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Results of Ground Level Radiation Measurements in Support of the 1978 Aerial Survey of the Lake Ontario Ordnance Works, Lewiston, New York

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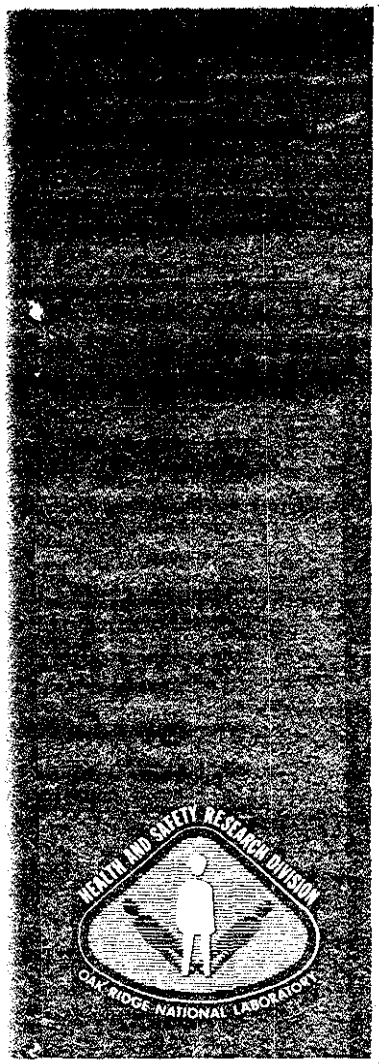

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RESULTS OF GROUND LEVEL RADIATION MEASUREMENTS IN SUPPORT OF THE 1978 AERIAL SURVEY OF THE LAKE ONTARIO ORDNANCE WORKS, LEWISTON, NEW YORK

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Work performed by
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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 Engineer 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 limited series of measurements at the Lake Ontario Ordnance Works site, three miles northeast of Lewiston, New York. The scope of this survey was not extensive, and the survey was conducted to support a concurrent aerial survey conducted by EG&G, Inc. Results of this survey indicate two sources of significant external gamma exposure on the site as well as several locations that retain low to intermediate levels of radioactivity in soil. Off-site soil radionuclide concentrations were well within background levels with one exception. Water radionuclide concentrations on the site in the Central Drainage Ditch are significantly above background levels but decrease with distance from the spoil pile, and are within restrictive concentration guides for off-site locations.

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RESULTS OF GROUND LEVEL RADIATION MEASUREMENTS IN SUPPORT OF THE 1978 AERIAL SURVEY OF THE LAKE ONTARIO ORDNANCE WORKS, LEWISTON, NEW YORK

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ABSTRACT

The results of a limited series of radiation measurements at the Lake Ontario Ordnance Works site are presented in this report. During the late 1940's, this site was used as a storage location for by-product chemical residues from uranium ore refining and miscellaneous contaminated material from other MED/AEC sites. During the 1950's and from 1964 to 1971, a boron isotope separation plant was operated at this site. Currently, the site is inactive. This limited survey included measurements of the following: external gamma exposure levels, ambient radon and radon daughter concentrations, and radionuclide concentrations in surface soil and water samples. Significant external gamma exposure levels were observed at the on-site K-65 silo and spoil pile area. Elevated concentrations of radium were found in the soil in the spoil pile area and associated drainage ditches. The spoil pile also appeared to be a significant source of radon emanation. All off-site measurements were within typical background levels with the exception of rock samples taken from Our Lady of Fatima religious shrine (approximately 1.3 miles southwest of the site), which contained significantly higher concentrations of uranium and radium. Water samples indicated that concentrations of radionuclides in the Central Drainage Ditch were significantly above background levels but decreased with distance from the spoil pile and were within restrictive concentration guides for off-site locations.

INTRODUCTION

At the request of the Department of Energy (DOE), a series of radiation measurements was made at the Lake Ontario Ordnance Works site, located approximately 2 miles east of the Niagara River and approximately 3 miles northeast of Lewiston, New York (see Figs. 1 and 2). The survey was requested in order to provide ground level support for an aerial survey conducted by EG&G, Inc.

In 1944, the Manhattan Engineer District (MED) requested use of a few small areas of the U.S. Army-operated Lake Ontario Ordnance Works (LOOW) site for storage of chemical residues from uranium refining.* From 1944 to 1946, low-grade pitchblende ore residues were stored at LOOW from the nearby Tonawanda refinery operated by Linde Air Products. In 1946, the Tonawanda refinery was decommissioned, and contaminated portions of the plant were disposed of at LOOW.

From 1946 through 1953, all uranium refining was conducted at a new plant (Mallinckrodt Chemical Works) in St. Louis, Missouri. Until 1949, residues from the high-grade Belgium Congo pitchblende were shipped from St. Louis to Belgium. These ores processed at St. Louis were sold to the United States by a Belgian company and handled by its agent, the African Metals Corporation of New York. Only the uranium in the ore was sold; all other minerals including the radium were to remain property of the vendor. After April 1, 1949, a portion of these residues were shipped to LOOW for storage. During this time, the Department of Defense decommissioned LOOW (1948); and the Atomic Energy Commission (AEC), successor to MED, acquired 1511 acres of the LOOW site, including the

*Information for this background summary of the LOOW site (unless otherwise noted) was obtained from several short unpublished DOE reports.

original storage areas. In 1952 and 1953, the high-grade residues (called K-65 residues) from St. Louis were transferred from 55-gal drums to a 165-ft high, reinforced-concrete tower subsequently named K-65 tower. Approximately 20,000 tons of these radium-bearing residues remain on the site. The majority of the residues belong to African Metals Corporation and are stored under a 25-year lease with the AEC (lease expiration date set for July 1, 1983).

During the late 1940's and early 1950's, LOOW was a central storage depot for contaminated materials from other MED sites and uranium billets from several steel plant-mills. Low-level radioactive wastes generated by the University of Rochester and Knolls Atomic Power Laboratory were also stored at LOOW.

In about 1953, the AEC, through its New York Operations Office (NYO), started a boron isotope-separation plant at LOOW. In 1954, the LOOW storage site and boron separation operation were transferred to Oak Ridge Operations (ORO). In about 1955, AEC/ORO declared 1298 acres of the LOOW site as surplus and subsequently transferred the 1298 acres to the General Services Administration (GSA). From about 1966 to 1968, GSA was successful in disposing of the property.

In 1958, at the termination of ore procurement contracts, lease agreements were negotiated with African Metals for storage of their residues. The boron separation was halted in 1958 and the LOOW site placed in standby (under NYO). In 1964, the boron separation operation was restarted and the site was again transferred back to ORO. Nuclear Materials and Equipment Corporation (NUMEC) was selected as operating contractor by ORO through December 31, 1971. The boron separation

operation was put on standby in July 1971, and National Lead Company of Ohio (NLO) assumed caretaker responsibilities.

In "spot-check" radiation surveys in October 1970, it was found that on-site and off-site radiation levels exceeded AEC guidelines. Local, state and federal agencies were notified and extensive surveys were conducted to characterize the extent of contamination. It was determined that 6.5 acres of the 1298 acres formerly held by the AEC exceeded the AEC standard of 50 μR/hr. Decontamination of the 6.5 acres was performed in May 1972 and a total of 15,000 to 20,000 cubic yards of contaminated soil and debris was placed on a one acre spoil pile (mounded to a height of 15 ft) on the remaining AEC site. A survey performed by EG&G[1] and AEC/ORO (see Appendix I) conducted post-decontamination, indicated that only a few portions of the central drainage ditch and Six Mile Creek exceeded the 50 μR/hr criterion at off-site locations. Since 1972, periodic short-term, limited surveys have been conducted by NLO for ground and surface water contamination at on and off-site locations, and the concentration of radon was measured at several fence-line locations.[2,3] Environmental Measurements Laboratory (EML) began off-site radon monitoring in August 1978 both indoors and outdoors to supplement data collected by NLO. Results from portions of the NLO-EML data are reported in Appendix I.

Currently, the Department of Energy (DOE) is the federal agency responsible for the LOOW site and NLO continues as the contracted caretaker. Approximately 60% of the residues at LOOW are owned by African Metals and are stored in four reinforced concrete structures. The type and quantity (tons) of the radioactive residues at LOOW as well as the ownership and storage location are listed in Table 1.

The terrain at the present 191-acre LOOW site is characterized by flat, marshy farmland. A few small streams and ponds are found at and around the site, and water flow is to the north in the direction of Lake Ontario. A central drainage ditch is located on the site on a north-south traverse. The central drainage ditch is approximately 170 ft east of the spoil pile with a branch drainage ditch that is approximately 30 ft west of the spoil pile. The predominate wind direction at this site is from the southwest to the northeast.

The area immediately surrounding the site is sparsely populated. A KOA campground is located approximately 0.5 mile to the southwest of the site.

RADIOLOGICAL SURVEY PLAN

The present survey was performed to provide useful information regarding the radiological status of the Lake Ontario Ordnance Work site and immediate surrounding area. The survey was conducted by two members of the Health and Safety Research Division of Oak Ridge National Laboratory (ORNL) during the period October 25, 1978 through November 1, 1978. The survey included the following measurements:

(1) external gamma exposure levels at 1 m above surface at 15 off-site locations and 48 on-site locations (including perpendicular traverses of the spoil pile with 23 measurements taken at 50 ft intervals);

(2) ^{222}Rn concentrations in air at four off-site and three on-site locations;

(3) ^{222}Rn daughter concentrations in air at eight on-site locations,

(4) concentrations of ^{238}U, ^{226}Ra, ^{232}Th, ^{227}Ac, and ^{137}Cs in surface soil samples at 25 on-site locations and concentrations of ^{238}U, ^{226}Ra, ^{232}Th, and ^{137}Cs at 15 off-site locations,

(5) concentrations of ^{238}U, ^{226}Ra, ^{210}Pb, and ^{230}Th in water samples at four on-site and three off-site locations.

RADIOLOGICAL SURVEY TECHNIQUES

Measurement of External Gamma Exposure Levels

External gamma exposure levels were measured by a Geiger-Mueller (G-M) tube in association with a battery-powered portable scaler (a "Phil" dosimeter). This instrument is described in Appendix II. Readings were taken at 1 m above the ground surface at all on- and off-site soil sample locations, and a series of 23 readings were taken on the spoil pile.

Measurement of ^{222}Rn in Air

Continuous measurements of ^{222}Rn concentrations in air were made at seven locations on and off the site using an instrument developed by Wrenn et al.[4] This instrument, described in Appendix II, was equipped with a printer that automatically recorded values proportional to the ^{222}Rn concentrations at 2000 sec intervals. Each reading represents an integrated concentration of ^{222}Rn for a 2 to 4 hr time period. The values represent a greater time frame than 2000 sec, due to the instrument responding to radon collected during earlier 2000 sec counting time intervals, but diffusing into the detection area of the instrument at a later time.

Measurement of ^{222}Rn Daughters in Air

For the measurement of radon daughter concentrations in air outdoors at eight on-site locations, air was pumped for 10 min at approximately 12 liters per minute through a membrane filter with a maximum pore size of 0.4 μm. The filter was counted using an alpha spectrometry technique described in Appendix II.

Soil Sampling and Radionuclide Analysis

Surface soil samples were collected at 25 on-site locations and 15 off-site locations. Each sample was packed in a plastic bag and returned to ORNL, where it was dried for 24 hr at 110°C and then pulverized to a particle size no greater than 500 μm in diameter (-35 mesh). Aliquots from the pulverized sample were transferred to plastic bottles, weighed and stored to allow buildup of radon and radon daughters. The samples were counted using a Ge(Li) detector, and the spectra obtained were analyzed using computer techniques. Description of the Ge(Li) detector and soil sample counting procedures are reported in Appendix III. Measurement of ^{238}U concentration in each sample was obtained by neutron absorption techniques[5] performed by the Analytical Chemistry Division at ORNL.

Water Sampling and Radionuclide Analysis

Water samples were collected at four on-site and three off-site locations. A one-liter water sample from each location was collected in a polyethylene jar and returned to ORNL, where the sample was analyzed by the Analytical Chemistry Division for ^{238}U, ^{226}Ra, ^{210}Pb and ^{230}Th. Techniques utilized in analyses are described in the Appendices to the ORNL Analytical Master Manual.[6]

RESULTS OF SURVEY MEASUREMENTS

External Gamma Exposure Levels

Off-site locations of measurements for external gamma exposure levels are shown in Fig. 3, and results are listed in Table 2. The highest off-site value observed was 11 μR/hr at LT014 (approximately 2.2 miles north of spoil pile), and the lowest off-site value observed was 3 μR/hr at LT06 and LT07 (approximately 2.0 miles and 1.3 miles northwest of the spoil pile, respectively). The mean off-site external gamma exposure level at 1 m above ground surface was 6 μR/hr for 15 locations. This mean value compares favorably with the 5 to 7 and 8 to 10 μR/hr values obtained by the EG&G/AEC/ORO 1972 survey for off-site external gamma exposure levels at 3 ft above ground surface (see Appendix I).

On-site locations of measurements for external gamma exposure levels are shown in Fig. 4, and results are listed in Table 3 (exclusive of the spoil pile found on the site). The highest value observed was 355 μR/hr at LT21 (approximately 100 ft west of the spoil pile), and the lowest value observed was 5 μR/hr at LT21 (approximately 1500 ft north of the spoil pile). The mean on-site external gamma exposure level at 1 m above ground surface was 51 μR/hr for 25 locations. Excluding values taken at locations in close proximity to the spoil pile and the K-65 silo (LT20, LT21 and LT23), the resulting mean of the remaining 22 on-site locations was 15 μR/hr. The 15 μR/hr mean compares favorably with the 16 μR/hr mean for on-site external gamma exposure (3 ft above the ground surface) by the EG&G/AEC/ORO survey in 1972 (exclusive of the

spoil pile). The K-65 silo was a substantial source of external gamma exposure with measured exposure rates of 250 μR/hr at approximately 50 ft distance.

