6	65	ND	15
46J	9.0 - 10.0	1.8	ND	ND	17	ND
47A	0 - 1.0	36	ND	ND	ND	ND
47B	1.0 - 2.0	78	ND	ND	ND	ND
47C	2.0 - 3.0	39	2.6	ND	47	ND
47D	3.0 - 4.0	53	ND	ND	ND	ND
47E	4.0 - 5.0	0.9	1.0	12	ND	19
47F	5.0 - 6.0	1.2	ND	ND	ND	ND
47G	6.0 - 7.0	1.0	ND	ND	ND	ND
47H	7.0 - 8.0	1.0	ND	ND	ND	ND
48A	0 - 1.0	37	ND	ND	ND	ND
48B	1.0 - 2.0	50	ND	ND	ND	ND
48C	2.0 - 3.0	35	ND	ND	ND	ND
48D	3.0 - 4.0	23	2.4	110	33	11
48E	4.0 - 5.0	19	ND	ND	ND	ND
48F	5.0 - 6.0	1.1	1.0	ND	ND	20
49A	0 - 1.0	36	3.6	750	47	ND
49B	1.0 - 2.0	30	ND	ND	ND	ND
49C	2.0 - 3.0	18	1.6	820	18	ND
49D	3.0 - 4.0	13	ND	840	13	ND
49E	4.0 - 5.0	2.5	1.0	73	ND	19
49F	5.0 - 6.0	0.9	ND	33	ND	20
49G	6.0 - 7.0	1.1	0.9	6.9	ND	ND
49H	7.0 - 8.0	1.0	1.0	5.6	ND	19
50A	0 - 1.0	5.3	1.2	60	3.9	20
50B	1.0 - 2.0	1.2	1.0	17	ND	19
50C	2.0 - 3.0	1.0	1.0	2.6	ND	20
50D	3.0 - 4.0	1.1	1.0	2.5	0.8	21
53A	0 - 1.0	1.1	ND	ND	ND	ND
53B	1.0 - 2.0	1.9	ND	ND	ND	ND

Table 3. (cont'd.) Concentration of ^{226}Ra, ^{232}Th, ^{238}U, ^{227}Ac, and ^{40}K in core hole samples

Sample	Depth (ft)	^{226}Ra (pCi/g)	^{232}Th (pCi/g)	^{238}U (pCi/g)	^{227}Ac (pCi/g)	^{40}K (pCi/g)
53C	2.0 - 3.0	0.9	1.0	ND	ND	18
53D	3.0 - 4.0	1.1	1.0	2.7	ND	20
54A	0 - 1.0	2.5	1.1	38	ND	18
54B	1.0 - 2.0	1.5	1.2	2.6	0.7	22
54C	2.0 - 3.0	0.9	0.9	2.2	ND	ND
54D	3.0 - 4.0	1.6	1.1	1.5	3.8	21
55A	0 - 1.0	6.1	1.1	58	1.9	17.5
55B	1.0 - 2.0	1.3	1.1	6.5	ND	19.4
55C	2.0 - 3.0	1.2	1.0	3.7	ND	19
55D	3.0 - 4.0	1.5	1.0	ND	ND	19
56B	1.0 - 2.0	1.1	ND	ND	ND	ND
56D	3.0 - 4.0	5.6	ND	ND	ND	ND
56E	4.0 - 5.0	1.0	1.2	2.2	ND	24
56F	5.0 - 6.0	1.3	1.0	4.6	ND	22
56H	7.0 - 8.0	0.8	0.9	2.1	ND	19
60A	0 - 1.0	7.3	ND	ND	ND	ND
60B	1.0 - 2.0	0.9	0.8	4.1	ND	17
60C	2.0 - 3.0	1.1	0.9	ND	ND	ND
60D	3.0 - 3.5	1.0	1.1	ND	0.1	22
61A	0 - 1.0	22	1.0	150	7.9	17
61B	1.0 - 2.0	1.9	0.8	25	0.4	15
61C	2.0 - 3.0	3.2	ND	ND	ND	ND
63A	0 - 1.0	2.6	ND	ND	ND	ND
63C	2.0 - 3.0	2.5	ND	ND	ND	ND
63D	3.0 - 4.0	0.9	ND	ND	ND	ND
63E	4.0 - 5.0	2.6	1.0	9.7	ND	ND
63F	5.0 - 6.0	1.2	1.0	ND	0.4	21
63G	6.0 - 7.0	2.3	0.9	ND	ND	21
63H	7.0 - 8.0	1.3	ND	ND	ND	22
64A	0 - 1.0	2.5	ND	ND	ND	ND
64B	1.0 - 2.0	4.5	ND	ND	ND	ND
64C	2.0 - 3.0	2.9	ND	ND	ND	ND
64D	3.0 - 4.0	1.1	ND	ND	ND	ND
64E	4.0 - 5.0	1.4	ND	ND	ND	ND
64F	5.0 - 6.0	0.8	ND	ND	ND	ND
66A	0 - 1.0	137	ND	260	ND	ND
66B	1.0 - 2.0	1.4	1.1	19	ND	23
66C	2.0 - 3.0	2.9	ND	ND	ND	ND
66D	3.0 - 4.0	1.8	ND	ND	ND	ND