Location of spoil pile measurements and external gamma exposure levels at those locations are shown in Fig. 5. These external gamma exposure levels are also listed in Table 4. Two traverses across the spoil pile were taken to obtain these values. Measurements were obtained every 50 ft in a north-south traverse and east-west traverse of the spoil pile. The highest value observed on the spoil pile was approximately 3 mR/hr, 400 ft east-center of the west edge of the spoil pile, and the lowest value obtained was 53 μR/hr, 600 ft north-center of the south edge of the spoil pile. The mean spoil pile external gamma exposure level at 1 m above the ground surface was 600 μR/hr. This mean may be compared to the extrapolated 700 μR/hr mean external gamma exposure value obtained by EG&G[1] (flying at 300-500 ft above ground surface) and the 1200 μR/hr mean external gamma exposure level obtained by AEC/ORO[1] (at 3 ft above ground surface). The discrepancy between these mean values observed at the spoil pile can probably be attributed to differences in the choice of measurement locations (traverse measurement vs. grid measurements) and technique of measurement (1 m above ground surface vs. 300 to 500 ft above ground surface).

External gamma exposure levels at off-site locations around the Lake Ontario Ordnance Works appear to be consistent with typical background measurements in this area (6 to 8 μR/hr). The only exception was along the Central Drainage Ditch where values up to 11 μR/hr were

observed. External gamma exposure levels at locations on the perimeter of the site appear to be at background or slightly elevated, excluding those locations in close proximity to the spoil pile and the K-65 silo. These two latter locations are significant sources of external gamma exposure. The spoil pile is of special concern because exposure levels are as high as 3 mR/hr. Highest readings on the spoil pile appear to be 350 ft away from the center of the spoil pile in the east-west directions and 75 to 100 ft away from the center of the spoil pile in the north-south directions. Results of this external gamma exposure survey appear to be consistent with results obtained by the EG&G/AEC/ORO 1972 survey.[1]

^{222}Rn Concentrations in Air

Off-site and on-site locations of measurements for ^{222}Rn concentrations are shown in Fig. 6 and Fig. 7, respectively. The results of these measurements and maximum and mean daily values are listed in Table 5. A summary of the mean values for each location is listed in Table 6. Mean values determined at off-site locations for radon concentration were close to those obtained by EML during August 1978 to April 1979 at similar measurement locations (see Fig. I-3 and Table I-7, Appendix I). Mean radon concentrations at on- and off-site locations (excluding locations 3 and 4 at spoil pile) were not significantly higher than background, ranging from 0.18 to 0.26 pCi/liter and averaging 0.21 pCi/liter. Measurements were taken at two locations on spoil pile (see Fig. 7). The mean radon concentration atop the spoil pile (location 4) is 72 pCi/liter and 44 pCi/liter at the north-center edge of the spoil pile (location 3). This indication that the spoil pile is a substantial source of radon released to the environment is further confirmed by

radon flux measurements taken by the EML (see Fig. I-3 and Tables I-8 and I-9, Appendix I). At K-65 silo, radon concentrations measured were within typical background levels. This indicates that the K-65 silo represents a significantly smaller source component than does the spoil pile.

Figure 8 is a graph of ^{222}Rn concentrations at two locations (atop the spoil pile, and at the KOA campground approximately 0.5 mile southwest of the spoil pile) over a period of several days. This graph illustrates several important points: (1) there is a substantial variation in radon concentration in a relatively short time period (hours); (2) there is a highly significant increase in radon concentration at the spoil pile relative to background radon concentrations; (3) times at which peak and valley concentrations of radon occur coincide at these locations, illustrating predominant environmental influences that are responsible for the substantial daily variation in radon concentration.

It appears from results of this survey and on-going EML surveys that, in spite of a significant radon source term, there is no significant increase in ^{222}Rn concentrations off the site. Nevertheless, more measurements are required before this conclusion can be justified.

^{222}Rn Daughter Concentrations in Air

Concentrations of ^{222}Rn daughters at eight on-site locations are listed in Table 7. Sampling locations are shown in Fig. 9. All measured radon daughter concentrations were well within normal background levels of most areas of the country. Potential alpha activity in air did not exceed 0.002 WL* at any location (excluding atop the spoil pile).

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

Radionuclide Concentrations in Surface Soil Samples

Off-site locations for surface soil samples are shown in Fig. 3. Results of radionuclide analysis of these samples are listed in Table 8. Cesium-137 was reported as a contaminant in an earlier site survey (see Appendix I) and was therefore listed in this survey report. Results of the off-site soil analysis indicates all values were well within typical background levels except location LTO16 (Our Lady of Fatima Shrine near Lewiston, New York). The concentration of ^{238}U at LTO16 was approximately 55 times background, and the ^{226}Ra concentration was approximately 40 times background. The sample taken at this site was from a crushed rock material used to cover the parking lot. It is believed that this cover material is actually a crushed slag. Preliminary spectrographic analyses indicate the slag is a synthetic CaO_3 called cyclo-wallastonite. Its origin is unknown; however, it is believed to have come from an electrochemical process that extracts phosphorous from phosphate rock. A brief external gamma survey of the parking lot indicated relatively uniform elevated exposure levels before the sample was collected. These results indicate a more extensive survey at this location is merited.

On-site locations for surface soil samples are shown in Fig. 4. Results of radionuclide analysis of these samples are listed in Table 9. These results indicate that there is significant ^{226}Ra contamination along the Central Drainage Ditch. The extent of contamination decreases with increasing distance from the spoil pile. Relatively high ^{226}Ra concentrations were observed along the branch drainage ditch west of the spoil pile and along the west fence line adjacent to the spoil pile.

Generally, most other on-site locations were much closer to background levels. The highest ^{226}Ra value observed was 260 pCi/g (LT23), and the mean on-site ^{226}Ra concentration was 23.4 pCi/g (off-site mean was 1.31 pCi/g). The highest on-site ^{238}U concentration was 11.7 pCi/g (LT21), and the mean on-site ^{238}U concentration was 2.28 pCi/g (off-site mean was 0.95 pCi/g). The mean on-site ^{137}Cs concentration was 1.18 pCi/g. Although this value was higher than the 0.76 pCi/g mean concentration at off-site locations for ^{137}Cs, the difference was not significant. Concentrations of ^{232}Th were within background levels at off and on-site locations.

Radionuclide Concentrations in Water Samples

Off-site and on-site locations for water samples are shown in Figs. 3 and 4, respectively. Results of radionuclide analysis of these samples are listed in Table 10. There were 7 sample locations (4 on-site, 3 off-site) of which 5 samples were taken from the Central Drainage Ditch. This drainage ditch begins on the site adjacent to the spoil pile and ultimately drains into Four Mile Creek, approximately 3 miles northwest of the site. The other two samples were obtained from Four Mile Creek and from an on-site branch of the Central Drainage Ditch.

Concentrations for ^{238}U, ^{226}Ra, ^{210}Pb, and ^{230}Th were determined for dissolved and solid fractions in water. The highest concentration for all radionuclides occurred at LWT2 (Central Drainage Ditch adjacent to northeast edge of spoil pile). The concentration of ^{226}Ra in water at this location was particularly high (0.0631 pCi/ml). There is a pattern of decreasing concentration of radionuclides in samples taken along the Central Drainage Ditch as sample locations are more distant

from the spoil pile. This pattern is observed even at off-site locations where lowest concentration values for all radionuclides are found at the farthest sampling site from the spoil pile at LTW7 (Four Mile Creek). A water sample taken from a branch ditch off the Central Drainage Ditch that runs along the west side of the spoil pile showed concentrations of radionuclides at or near background levels. These data indicate that some contaminated material from LOOW may be migrating off the site through the Central Drainage Ditch. It should be noted however, that all off-site radionuclide concentrations in water were well within the most restrictive concentration guide (CG_w) for uncontrolled areas (see Table 10). These results indicate a more extensive survey of surface and groundwater is merited at and around LOOW.

SUMMARY

Limited radiation measurements were made at the Lake Ontario Ordnance Works site, 3 miles northeast of Lewiston, New York. This work was performed to provide ground level measurements in support of a concurrent low-altitude aerial survey conducted by EG&G, Inc. During the late 1940's this site was used as a storage location for by-product chemical residues from uranium refining and miscellaneous contaminated material from other MED/AEC sites. During the 1950's, a boron isotope separation plant operated at this site. Currently the site is inactive.

The present survey was non-extensive due to time limitations; however, measurements were made of the following: external gamma exposure levels, ambient ^{222}Rn and ^{222}Rn daughter concentrations, and radionuclide concentrations in surface soil and water samples.

External gamma exposure levels averaged 6 μR/hr at 15 off-site locations and 15 μR/hr at 22 on-site locations (excluding those locations in close proximity to the K-65 silo and the spoil pile area). These values are in reasonable agreement with those values observed in earlier surveys of the site. Exposures resulting from materials in the K-65 silo measured 250 μR/hr at approximately 50 ft, and the maximum value observed atop the spoil pile was approximately 3 mR/hr. This indicates that these two areas represent sources of significant external gamma exposure at this site.

The concentration of ^{222}Rn at all locations measured (including 50 ft north of K-65 silo) were within typical background levels with the exception of the spoil pile. Two locations were sampled on the spoil pile. The mean ^{222}Rn concentration atop the spoil pile was 72 pCi/liter (location 4) and 44 pCi/liter at the north-center edge of the spoil pile (location 3). This is an indication that the spoil pile is a substantial source of radon emanation. This conclusion is supported by data from EML (see Appendix I). Radon daughter concentrations, however, were within background levels at all locations during the time in which measurements were taken (excluding atop the spoil pile).

Elevated concentrations of radium in soil were found in the spoil pile area and associated drainage ditches. Values as high as 260 pCi/g of ^{226}Ra were observed (at a drainage ditch located approximately 200 ft northeast of the spoil pile). The mean ^{226}Ra concentration on the site was 23.4 pCi/g (mean value off the site was 1.31 pCi/g), and the mean on-site ^{238}U concentration was 2.20 pCi/g (mean value off the site was 0.95 pCi/g). All off-site measurements were within typical background

levels with the exception of rock samples taken from Our Lady of Fatima religious shrine (approximately 1.3 mile southwest of the site), which contained concentrations 55 and 40 times background for ^{238}U and ^{226}Ra, respectively.

Concentrations of ^{238}U, ^{226}Ra, ^{210}Pb, and ^{230}Th in dissolved and solid fractions of water samples were significantly above background levels at the sampling location closest to the spoil pile. Concentrations of radionuclides decreased in the Central Drainage Ditch with increasing distance from the spoils pile. Lowest concentrations were observed at the location (Four Mile Creek) furthest from the spoil pile. Radionuclide concentrations in water at off-site sample locations were above background levels, but were well within restrictive concentration guides for uncontrolled areas. There is some indication that small amounts of contaminated material from LOOW may be migrating off the site through the Central Drainage Ditch.

The results of this limited survey of the Lake Ontario Ordnance Works site may be summarized in the following statements:

1) There is extensive on-site contamination concentrated in the spoil pile area in soil, water, and air, and the spoil pile is a source of external gamma exposure.

2) The contents of the K-65 silo is a source of external gamma exposure, but there is no evidence of migration of radioactive material into the environment.

3) The Central Drainage Ditch shows elevated concentrations of ^{226}Ra in soil and water and may represent a vehicle for transport of contaminated material off the site.

4) There was no significant contamination noted off the site excepting rock samples from Our Lady of Fatima Shrine (LTO16). These uranium and radium bearing rocks apparently did not originate at LOOW, nor did they originate as a result of MED/AEC work at another formerly utilized MED/AEC site.

5) This site merits a more detailed radiological characterization of radon and radon daughter concentrations on and off the site and concentrations of radionuclides in soil and water at on- and off-site locations.

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ORNL-DWG. 79-14108

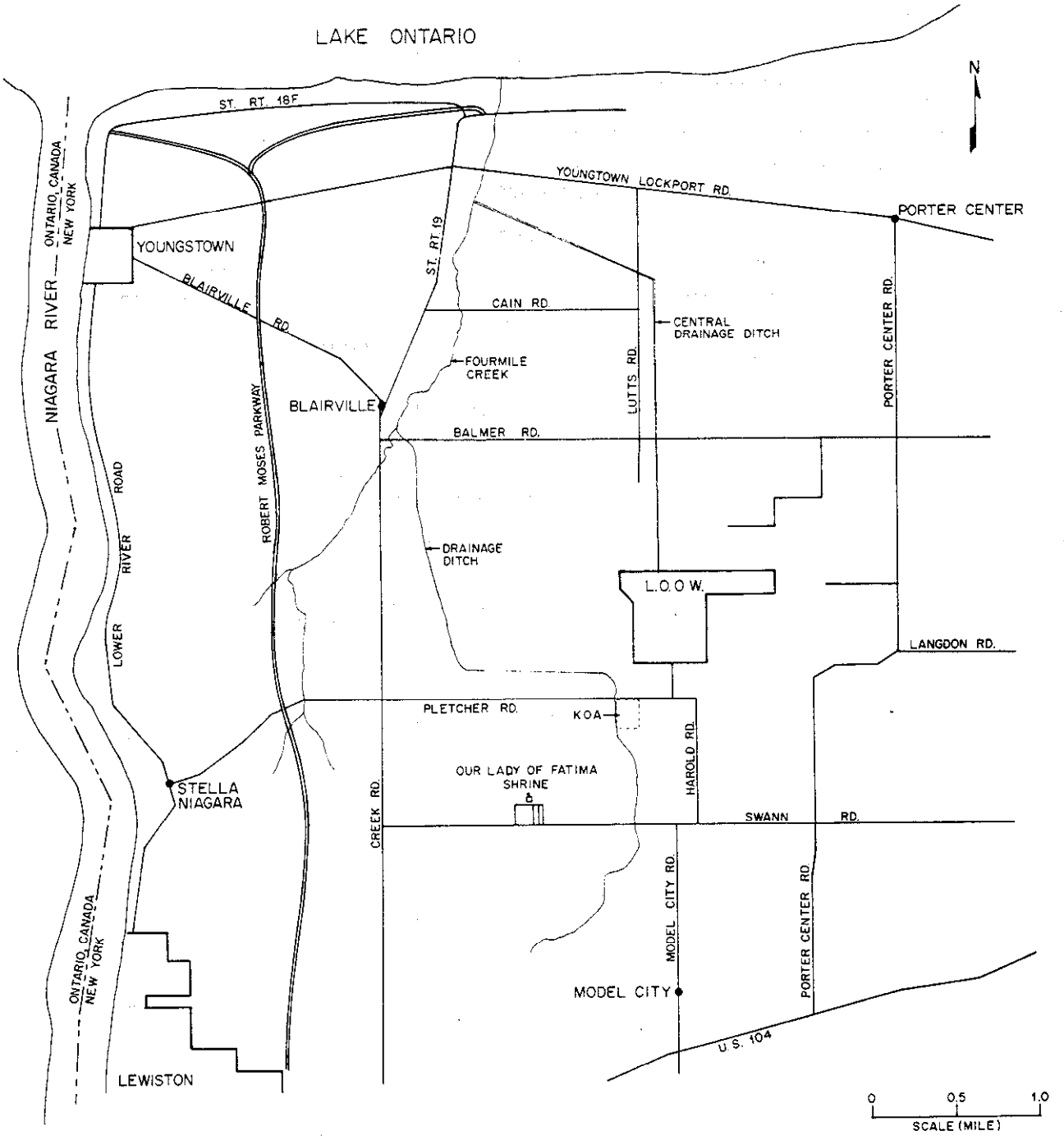

Fig. 1. Location of Lake Ontario Ordnance Works site and view of surrounding area.

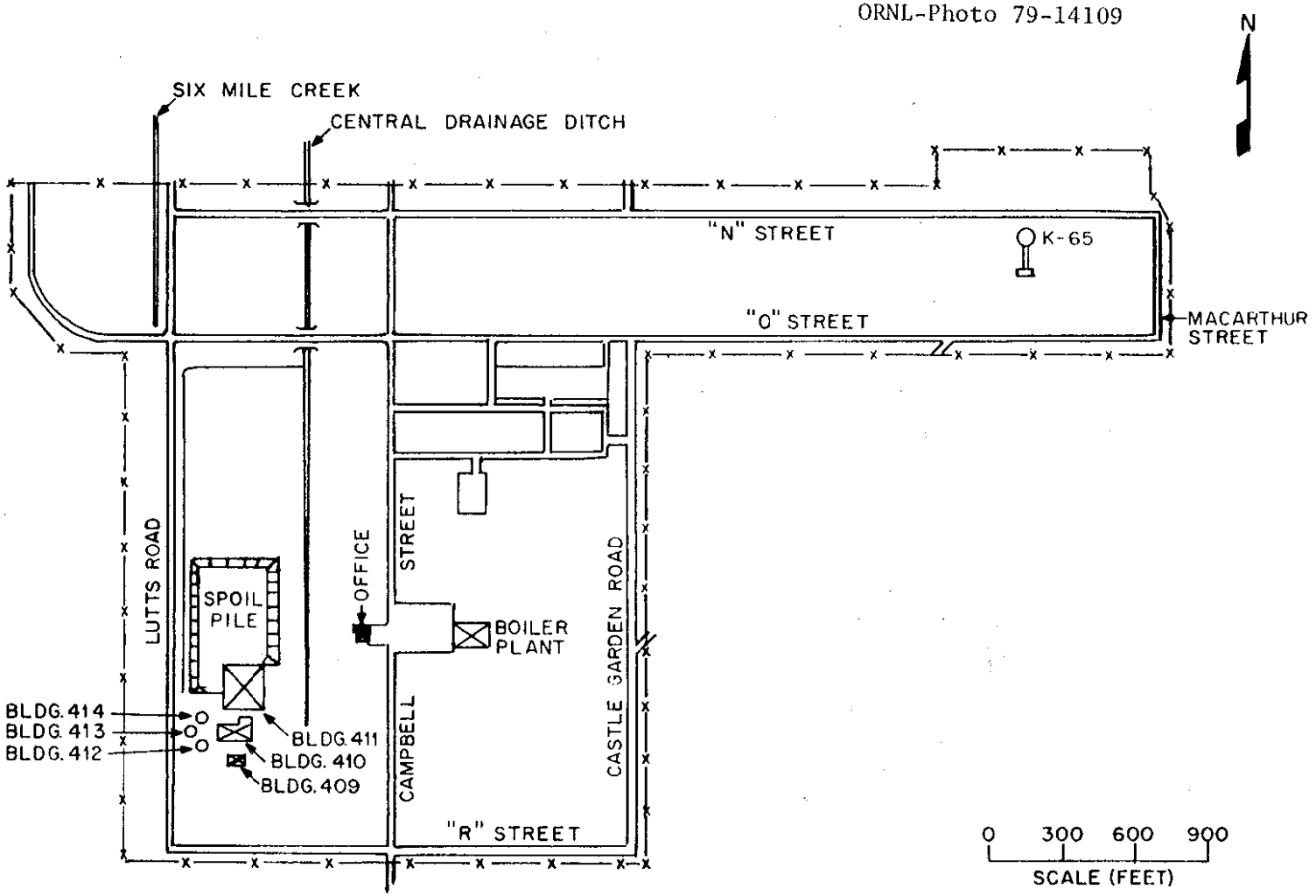

Fig. 2. Scaled drawing of Lake Ontario Ordnance Works site.

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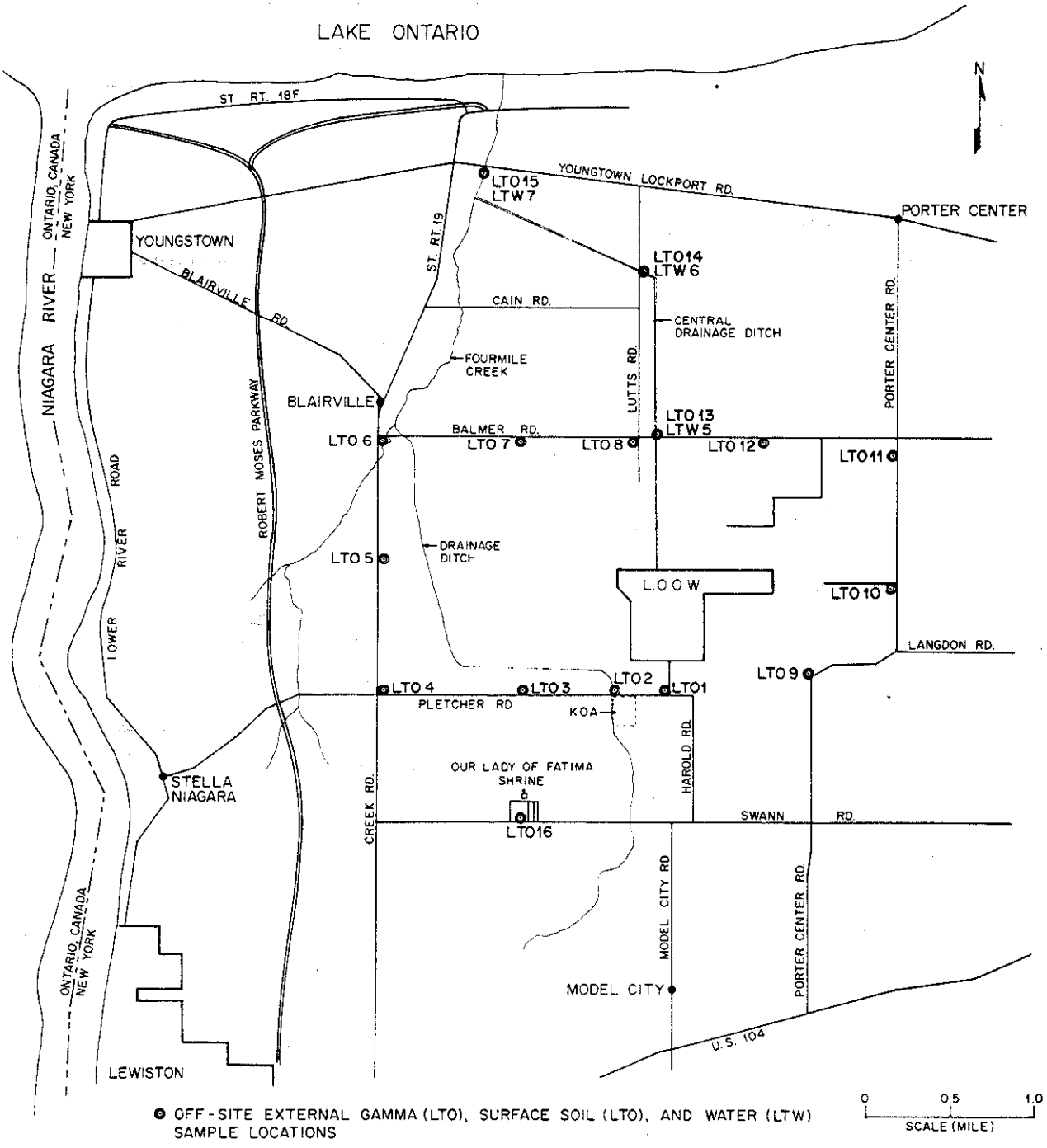

Fig. 3. Off-site locations of external gamma measurements and samples of surface soil and water.

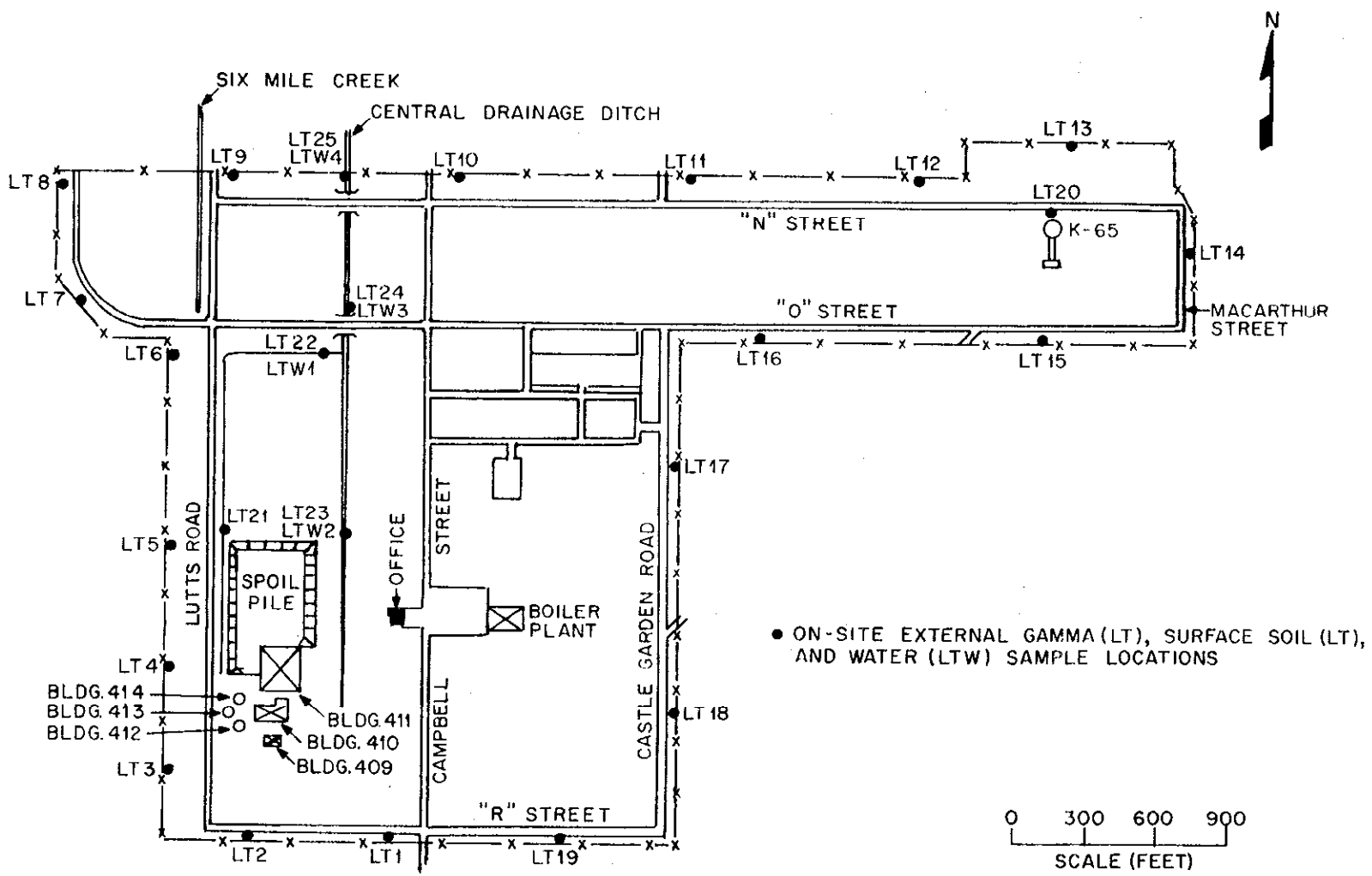

Fig. 4. On-site locations of external gamma measurements and samples of surface soil and water (excluding spoil pile).