[a]ND = not determined.

Table 4. External gamma radiation readings in core holes at which no soil samples were taken

Location	Depth (ft)	Gamma radiation (μR/hr)	Location	Depth (ft)	Gamma radiation (μR/hr)
9	1	6	16	2	7
	2	7		4	31
	3	7		5	28
	4	8		6	194
	5	33		7	192
				8	94
10	1	6		9	8
	2	6		10	10
	3	8			
	4	12	17	1	14
	5	26		2	32
	6	36		3	21
	7	30		4	21
	8	8		5	27
	9	6		6	150
	10	6		7	150
				8	78
12	1	26		9	70
	2	24		10	12
	3	24			
	4	50	18	1	24
	5	66		2	30
	6	67		3	30
	7	19		4	32
	8	8		5	40
	9	7		6	154
	10	6		7	175
				8	154
14	1	15		9	75
	2	13		10	10
	3	27			
	4	118	19	1	80
	5	50		2	450
	6	47		3	500
	7	19		4	400
	8	8		5	800
	9	7		6	1200
	10	5		7	1400
				8	350
				9	42
				10	10

Table 4. (cont'd.) External gamma radiation readings in core holes at which no samples were taken

Location	Depth (ft)	Gamma radiation (μR/hr)	Location	Depth (ft)	Gamma radiation (μR/hr)
20	1	7	24	1	12
	2	10		2	27
	3	10		3	14
	4	12		4	10
	5	10		5	9
	6	7		6	9
	7	8		7	8
	8	8		8	9
	9	8			
	10	7	25	1	6
				2	7
21	1	5		3	7
	2	7		4	7
	3	8		5	5
	4	9		6	6
	5	6		7	5
	6	7		8	5
	7	7		9	5
	8	7		10	4
	9	7			
	10	5	26	1	9
				2	9
22	1	4		3	9
	2	7		4	10
	3	10		5	9
	4	7		6	42
	5	4		7	14
	6	7		8	10
	7	8		9	10
	8	7		10	6
	9	8			
	10	5	37	1	88
				2	550
23	1	7		3	600
	2	6		4	500
	3	7		5	300
	4	8		6	20
	5	7		7	9
	6	7		8	6
	7	7			
	8	8			

Table 4. (cont'd.) External gamma radiation readings in core holes at which no samples were taken

Location	Depth (ft)	Gamma radiation (μR/hr)	Location	Depth (ft)	Gamma radiation (μR/hr)
38	1	14	57	1	7
	2	120		2	4
	3	18		3	4
	4	14		4	6
	5	9		5	7
	6	9		6	7
	7	8		7	7
	8	6		8	18
				9	28
41	1	4		10	11
	2	9		11	8
	3	10			
	4	10	58	1	7
	5	11		2	7
	6	14		3	8
	7	35		4	5
	8	26		5	13
	9	12		6	16
	10	8		7	12
	11	10		8	38
	12	10		8.5	14
	14	10			
			59	1	12
51	1	9		2	7
	2	10		3	5
	3	7		4	8
	4	8		5	8
	5	7		6	8
	6	8		7	36
	7	9		7.5	62
	8	6		8	42
				9	78
52	1	11		10	42
	2	14		11	12
	3	26		12	7
	4	36		13	8
	5	18			
	6	14			
	7	52			
	8	24			
	9	9			
	10	7			
	11	10			
	12	6			

Table 4. (cont'd.) External gamma radiation readings in core holes at which no samples were taken