ORNL-DWG. 79-14112

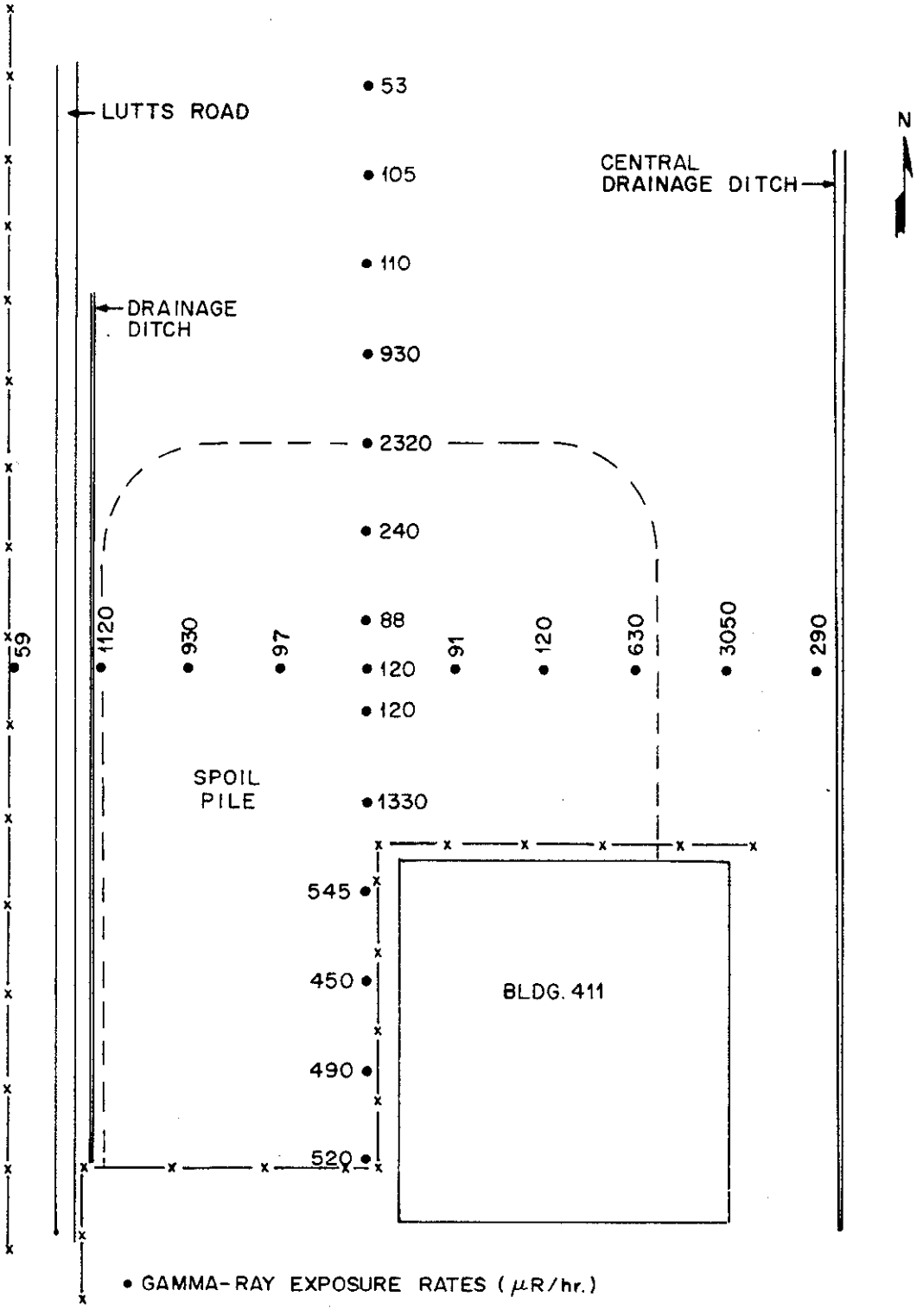

Fig. 5. On-site locations and mean external gamma exposure levels (μR/hr) taken on the spoil pile.

ORNL-DWG. 79-14113

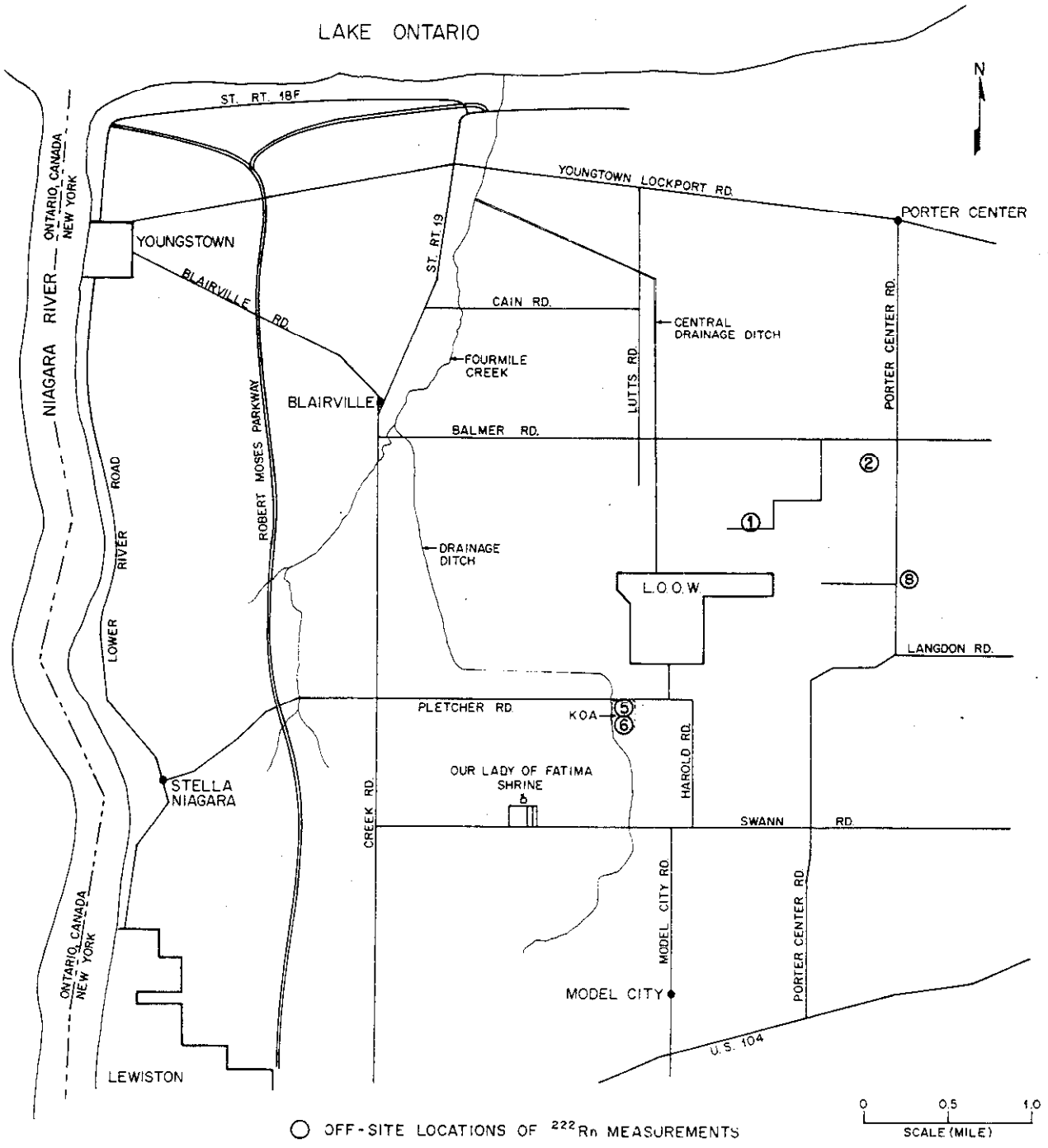

Fig. 6. Off-site locations of measurements for ^{222}Rn concentrations in air.

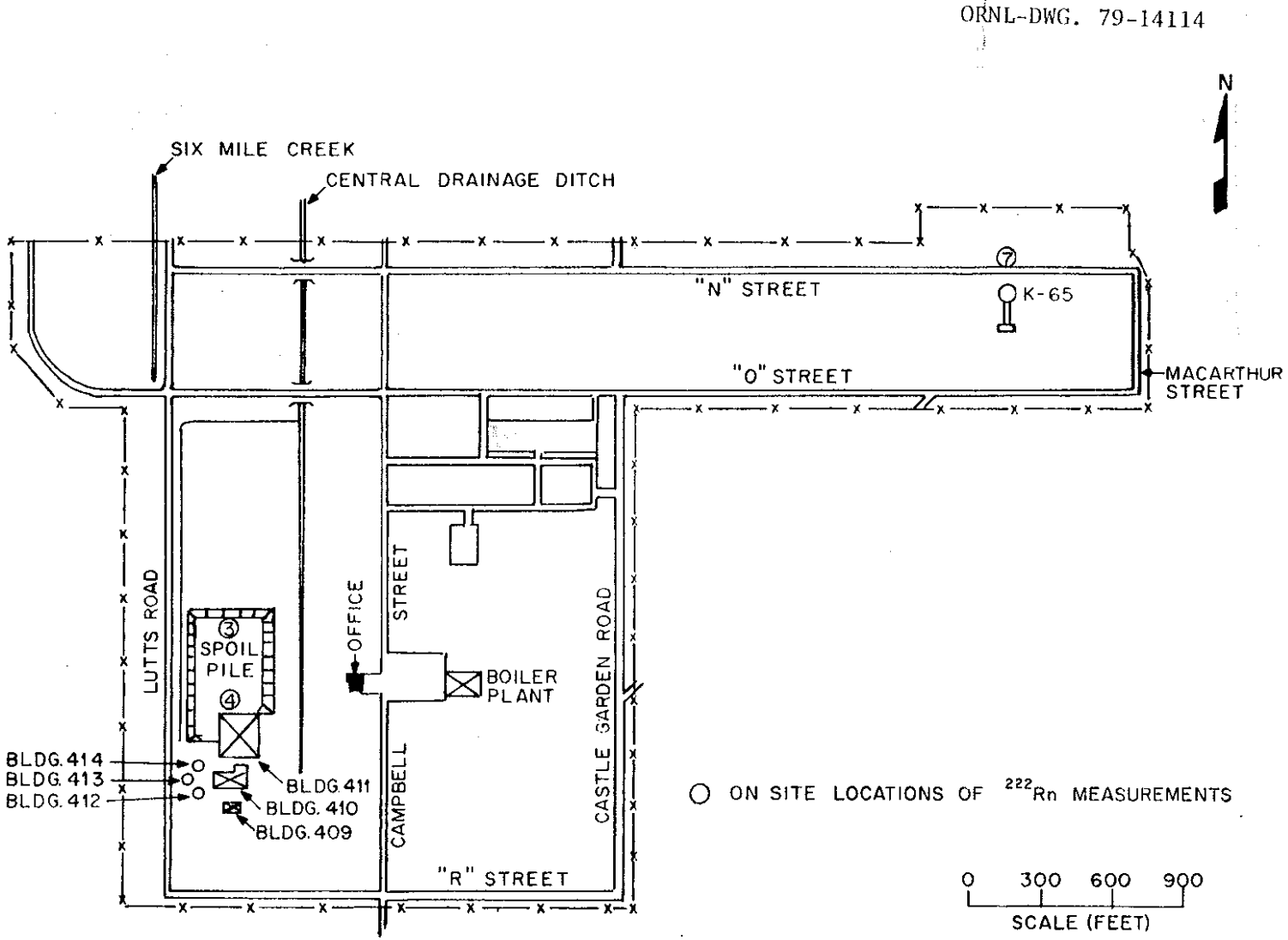

Fig. 7. On-site locations of measurements for ^{222}Rn concentrations in air.