Location	Depth (ft)	Gamma radiation (μR/hr)	Location	Depth (ft)	Gamma radiation (μR/hr)
62	1	8	65	1	7
	2	8		2	8
	3	8		3	9
	4	6		4	8
	5	7		5	7
	6	8			
	7	14			
	8	26			
	9	10			

Table 5. Fractions of bare pile ^{222}Rn flux transmitted by stabilization materials[a]

Depth (ft)	Material		
	Sand	Loam or clay	Concrete
0.5	9×10^{-1}	6×10^{-1}	7×10^{-3}
1.0	9×10^{-1}	4×10^{-1}	1×10^{-3}
1.5	8×10^{-1}	3×10^{-1}	1×10^{-4}
2.5	7×10^{-1}	2×10^{-1}	3×10^{-6}
5	4×10^{-1}	2×10^{-2}	
10	2×10^{-1}	4×10^{-3}	
15	8×10^{-2}	3×10^{-4}	
20	3×10^{-2}	3×10^{-5}	
30	6×10^{-3}	2×10^{-7}	
40	1×10^{-3}		

[a]Values based on data presented by M. V. J. Culot, H. G. Olson, and K. J. Schiager, Radon Progeny Control in Buildings, COO-2273-1, Colorado State University, Fort Collins (May 1973).

THIS PAGE

WAS INTENTIONALLY

LEFT BLANK

APPENDIX I

Description of Radiation Survey Meters

RADIATION SURVEY METERS

Beta-Gamma Survey Meter

A portable Geiger-Muller (G-M) survey meter is the primary instrument for measuring beta-gamma contamination. The G-M tube is a halogen-quenched stainless steel tube having a 30 mg/cm^2 wall thickness and presenting an active volume of approximately 150 cm^2. Since the G-M tube is sensitive to both beta and gamma radiation, measurements are taken in both an open-window and a closed-window configuration. Beta radiation cannot penetrate the closed window and thus the beta reading can be determined by taking the difference between the open and closed window readings. This meter is shown in Fig. I-A.

The G-M survey meter was calibrated at ORNL for gamma radiation using a National Bureau of Standard (NBS) ^{226}Ra source and a depleted uranium source. The gamma calibration factor is typically of the order of 2600 cpm per mR/hr. The beta-gamma calibration for this site was determined by comparison with a Victoreen Model 440 ionization chamber (see Fig. I-B). Based on the measurement of a variety of uranium-contaminated surfaces, the beta-gamma calibration factor was determined to be 1750 cpm per mrad/hr with a standard deviation of 25%.

Gamma Scintillation Meter

A portable survey meter with a NaI scintillation probe is used to measure low-level gamma radiation exposure (see Fig. I-C). The scintillation probe is a 3.2 x 3.8 cm NaI crystal mounted on a photomultiplier tube. This probe is coupled with a Victoreen Model Thyac III ratemeter

(see Fig. I-C). The unit is capable of measuring radiation levels from a few μR/hr to several hundred μR/hr. It is calibrated at ORNL with an NBS standard ^{226}Ra source. Typical calibration factors are of the order of 250 to 400 cpm per μR/hr.

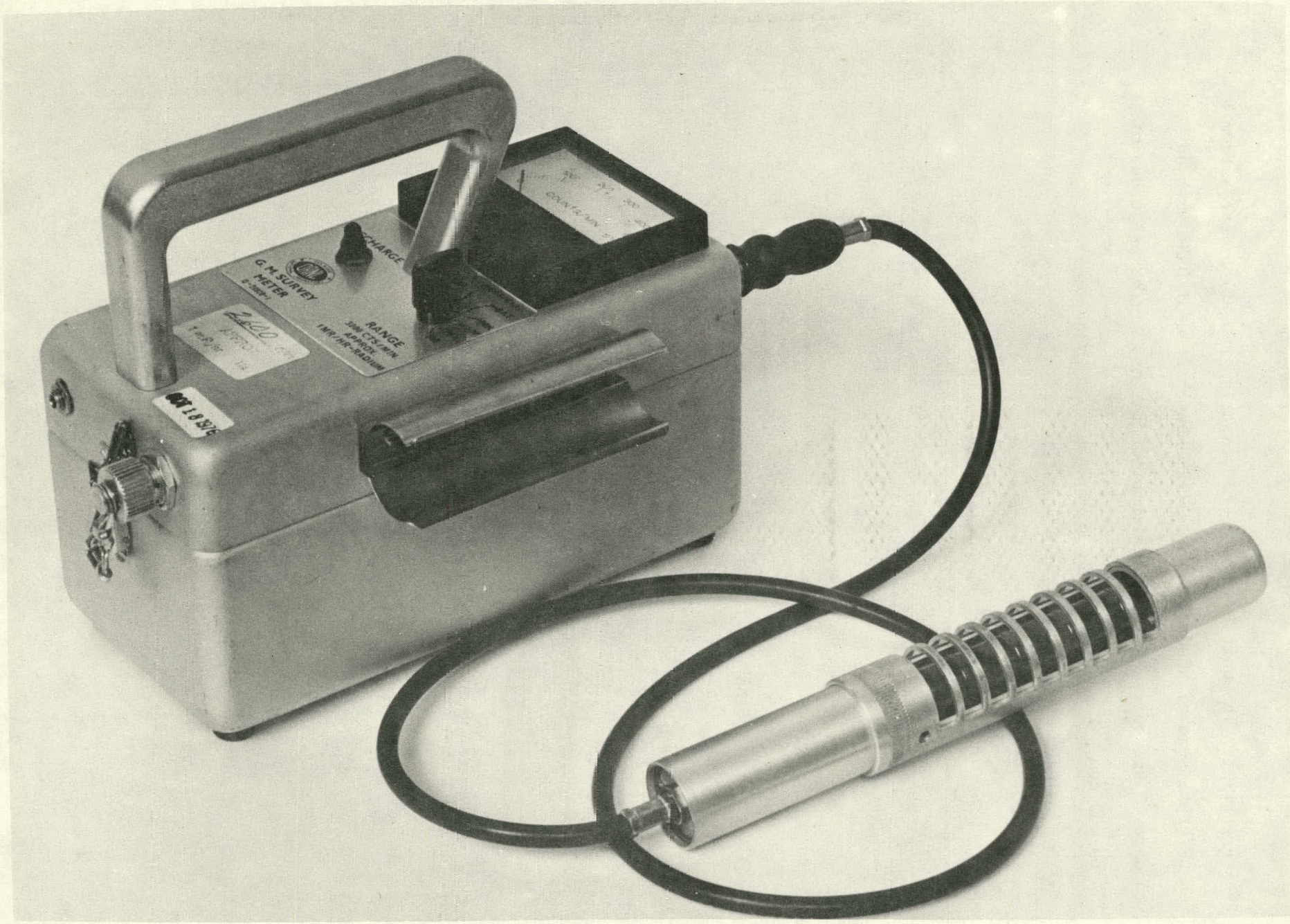

Fig. I-A. Geiger-Muller survey meter.

Fig. I-B. Victoreen Model 440 Ionization chamber.