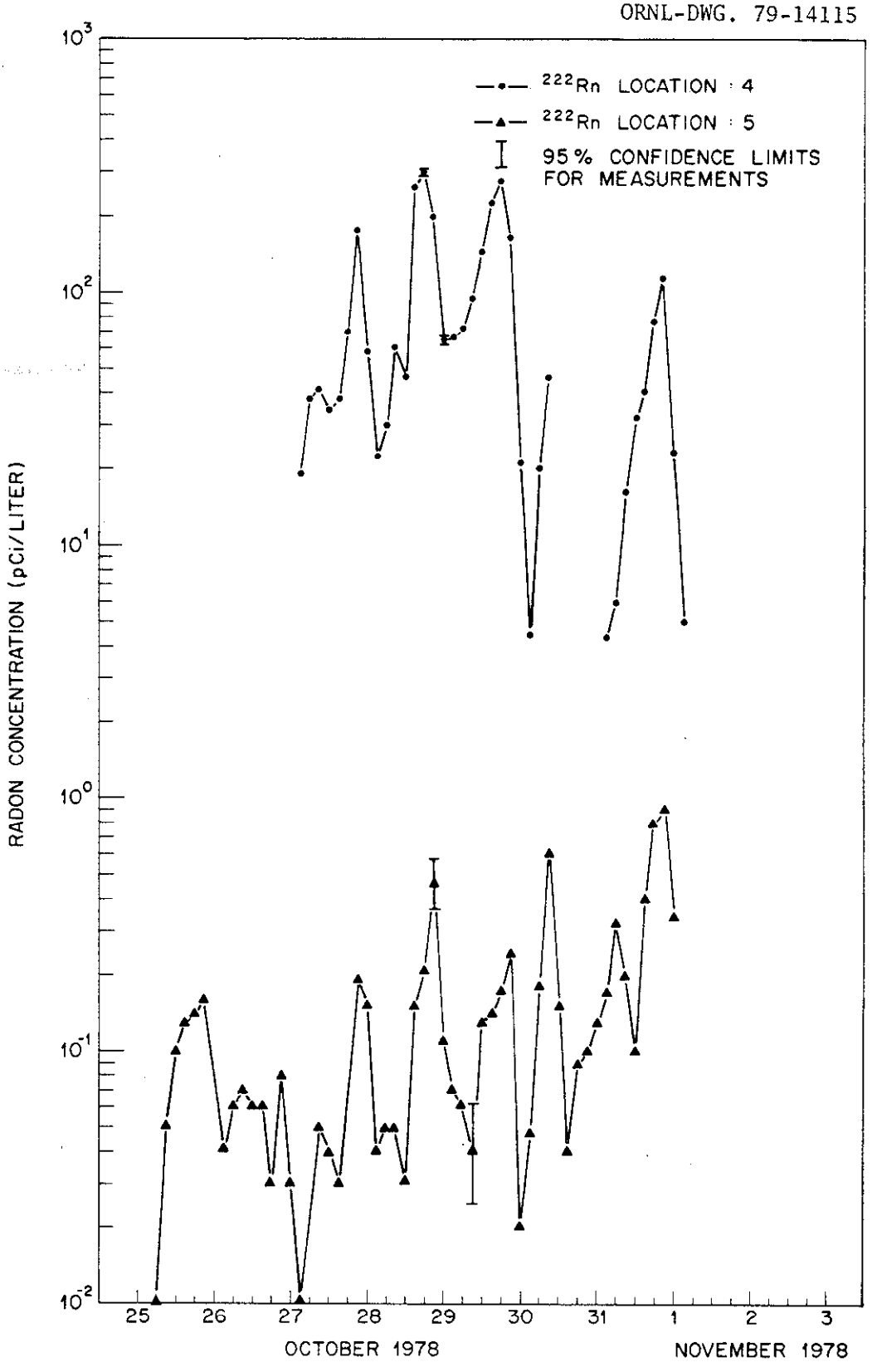

Fig. 8. Graph of ^{222}Rn concentration change with time at one on-site and one off-site location.

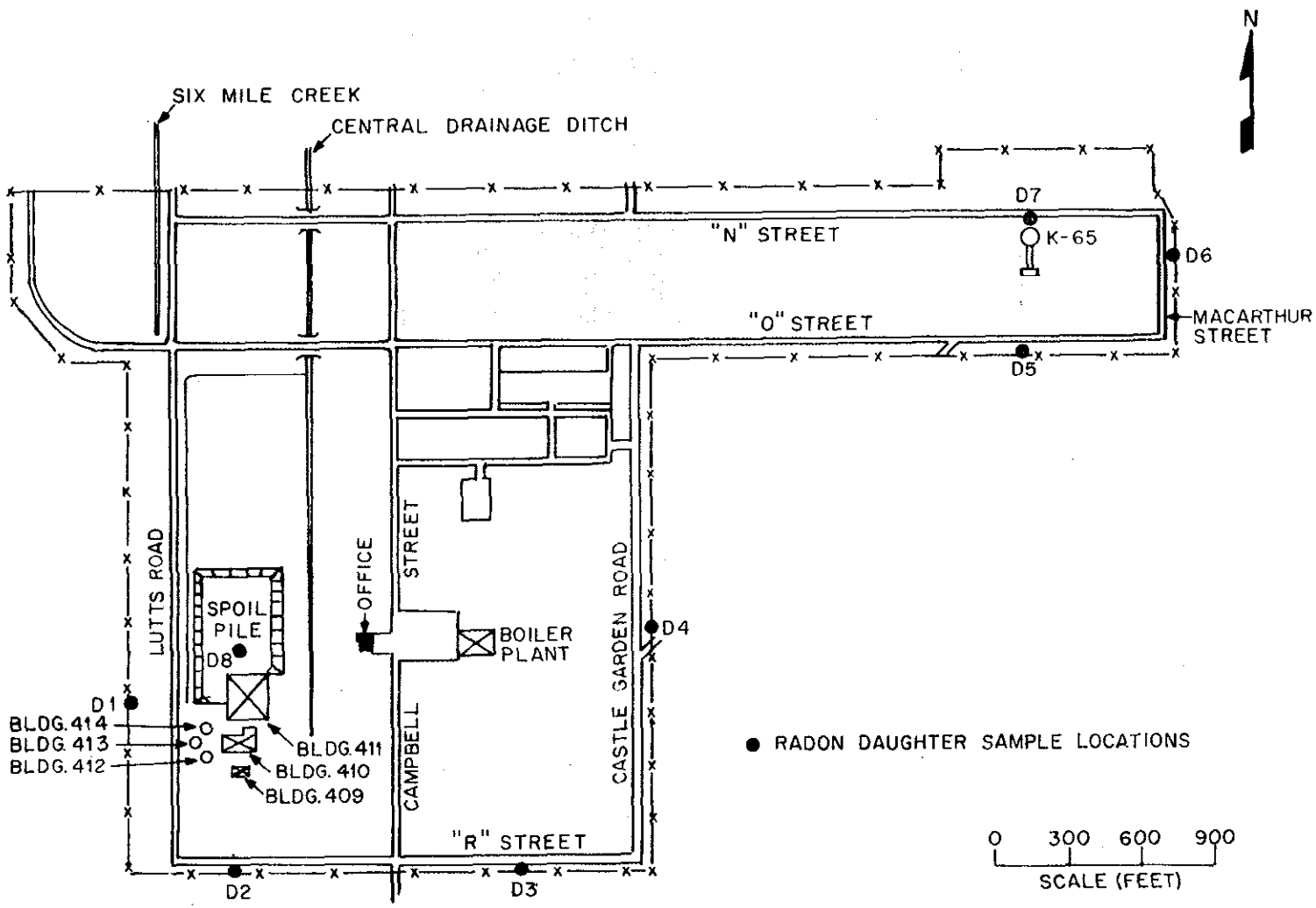

Fig. 9. Locations of measurements for ^{222}Rn daughter concentrations in air.

Table 1. Radioactive residues stored at Lake Ontario Ordnance Works site (adapted from references 2 and 3)

Ownership	Residue	Storage location[a]	Dry weight (tons)	U content (tons)
DOE	Middlesex sands	410	2	0.09
DOE	R-10	[b]	8235	10.1
	R-10 Iron cake	[b]	150	0.5
African metals	K-65	K-65 tower	1757	5.5
African metals	F-32	[c]	138	1.5
African metals	L-30	411	8227	20.3
African metals	L-50	413 and 414	1878	2.1

[a] See Fig. 2 for location.

[b] Stored on spoil pile and covered by topsoil.

[c] Southwest corner of Bldg. 411 between Bldgs. 410 and 411.

Table 2. Mean external gamma exposure levels at off-site locations 1 m above ground surface

Location shown in Fig. 3	Reading (μR/hr)
LTO1	8
LTO2	5
LTO3	8
LTO4	3
LTO5	4
LTO6	3
LTO7	3
LTO8	6
LTO9	6
LTO10	6
LTO11	6
LTO12	5
LTO13	10
LTO14	11
LTO15	6

Table 3. Mean external gamma exposure levels at on-site locations (excluding spoil pile) 1 m above ground surface

Location shown in Fig. 4	Reading (μR/hr)
LT1	8
LT2	10
LT3	13
LT4	46
LT5	33
LT6	8
LT7	5
LT8	8
LT9	5
LT10	8
LT11	8
LT12	17
LT13	21
LT14	23
LT15	36
LT16	13
LT17	9
LT18	8
LT19	7
LT20	250
LT21	355
LT22	8
LT23	325
LT24	22
LT25	18

Table 4. Mean external gamma exposure levels on the spoil pile at on-site locations 1 m above ground surface[a]

South to north traverse of spoil pile		West to east traverse of spoil pile	
Distance from south end (ft)	Reading (μR/hr)	Distance from west end (ft)	Reading (μR/hr)
0	520	0	59
50	490	50	1100
100	450	100	930
150	540	150	97
200	1300	200	120
250	120	250	91
300	88	300	120
350	240		
400	2300	350	630
450	930	400	3000
500	110	450	290
550	100		
600	53		

[a]See Fig. 5.

Table 5. Concentration of ^{222}Rn in air at off-site and on-site locations[a]

Location (Chamber No.)	Date	No. of measurements	Period of time monitored	Maximum value observed (pCi/liter)	Time of maximum value	Daily mean (pCi/liter)
1	10/26/78	7	3:06PM – 10:53PM	0.25	6:26PM	0.13
1	10/27/78	21	12:00AM – 11:10PM	0.37	10:04PM	0.17
1	10/28/78	21	12:00AM – 11:00PM	0.41	1:00PM	0.21
1	10/29/78	17	12:06AM – 5:00PM	0.76	6:46AM	0.28
1	10/30/78	8	4:13PM – 11:59PM	0.55	8:40PM	0.34
1	10/31/78	21	12:00AM – 11:19PM	0.39	5:47PM	0.26
1	11/1/78	11	12:00AM – 11:51AM	0.78	7:24AM	0.45
2	10/25/78	7	4:28PM – 11:28PM	0.70	11:28PM	0.43
2	10/26/78	24	12:00AM – 11:59PM	0.71	12:29PM	0.27
2	10/27/78	24	12:00AM – 11:59PM	0.71	4:02PM	0.24
2	10/28/78	24	12:00AM – 11:59PM	0.66	12:05AM, 1:05PM	0.23
2	10/29/78	24	12:00AM – 11:59PM	0.45	6:08AM	0.15
2	10/30/78	24	12:00AM – 11:59PM	0.27	7:11AM	0.10
2	10/31/78	23	12:00AM – 10:09PM	0.45	11:09AM	0.20
2	11/1/78	11	12:00AM – 10:12AM	0.43	8:12AM	0.24
3	10/27/78	10	1:58PM – 11:58PM	3.3	5:58PM	2.8
3	10/28/78	23	12:00AM – 10:58PM	17	7:58AM	4.7
3	10/29/78	24	12:00AM – 11:59PM	44	6:28AM	16
3	10/30/78	18	12:00AM – 4:28PM	36	3:28AM	24
3	10/31/78	11	12:58PM – 11:53PM	110	5:58PM	27
3	11/1/78	14	12:00AM – 1:55PM	435	6:55AM	190
4	10/27/78	10	1:58AM – 11:58PM	44	6:58PM	34
4	10/28/78	24	12:00AM – 11:59PM	220	7:01AM	64
4	10/29/78	24	12:00AM – 11:59PM	345	4:28AM	150
4	10/30/78	19	12:00AM – 6:58PM	340	3:58AM	115
4	10/31/78	10	1:23PM – 11:23PM	39	11:23PM	16
4	11/1/78	14	12:00AM – 1:25AM	125	5:25AM	55

Table 5. (continued)

Location (Chamber No.)	Date	No. of measurements	Period of time monitored	Maximum value observed (pCi/liter)	Time of maximum value	Daily mean (pCi/liter)
5	10/25/78	8	3:40PM – 11:40PM	0.14	11:40PM	0.06
5	10/26/78	24	12:00AM – 11:59PM	0.24	8:40AM	0.09
5	10/27/78	24	12:00AM – 11:59PM	0.10	7:40AM	0.04
5	10/28/78	24	12:00AM – 11:59PM	0.25	8:40AM	0.08
5	10/29/78	24	12:00AM – 11:59PM	0.57	6:40AM	0.16
5	10/30/78	24	12:00AM – 11:59PM	0.74	7:40PM	0.19
5	10/31/78	24	12:00AM – 11:59PM	0.49	5:40PM	0.14
5	11/1/78	10	12:00AM – 9:40AM	1.1	6:40AM	0.66
6	10/25/78	8	3:40AM – 11:40PM	0.14	6:40PM	0.07
6	10/26/78	24	12:00AM – 11:59PM	0.19	10:40AM	0.09
6	10/27/78	24	12:00AM – 11:59PM	0.10	3:40AM, 8:40PM	0.05
6	10/28/78	24	12:00AM – 11:59PM	0.27	8:40AM	0.12
6	10/30/78	24	12:00AM – 11:59PM	0.92	7:40PM	0.26
6	10/31/78	24	12:00AM – 11:59PM	0.57	5:40PM	0.20
6	11/1/78	10	12:00AM – 9:40PM	1.1	5:40AM	0.69
7	10/27/78	13	10:25AM – 11:25PM	0.18	12:25PM	0.12
7	10/28/78	2	12:00AM – 1:25AM	0.06	12:25AM	0.04
7	10/29/78	1	12:56AM – 1.56AM	0.02	1:56AM	0.02
7	10/30/78	13	10:58AM – 11:58PM	1.4	7:58PM	0.45
7	10/31/78	24	12:00AM – 11:59PM	1.9	5:58PM	0.41
8	10/25/78	6	5:10PM – 11:10PM	0.13	7:10PM	0.09
8	10/26/78	24	12:00AM – 11:59PM	0.34	5:15PM	0.14
8	10/27/78	24	12:00AM – 11:59PM	0.22	8:10AM	0.10
8	10/28/78	24	12:00AM – 11:59PM	0.52	9:13AM	0.17
8	10/29/79	24	12:00AM – 11:59PM	0.23	2:16AM, 6:16PM	0.09
8	10/30/79	24	12:00AM – 11:59PM	0.43	7:19PM	0.12
8	10/31/79	24	12:00AM – 11:59PM	1.4	3:16PM	0.28
8	11/1/79	11	12:00AM – 10:19AM	0.86	6:19AM	0.51

[a]See Fig. 6 and 7, respectively.