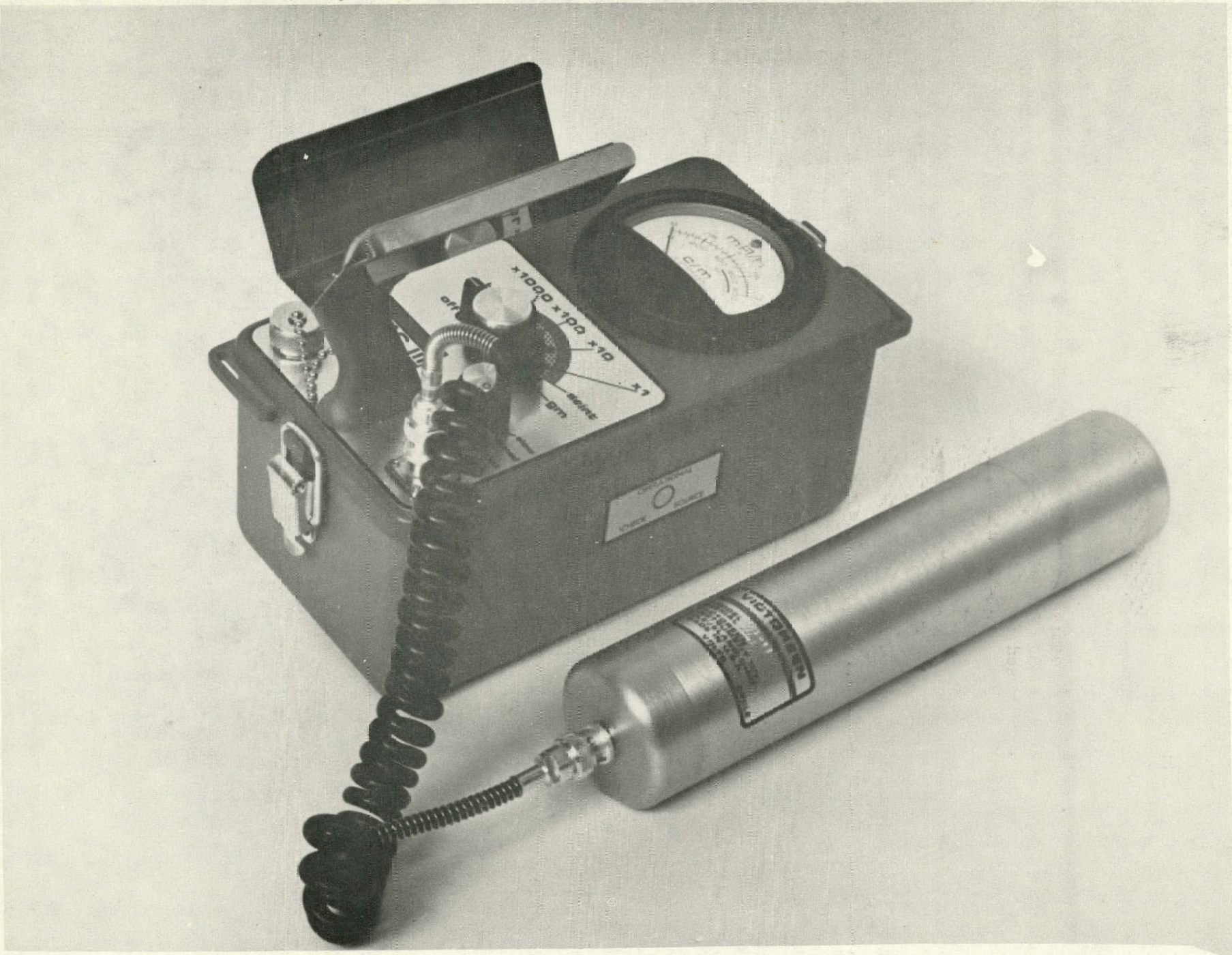

Fig. I-C. Gamma scintillation survey meter.