Table 6. Summary of mean concentrations of ^{222}Rn in air at off-site and on-site locations

Location[a]	Time interval (days)	Mean ^{222}Rn concentration (pCi/liter)
1	7	0.26
2	8	0.23
3	6	44
4	6	72
5	8	0.18
6	8	0.21
7	5	0.21
8	8	0.19

[a]See Fig. 6 and 7.

Table 7. Concentrations of ^{222}Rn daughters in air

Location shown in Fig. 9	Radionuclide concentrations in air (pCi/liter)			Working levels
	^{218}Po(RaA)	^{214}Pb(RaB)	^{214}Bi(RaC)	
D1	0.04	0.09	0.03	0.001
D2	0.04	0.06	0.09	0.001
D3	0.03	0.08	0.06	0.001
D4	0.11	0.11	0.06	0.001
D5	0.18	0.14	0.17	0.002
D6	0.20	0.17	0.17	0.002
D7	0.24	0.16	0.16	0.002
D8	0.46	0.04	0.06	0.001
D8	0.28	0.00	0.09	0.001

Table 8. Concentration of ^{238}U, ^{226}Ra, ^{232}Th, and ^{137}Cs in surface soil samples at off-site locations

Location shown in Fig. 3	Radionuclide concentrations (pCi/g)[a]			
	^{238}U	^{236}Ra	^{232}Th	^{137}Cs
LT01	1.89	1.23 ± 2%	1.0 ± 3%	0.74
LT02	1.32	1.23 ± 3%	1.1 ± 3%	0.84 ± 2%
LT03	0.88	1.01 ± 3%	0.76 ± 4%	0.76 ± 4%
LT04	0.85	1.57 ± 1%	0.94 ± 3%	0.97 ± 26%
LT05	0.88	0.66 ± 5%	0.55 ± 14%	0.49 ± 6%
LT06	0.77	0.80 ± 4%	0.73 ± 3%	0.20 ± 10%
LT07	0.91	0.79 ± 3%	0.97 ± 4%	1.02 ± 2%
LT08	1.04	0.77 ± 4%	0.49	0.96 ± 3%
LT09	0.98	1.01 ± 2%	1.07 ± 3%	0.18 ± 6%
LT010	0.94	0.86 ± 2%	0.87 ± 2%	1.50 ± 5%
LT011	0.74	[b]	0.53 ± 4%	0.74 ± 7%
LT012	0.78	0.77 ± 3%	0.79 ± 3%	0.78 ± 3%
LT013	1.37	5.83 ± 11%	0.93 ± 4%	0.70 ± 3%
LT014	0.22	1.10 ± 4%	0.75 ± 4%	[b]
LT015	0.71	0.67 ± 3%	0.55 ± 11%	[b]
LT016	52.7	53.7 ± 1%	[b]	[b]
Mean	0.95[c]	1.31[c]	0.80	0.76

[a] Indicated errors associated with these concentrations are two sigma (95% confidence).

[b] Below detection limits.

[c] LT016 was omitted in determining mean.

Table 9. Concentration of ^{238}U, ^{226}Ra, ^{227}Ac, ^{232}Th, and ^{137}Cs in surface soil samples at on-site locations

Location shown in Fig. 4	Radionuclide concentrations (pCi/g)[a]				
	^{238}U	^{226}Ra	^{227}Ac	^{232}Th	^{137}Cs
LT1	1.72	1.64 ± 2%	[b]	1.02 ± 4%	0.35 ± 6%
LT2	1.88	1.82 ± 2%	[b]	1.11 ± 4%	1.02 ± 2%
LT3	1.50	1.21 ± 3%	[b]	0.85 ± 5%	0.40 ± 5%
LT4	2.04	9.27 ± 1%	[b]	1.08 ± 5%	1.15 ± 2%
LT5	2.13	12.9 ± 1%	[b]	1.11 ± 5%	1.38 ± 4%
LT6	0.99	8.07 ± 1%	[b]	[b]	[b]
LT7	1.02	0.79 ± 3%	[b]	0.97 ± 2%	1.05 ± 4%
LT8	2.05	0.77 ± 6%	[b]	0.90 ± 4%	1.00 ± 3%
LT9	0.87	0.89 ± 2%	[b]	0.76 ± 4%	1.91 ± 2%
LT10	0.95	1.27 ± 2%	[b]	1.03 ± 3%	1.01 ± 4%
LT11	0.96	1.52 ± 3%	[b]	0.77 ± 3%	0.67 ± 66%
LT12	0.98	1.21 ± 2%	[b]	1.05 ± 4%	0.83 ± 2%
LT13	0.80	1.63 ± 1%	[b]	0.84 ± 32%	0.77 ± 5%
LT14	0.85	0.83 ± 5%	[b]	0.51 ± 6%	0.86 ± 6%
LT15	1.07	1.13 ± 3%	[b]	0.71 ± 4%	1.98 ± 3%
LT16	0.97	2.39 ± 2%	[b]	1.00 ± 3%	1.07 ± 4%
LT17	1.45	3.72 ± 1%	[b]	0.99 ± 3%	1.11 ± 2%
LT18	3.08	1.76 ± 2%	[b]	1.19 ± 3%	1.57 ± 35%
LT19	1.74	1.40 ± 2%	[b]	1.08 ± 2%	1.11 ± 3%
LT20	0.89	4.49 ± 2%	[b]	0.47 ± 11%	3.16 ± 2%
LT21	11.7	239 ± 1%	13.6 6%	1.76 ± 18%	[b]
LT22	1.21	16.0 ± 1%	[b]	1.05 ± 33%	[b]
LT23	8.50	260 ± 1%	11.4 ± 10%	[b]	[b]
LT24	5.10	6.52 ± 2%	0.07 ± 29%	1.02 ± 4%	[b]
LT25	2.48	4.21 ± 1%	0.58 ± 10%	1.07 ± 4%	[b]
Mean	2.28	23.4	[c]	0.97	1.18

[a] Indicated errors associated with these concentrations are two sigma (95% confidence).

[b] Below detection limits.

[c] No sufficient number of values for representative mean.

Table 10. Concentrations of ^{238}U, ^{226}Ra, ^{210}Pb, and ^{230}Th in water samples at off-site and on-site locations

Location shown in Figs. 3 and 4	Radionuclides in water (pCi/ml)[a]				Radionuclides in water solids (pCi/g)[a]			
	^{238}U	^{226}Ra	^{210}Pb	^{230}Th	^{238}U	^{226}Ra	^{210}Pb	^{230}Th
LTW1	0.0043	0.0009 ± 100%	0.0032 ± 86%	<0.0005	0.0018	9.00 ± 125%	45.0 ± 150%	7.66 ± 24%
LTW2	0.0926	0.0631 ± 43%	0.0252 ± 23%	0.0162 ± 8%	1.54	250 ± 5%	292 ± 5%	401 ± 2%
LTW3	0.0746	0.0032 ± 14%	0.0090 ± 50%	0.0014 ± 33%	0.0390	57.7 ± 12%	<45.0	122 ± 5%
LTW4	0.0729	0.0027 ± 17%	0.0090 ± 50%	0.0009 ± 50%	0.0239	36.0 ± 19%	<45.0	59.0 ± 9%
LTW5	0.0466	<0.0005	0.0045 ± 100%	0.0009 ± 50%	0.0038	5.86 ± 231%	45.0 ± 300%	<13.5
LTW6	0.0240	0.0009 ± 50%	0.0045 ± 100%	<0.0005	0.0044	13.5 ± 133%	54.1 ± 250%	<18.0
LTW7	0.0017	<0.0005	<0.0045	<0.0005	*b*	*b*	*b*	*b*
CG_w[c]	30	0.03	0.10	2.0				

[a] Indicated errors associated with these concentrations are two sigma (95% confidence).

[b] Insufficient solid fraction available for analysis.

[c] Concentration guide for soluble radionuclide above natural background for water, 10 CFR 20, Appendix B, Table II, Column 2, and ERDAM 0524, Annex A.

APPENDIX I

SUMMARY OF PREVIOUS RADIOLOGICAL SURVEYS AT LAKE ONTARIO ORDNANCE WORKS SITE

AEC RADIATION SURVEY: October 12-16, 1970[I-1]

During the period October 12-16, 1970, a five-man AEC team performed a radiation survey of selected on- and off-site locations that once comprised the Lake Ontario Ordnance Works (LOOW) site. The survey indicated there were about seven main contaminated areas on the LOOW site in addition to recognized residue storage areas. Three of these locations (areas 200 ft^2 to about an acre) measured external gamma levels from 1 mR/hr to a maximum of 125 mR/hr. Soil samples at these three locations indicated ^{137}Cs was the contaminant at one location and uranium and radium at the other two locations. The remaining four locations at LOOW involved localized contamination with no area greater than a 5 ft radius. Maximum reading found at any of these four locations was 40 mR/hr.

One day was given to surveying five off-site locations. Two of these locations (approximately 1000 and 1500 ft north of LOOW site) indicated presence of storage and/or burial of radioactive material. The areas were 700 and 400 ft^2 with an adjacent three to five acres of contaminated stored scrap. Several specific areas at these two locations measured external gamma levels above 1 mR/hr and up to a maximum of 50 mR/hr at one spot. The other three off-site locations surveyed contained low-level contaminated scrap with a few specific small spots (2 to 20 ft^2) with radiation levels up to 40 mR/hr.

RADIATION SURVEY: NOVEMBER 30 - December 7, 1970[I-2]

During the period November 30 through December 7, 1970, a ten-man team was assembled to evaluate the extent of radioactive contamination

on approximately 1100 acres of land previously included in the LOOW site. All areas off the site that indicated a history of potential contamination (approximately 100 acres) were surveyed. The remaining 1000 acres were to be surveyed at a later date. Location of those areas that were surveyed are shown in Fig. I-1, and summary results are listed in Table I-1. From the results obtained, it was estimated that decontamination of these areas required excavation of 4200 yd^3 of material.

RADIATION SURVEY: JUNE 7-20, 1971[I-3]

During the period June 7-20, 1971, a ten-man team was assembled to survey all property previously under AEC control at the LOOW site to determine the extent of radioactive contamination. Results of this survey dictated the areas to be decontaminated at locations exceeding the AEC criteria of 50 μR/hr (including background). Low-level NaI scintillation survey meters were used during the survey. The location of the areas surveyed are shown in Fig. I-1. Table I-2 lists results of the survey where measurements were made at 50 ft intervals. Table I-3 lists results of the survey measurements made at 20 ft intervals, and Table I-4 is a table summarizing areas exceeding various dose-rate levels. Based on this survey, it was concluded that approximately 6.5 acres exceeded the AEC 50 μR/hr standard. Decontamination was performed by contracted excavation of soil, gravel, and rubble from local areas of contamination to a depth of 1 ft. A total of 15,000 to 20,000 yd^3 of excavated material was removed to a spoil pile on the remaining AEC site.

A post-decontamination survey was performed, and the results are summarized in Table I-5. The survey indicated that only a few portions of the central drainage ditch and Six Mile Creek exceeded the 50 μR/hr criteria (highest levels noted were 120 and 70 μR/hr, respectively) and beta-gamma levels measured at contact were less than 0.2 mrad/hr.[I-3,I-4]

EG&G AERIAL RADIOLOGICAL SURVEY: JUNE 17, 1972

On June 17, 1972, the Aerial Radiological Measuring System (ARMS) operated by EG&G, Inc., performed an aerial radiological survey of LOOW to supplement measurements taken by the AEC/ORO.[I-5] External gamma measurements were taken at approximately 300 ft. Results of the aerial survey are listed in Table I-6 and compared with values obtained by the AEC/ORO survey conducted concurrently with the ARMS survey. Values in Table I-6 have been averaged over each area and are reported in μR/hr.

RADIOLOGICAL SURVEYS: 1973 - April 1979

The National Lead Company of Ohio (NLO) has sampled and analyzed ground and surface water on and around the LOOW site at periodic intervals for a number of years. Analyses do not indicate radioactivity in surface water significantly above background. Well water sample analyses indicate that ^{226}Ra and uranium concentrations are substantially below levels specified in guidelines for water in uncontrolled areas.[I-4]

National Lead Company of Ohio has periodically utilized the DOE Environmental Measurements Laboratory's (EML) sampling equipment and analytical services for radon sampling since August 1977. In August 1978, the EML began on- and off-site radon monitoring (indoors and

outdoors) to supplement fence-line monitoring conducted by National Lead Company of Ohio.[I-4] Samples have been taken for one week periods approximately twice a month since this time. Sampling locations for radon concentration measurements are illustrated in Fig. I-2. Table I-7 lists radon concentrations in air at on- and off-site locations for the week ending April 5, 1979 and the range and mean of values obtained since August 1978 for each location.

Radon flux has been measured at on-site locations by EML. A portion of these measurements have been concentrated on the spoil pile. Measurements were made using a passive charcoal canister. Figure I-3 shows measurement locations on and around the spoil pile. Table I-8 lists results of measurements obtained November 13-14, 1978, and Table I-9 lists results of measurements November 20-21, 1978 (sampling time was approximately 17 hours).[I-6]

A radiological survey of the spoil pile was performed by NLO in April 1979 (see ref. I-7). The spoil pile area was laid out in 20 ft spacing in north-south and east-west directions. A G-M survey meter was used for beta-gamma measurements at 1 cm above ground. Test holes were drilled in several locations, surveyed with the G-M instrument, and visually examined for the presence of residues or other contaminated material. It was concluded from this survey that the reason for high and sometimes erratic radon concentrations in air above the spoil pile[I-6] was because of a portion of the original residue deposit was left uncovered by the spoil pile earth, and uranium and radium from the stored residues were leached by run-off water with subsequent deposition in localized areas with poor drainage characteristics.[I-7]

REFERENCES FOR APPENDIX I

I-1. Radiation Survey of LOOW Site, October 1970, report from W. T. Thornton to W. S. Johnson, dated October 26, 1970, USAEC/ORO.

I-2. Lake Ontario Ordnance Works, Niagara Falls Site, report dated January 15, 1971.

I-3. Radiation Survey and Decontamination Report of the Lake Ontario Ordnance Works Site, ORO report dated January 1973.

I-4. *Background Report for the DOE Niagara Falls Storage Site (former Lake Ontario Ordnance Works)*, Working draft, DOE, dated March 14, 1979.

I-5. EG&G, *Radiological Survey of the Lake Ontario Ordnance Works and Vicinity in June 1972*, EGG-1183-155, Technical Report No. L-1076 (November 1972).

I-6. Letter from A. C. George, Aerosol Studies Division, Environmental Measurements Laboratory/Department of Energy to M. W. Boback, National Lead Company of Ohio, dated November 28, 1978.

I-7. National Lead Company of Ohio, *Spoil Pile Radiological Survey, DOE-Niagara Falls Site, Lewiston, New York*, NCLO No. 001EV (May 17, 1979).

ORNL-DWG. 79-14131

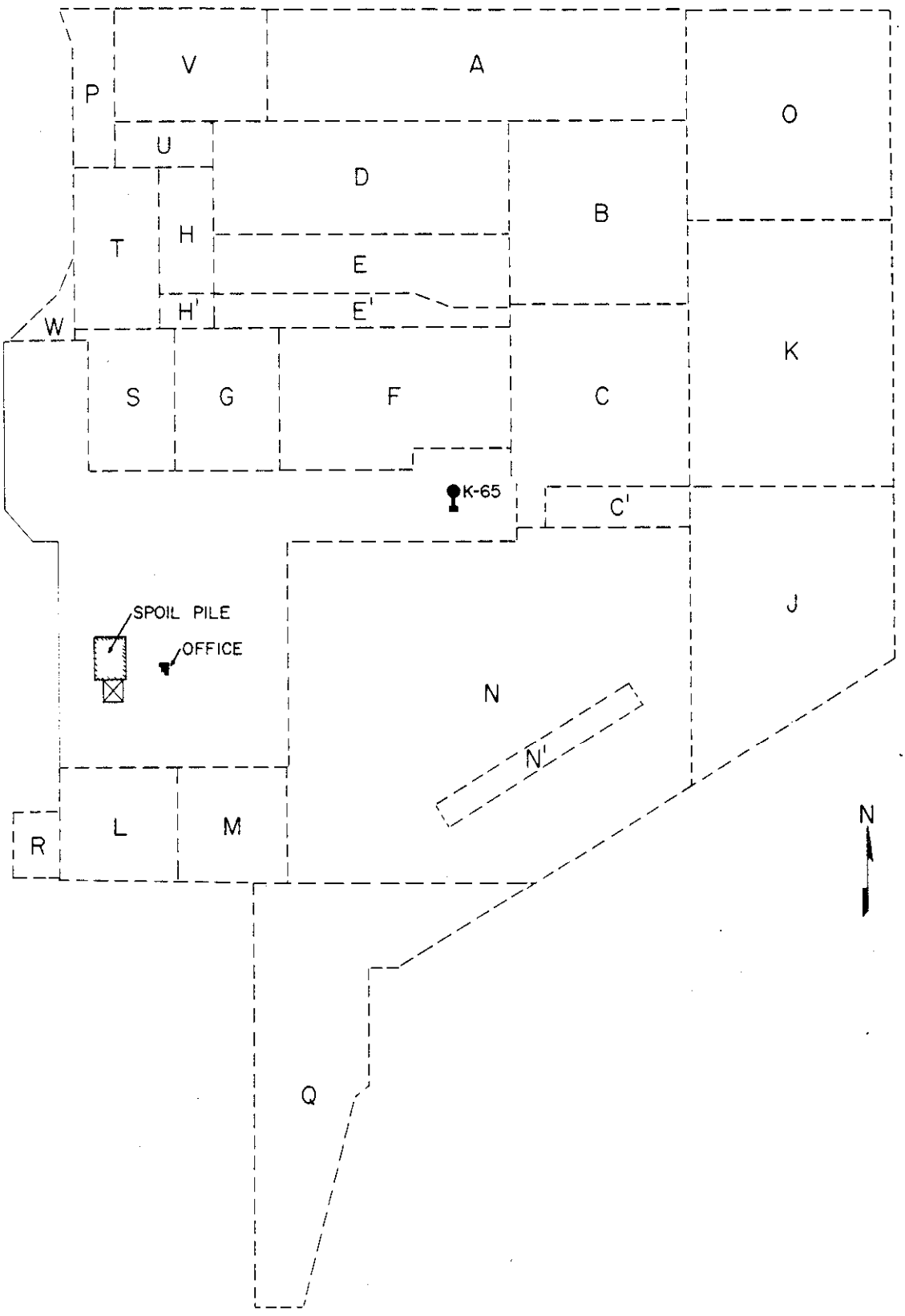

Fig. I-1. Location of survey areas at Lake Ontario Ordnance Works site.

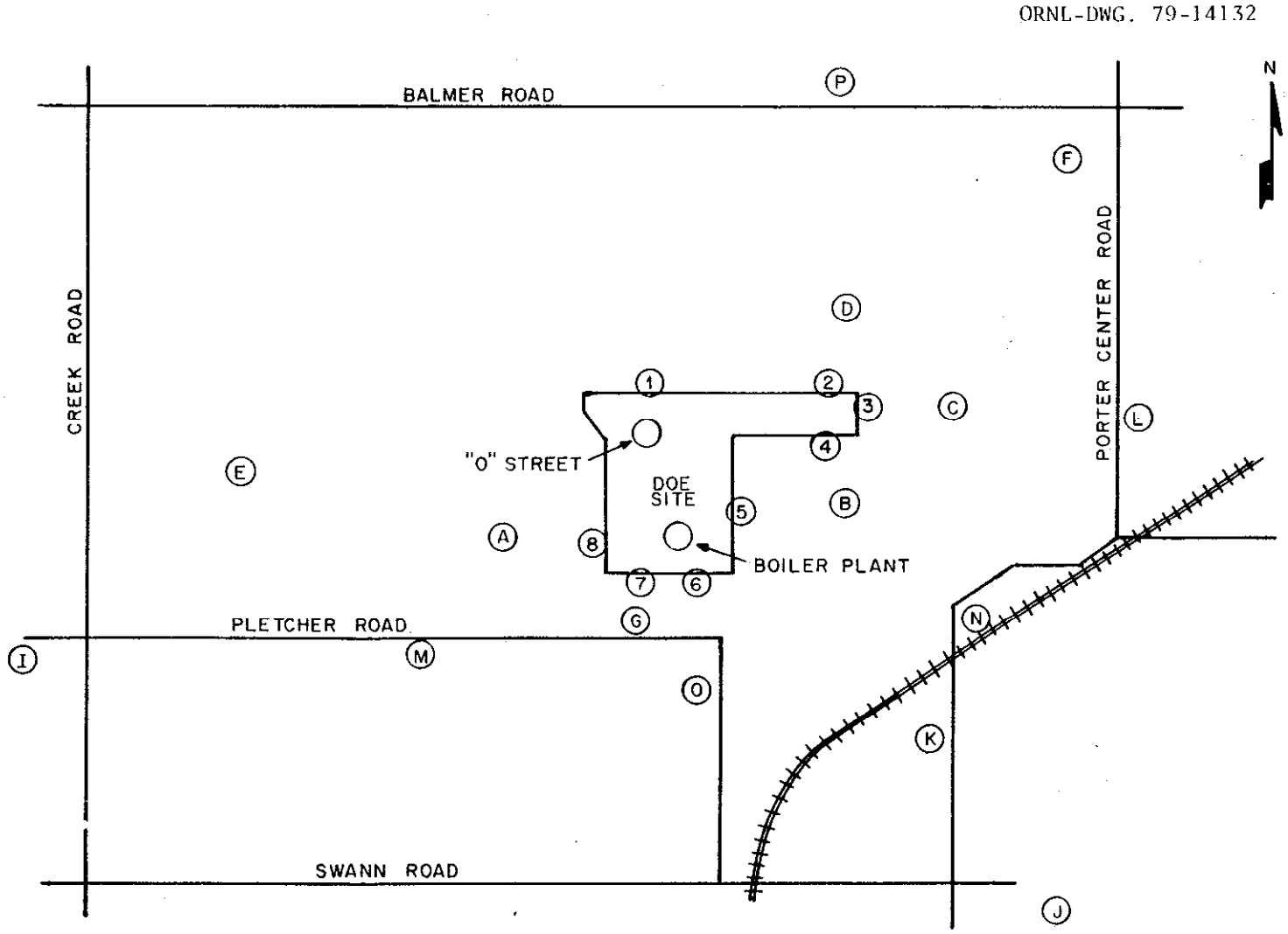

Fig. I-2. National Lead Company of Ohio/Environmental Measurements Laboratory radon monitoring locations at Lake Ontario Ordnance Works site (Ref. I-4).

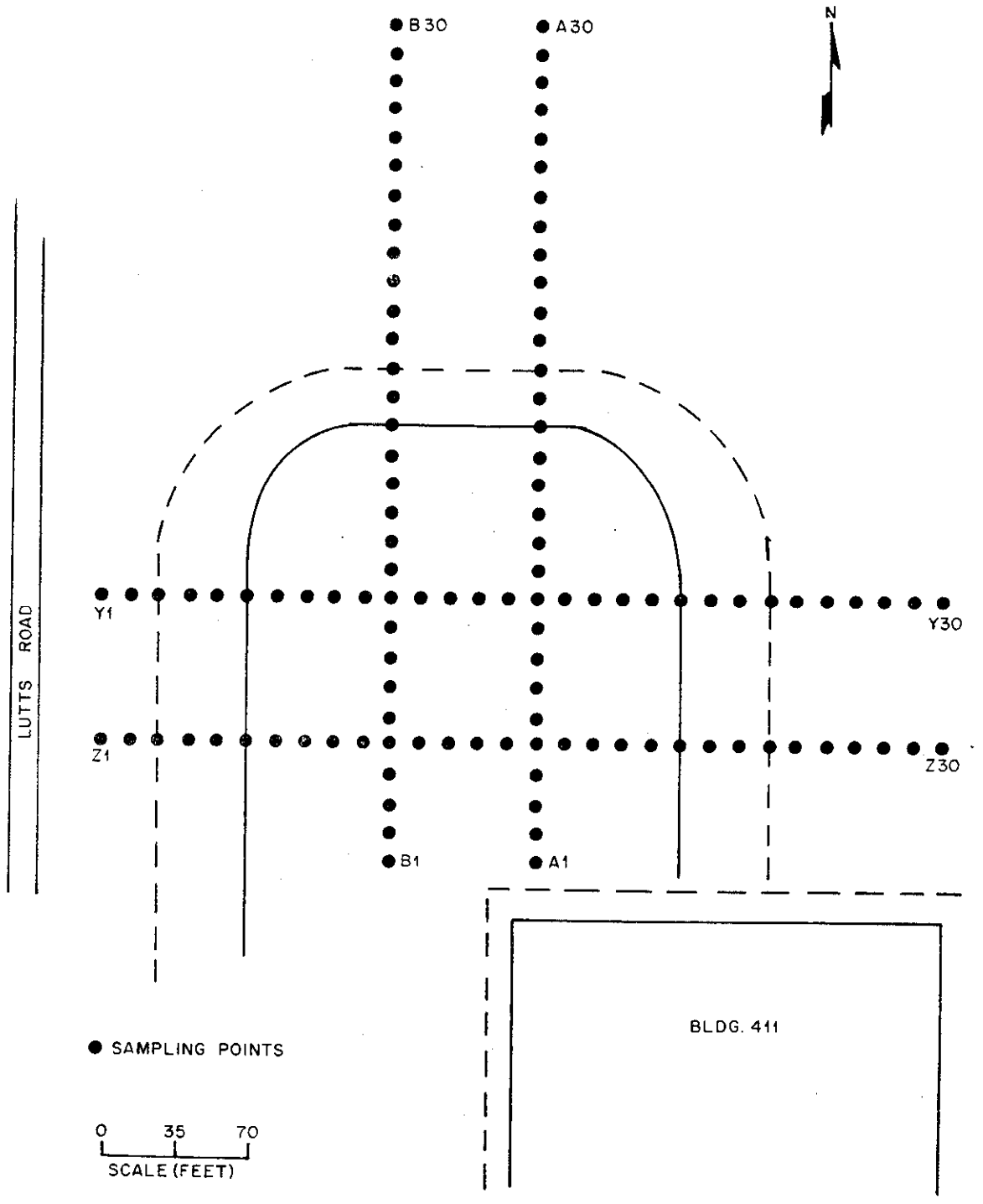

Fig. I-3. Radon flux measurement locations on and around the spoil pile at Lake Ontario Ordnance Works site.