APPENDIX II

Description of Ge(Li) Detector and Soil Counting Procedures

DESCRIPTION OF Ge(Li) DETECTOR SYSTEM

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

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

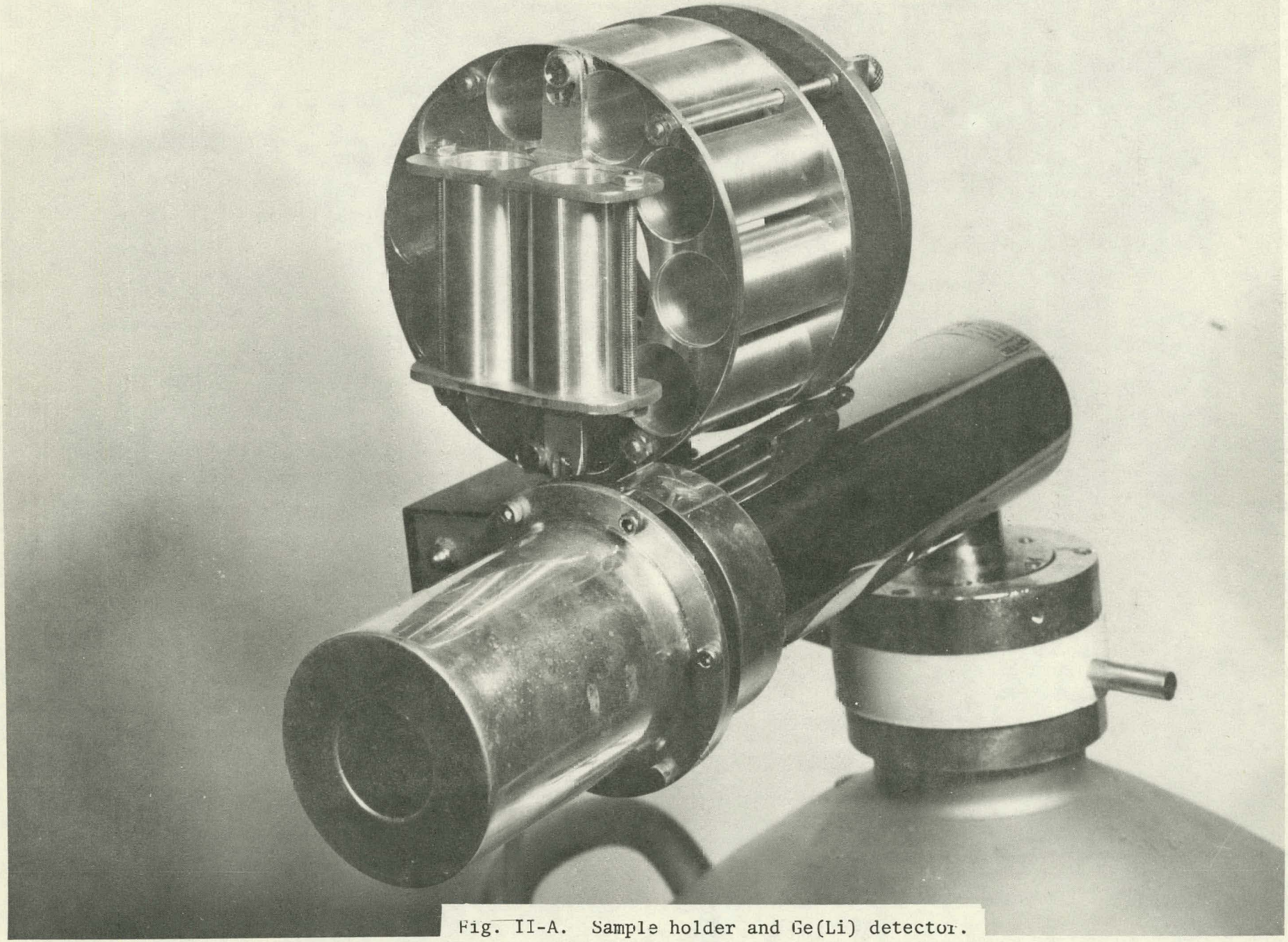

Fig. II-A. Sample holder and Ge(Li) detector.

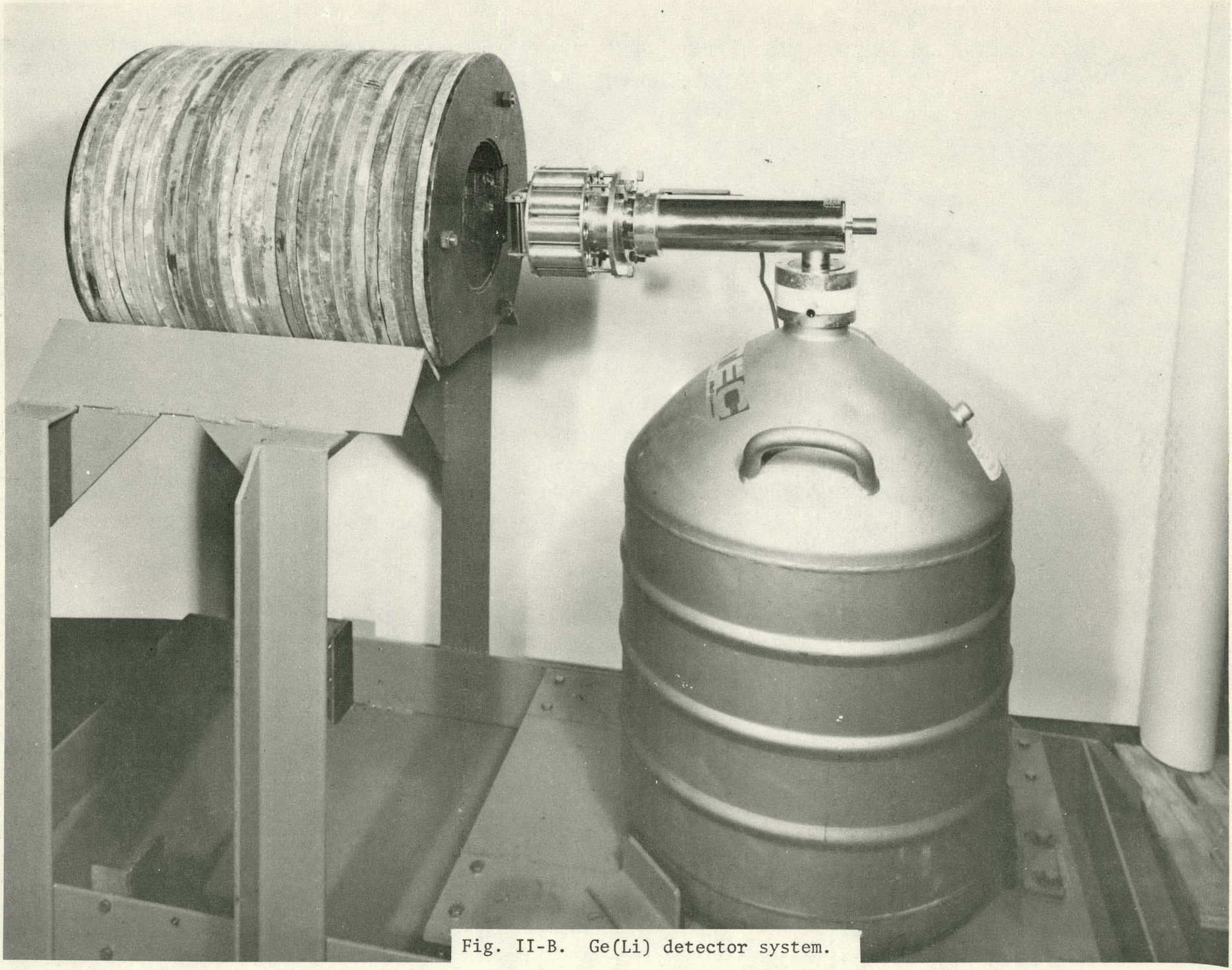

Fig. II-B. Ge(Li) detector system.

APPENDIX III

Assumptions Used in Radon Emanation Estimates

PROCEDURE FOR ESTIMATION OF RADON EMANATION

Regions with similar patterns of ^{226}Ra concentrations in the soil were grouped into a single area. For each of these areas averages of the ^{226}Ra concentrations were calculated for topsoil and for contaminated soil. Then estimates for radon emanation were made from the average ^{226}Ra concentration in the contaminated soil using Table 5 and the "moist tailings" curve in Fig. 13. If the radon contribution from the topsoil also seemed significant compared with emanation from the more contaminated soil, estimates for emanation from the topsoil were added. The areas with similar contamination patterns are identified in Fig. 14 and have been assigned a letter designation. Each of these areas is discussed below.

Area P

The highest ^{226}Ra concentrations were near the surface. The average concentration for 0-2 ft was about 12 pCi/g. It was conservatively assumed that this was the average concentration for the first 4 ft of soil in area P. Table 5 was not used in this case.

Area Q

There are some tailings near the surface, and external gamma radiation levels in this area were higher than in the rest of the site. It was conservatively assumed that ^{226}Ra concentration in area Q was 40 pCi/g from 0-5 ft. This is slightly higher than the average concentration at locations 47, 48, and 49, which had the highest average concentrations in this area. Again Table 5 was not used.

Area R

The average ^{226}Ra concentration from 0-3 ft was about 5 pCi/g. From the "moist tailings" curve in Fig. 13, this would result in

a radon emanation of about 2.5 pCi/m^2-s. In addition, a radon emanation of approximately 3.5 pCi/m^2-s would result from the average concentration of 30 pCi/g from 3-10 ft, assuming there are 3 ft of clay topsoil.

Areas S and W

Radium-226 concentrations were low in the first several feet and external gamma radiation levels appeared to be near background in those areas. The estimate of 2 pCi/m^2-s appears conservative for an average of this area, although it may be low for specific isolated spots. Two pCi/m^2-s is about 5 times the average background level for the entire country.

Area T

It was assumed that this area is covered by 2 ft of clay topsoil and that the average ^{226}Ra concentration from 2-7 ft is 125 pCi/g. (This is the average at location 27; this location had the highest ^{226}Ra concentrations found in and near area T.)

Area U

It was conservatively assumed that this area is covered by 2 ft of clay topsoil and that the average ^{226}Ra concentration from 2-7 ft is 140 pCi/g.

Area V

The ^{226}Ra concentration was assumed to be 4 pCi/g at 0-3 ft and 36 pCi/g from 3-7 ft. The resulting radon emanations, estimated from Table 5 and Fig. 13 for both of these depths, were added.

★ U.S. GOVERNMENT PRINTING OFFICE: 1978— 261-324/67