Table I-1. Analyses of samples taken during November 30-December 7, 1970, radiation survey at the Lake Ontario Ordnance Works

Sample location (map area)	Stake No.	Uranium (mg/g)	^{226}Ra (μg/g)	^{137}Cs (dpm/g)	^{90}Sr (dpm/g)	^{239}Pu (dpm/g)
B	103	4.42[a]	4.04×10^{-2}	$\leq 6.00 \times 10^{3}$	<100	<70
B	103	20.88[a]	9.8×10^{-1}	$\leq 5 \times 10^{3}$		<50
B	104	0.034[a](soil)	$\leq 4.5 \times 10^{-3}$	2.47×10^{5}	<100	<10
		0.002(ceramic)		1.2×10^{8} (total)	<100 (total)	<10 (total)
B	105	125(cast iron + soil)	2.02×10^{-3}	$\leq 4.0 \times 10^{1}$		<10
G	124	52.29	2.68×10^{-2}	$\leq 2.0 \times 10^{2}$		<20
G	131	86	$\leq 1.0 \times 10^{-4}$	$\leq 2.5 \times 10^{1}$		<20
G	132	2.10[a]	1.26×10^{-2}	$\leq 1.25 \times 10^{2}$		<10
K	152	32.46[a]	3.8×10^{-1}	$\leq 2.5 \times 10^{3}$		<10
K	155	0.56[a]	1.08×10^{-2}	$\leq 9.0 \times 10^{1}$		<10
K	159	1.25[a]	1.82×10^{-3}	$\leq 3.0 \times 10^{1}$		<10
L	148	1.90[a]	2.57×10^{-1}	$\leq 3.50 \times 10^{3}$	<100	<30
L	148 (packing gland)	2470 (total)	$<6 \times 10^{-3}$ (total)			<10 (total)
L	149	193	$\leq 1.3 \times 10^{-4}$	$\leq 3.0 \times 10^{1}$		<10
M	142	330 (yellow rock)	$\leq 2.0 \times 10^{-4}$	$\leq 5.0 \times 10^{1}$		<10
Q	14	U-metal	$\leq 3.2 \times 10^{-4}$	$\leq 1.47 \times 10^{2}$		<10
Q	15	U-metal	$\leq 8.50 \times 10^{-5}$	$\leq 7.80 \times 10^{-1}$		<10
R	16	107	$\leq 7.5 \times 10^{-5}$	$\leq 3.4 \times 10^{-1}$		<10
S	41	0.085[a]	1.46×10^{-2}	$\leq 8.3 \times 10^{1}$		<10
T	42	509	$\leq 4.6 \times 10^{-4}$	$\leq 1.8 \times 10^{-2}$		
U	7	3.27[a]	2.0	$\leq 1.4 \times 10^{3}$		<20
V		0.61[a]	1.28×10^{-3}	$\leq 1.23 \times 10^{3}$	<100	<20
W	12	0.032[a] (charcoal)	$\leq 1.90 \times 10^{-3}$	1.77×10^{4}	6.3×10^{3}	<10
	13	0.20[a]	$\leq 7.2 \times 10^{-4}$	1.88×10^{5}	<100	<10

[a] Fluorometric assay.

[b] Weights given are on a dry sample basis.

Table I-2. Results of exposure levels at areas off the site of LOOW measured at 50-ft intervals prior to decontamination during June 7-20, 1971 (ref. I-3)

Area designation	Area (Ac)	Total No. readings	Readings <20 μR/hr	Area[a] <20 (ft^2)	Readings <50 μR/hr	Area[a] <50 (ft^2)	Readings <100 μR/hr	Area[a] <100 (ft^2)
H	16	306	28	70,000	1	2,500	0	0
J	102	1,620	0	0	0	0	0	0
A	90	1,458	0	0	0	0	0	0
E	37	654	13	32,500	0	0	0	0
D	65	1,004	2	5,000	1	2,500	0	0
C	66	1,037	104	260,000	2	5,000	2	5,000
L	27	482	220	550,000	0	0	0	0
F	52	884	214	535,000	2	5,000	0	0
Q	89	1,466	42	105,000	3	7,500	2	5,000
T	20	507	70	175,000	3	7,500	1	2,500
V	38	758	43	107,500	8	20,000	1	2,500
U	12	216	25	62,500	0	0	0	0
W	5	140	11	27,500	4	10,000	1	2,500
R	5	136	19	47,500	0	0[b]	0	0[b]
S	23	481	58	145,000	19	25,000[b]	8	10,000[b]
P	17	280	1	2,500	0	0	0	0
B[c]	59	570	10	25,000	1	2,500	1	2,500
O	99	1,710	4	10,000	0	0	0	0
M	25	432	35	87,500	0	0	0	0
K	110	1,872	0	0	0	0	0	0
N	265	3,541	402	1,005,000	13	7,500	1	2,500
Totals	1,222	19,554	1,301	3,005,000	57	105,000	16	30,000

[a]Areas were estimated on the basis of 2500 ft^2 per reading except as noted.

[b]Areas estimated previously on the basis of 1250 ft^2 per reading – all but one reading was found in main drainage ditch.

[c]About one-third of Area B was swamp.

Table I-3. Results of exposure levels at areas off the site of LOOW measured at 20-ft intervals prior to decontamination during June 7-20, 1971 (ref. I-3)

Area designation	Area (Ac)	Total No. readings	Readings <20 μR/hr	Area[a] <20 (ft^2)	Readings <50 μR/hr	Area[a] <50 (ft^2)	Readings <100 μR/hr	Area[a] <100 (ft^2)
H'	5	532	97	38,800	39	15,600	10	4,000
C'[a]	10	546	89	35,600	16	6,400	5	2,000
N'	13	1,313	800	320,000	96	38,400	53	21,200
E'	19	1,915	827	300,800	194	77,600	84	33,600
G	29	2,954	365	146,000	19	7,600	7	2,800
Totals	76	7,260	2,178	871,200	364	145,600	159	63,600

[a]About one-half of Area C' was swamp.

Table I-4. Summary of areas exceeding various dose-rate levels during LOOW survey prior to decontamination during June 7-20, 1971 (ref. I-3)

Total area surveyed	Area w/readings <20 μR/hr	Area w/readings <50 μR/hr	Area w/readings <100 μR/hr
1,298 acre	4,123,700 ft^2 (95 acre) (7% of tot)	250,000 ft^2 (6.5 acre) (0.5% of tot)	93,000 ft^3 (2 acre) (0.2% of tot)

Table I-5. Summary of post-decontamination survey, June 1972 (ref. I-3)

Area identification	Approximate area requiring decontamination (ft^2)	Depth of material removed	Type of material removed	Radiation level at 3 ft above ground surface in μR/hr									Post decontamination radium soil concentration (pCi/g)
				Before decontamination			After decontamination						
							Before backfill			After backfill			
				Min.	Max.	Avg.	Min.	Max.	Avg.	Min.	Max.	Avg.	
Area Q													
(Q-1)	200	10-12 in.	soil and gravel	35	60	45	35	50	40	30	50	37	
(Q-2)	1,000	3-4 ft	RR ballast and ties	30	4,000	1,000	30	50	40	30	50	37	
(Q-3)	6	3 ft	soil and gravel	12	600	130	10	45	21	10	30	18	
Area N'													
SW area	10,800	1 ft	rubble and soil	23	600	77	9	25	17	No backfilling done			<1
NE area	17,000	1-2 ft	rubble and soil	16	2,300	170	10	45	21	No backfilling done			82
Area H'	35,000	1-3 ft	soil	14	600	53	8	50	18	No backfilling done			<1
Area S	225	10-12 in.	soil and gravel	24	55	35	24	45	32	No backfilling done			
Area T													
(T-1)	225	10-12 in.	soil and gravel	12	75	32	12	30	23	No backfilling done			
Area B													
(B-1)	50	10-12 in.	asphalt and base	10	150	50	10	45	24	10	25	19	
Area D													
(D-1)	100	10-12 in.	soil and gravel	11	55	23	11	40	19	No backfilling done			
Area H													
(H-1)	150	10-12 in.	soil and gravel	14	70	40	14	40	31	No backfilling done			
Area V													
(V-1)	1,600	10-12 in.	soil and gravel	20	150	67	12	35	18	8	30	12	
(V-2)	1,500	10-12 in.	soil and gravel	50	90	66	17	35	24	No backfilling done			4
Area C'	5,500	10-12 in.	soil	30	800	130	8	35	16	No backfilling done			<1
Area E'													
(E-1)	134,000	1-3 ft	soil, concrete debris	14	1,500	59	8	50	20	No backfilling done			<1, 14, 19
(E-3)	1,500	3-4 ft	soil and debris	16	60	33	35	40	38	11	20	15	12
(E-4)	2,700	1-3 ft	soil and RR ballast ties	9	3,000	35	9	50	17	9	50	16	16

Table I-5. (continued)

Area identification	Approximate area requiring decontamination (ft^2)	Depth of material removed	Type of material removed	Radiation level at 3 ft above ground surface in μR/hr									Post decontamination radium soil concentration (pCi/g)
				Before decontamination			After decontamination						
							Before backfill			After backfill			
				Min.	Max.	Avg.	Min.	Max.	Avg.	Min.	Max.	Avg.	
Area N													
(N-1)	100	10-12 in.	soil and debris	15	70	23	15	0	17	No backfilling done			
Nine spots beside Vine Street	15-200 ea.	10-12 in.	soil	15	3,000	300	12	45	23	No backfilling done			30
Area G													
(G-1)	30	0	timbers	15	60	24	15	22	17	No backfilling done			
(G-2)	5,100	0	rubble	11	190	24	7	35	13	No backfilling done			28
(G-3)	100 and 150	10-12 in.	soil and debris	14	110	32	14	40	24	No backfilling done			
(G-4)	10 and 10	8-10 in.	soil	15	200	81	15	30	21	No backfilling done			
(G-5)	10	8-10 in.	soil and debris	14	140	50	14	40	29	No backfilling done			
(G-6)	900	10-18 in.	soil and gravel	14	300	48	20	45	29	10	30	15	71
(G-7)	1,500	6-10 ft	soil and drums	12	350	24	14	30	25	7	25	9	3
Area W													
Six-Mile Creek	3,000	12-14 in.	soil	40	250	160	10	70	32	No backfilling done			
Central drainage ditch	18,000	12-14 in.	soil	20	650	96	9	120	36	No backfilling done			

Note: a. Area (E-2) was obscured by Chemtrol Corporation development activities; therefore, decontamination of this spot was not feasible.
b. The following spots, which were located during the June 1971 survey, were found during the May and June 1972 cleanup to be disturbed by the property owners such that the radiation levels were below the level requiring decontamination. The radiation level recorded during the cleanup was included within the final survey data. The spots are as follows: (F-1, (T-2), (T-3), the spot in Area C, the 70 μR/hr reading in the SE corner of Area W, the 90 μR/hr reading in SW part of (E-4) and G-8).

Table I-6. Exposure rates for ARMS and AEC/ORO survey post-decontamination during June 1972 (ref. I-5)

Area	ARMS, μR/hr[a]	AEC/ORO μR/hr[b]
B	8 ± 2	12 ± 3
C	13 ± 4	16 ± 7
D	8 ± 2	12 ± 2
F	13 ± 4	20 ± 10
G	10 ± 2	17 ± 5
H	9 ± 2	14 ± 5
N	11 ± 2	17 ± 7
N[1]	9 ± 2	19 ± 6
Q	9 ± 2	14 ± 3
S	10 ± 2	17 ± 7
T	9 ± 2	18 ± 7
V	8 ± 2	12 ± 3
Spoil pile	700 ± 100	1200 ± 900

[a]Values shown are averaged over the flight line(s) crossing the area.

[b]Values shown are averaged over the entire area designated.

Table I-7. Radon concentration measurements on and around the Lake Ontario Ordnance Works site

Location	Weekly mean radon concentration (pCi/liter)		
	This reporting period[a]	All measurements to date	
		Range	Average
On site			
Fence line no. 1		0.2 - 2.3	0.9
2	0.3	0.05 - 1.0	0.3
3	0.3	0.04 - 1.1	0.5
4		0.01 - 0.8	0.4
5		0.2 - 1.0	0.4
6		0.05 - 1.6	0.6
7	1.0	0.06 - 15	1.9
8	3.9	0.2 - 23	5.4
9	1.1	0.1 - 5.7	2.3
"O" Street		0.05 - 2.1	0.7
Boiler Plant		0.1 - 1.9	0.7
Off Site, Outdoors			
A - F. Guard Property		0.2 - 0.6	0.4
B - F. Monroe Property	0.3	0.03 - 0.8	0.4
C - Chemtrol "A"	0.2	<0.03 - 0.5	0.3
D - Chemtrol "B"	0.2	<0.03 - 0.8	0.3
E - Lew Port School		0.1 - 0.4	0.3
F - Nike Site		0.1 - 0.4	0.2
G - Radar Station		0.2 - 1.6	0.6
H - Ransomville		0.1 - 0.6	0.2
I - Ganon Residence		0.1 - 0.3	0.2
J - Oliphant Residence		0.2 - 0.4	0.2
K - W. Schultz Residence	0.1	0.1 - 0.5	0.2
L - A. Schultz Residence	0.2	0.1 - 0.6	0.2
M - Jackson Residence	0.2	0.08 - 0.4	0.2
N - Jowdy Residence		0.2 - 0.4	0.3
O - Daul Residence		0.2 - 0.3	0.2
P - Bell Aircraft		0.2 - 0.4	0.3
Off Site, Indoors			
H - Kruger Chevrolet (Ransomville)		0.4 - 1.0	0.6
I - Gannon Residence		0.3 - 1.6	1.0
J - Oliphant Residence		0.4 - 0.6	0.5
K - W. Schultz Residence	0.4	0.2 - 0.6	0.4
L - A. Schultz Residence		0.4 - 0.9	0.6
M - Jackson Residence	0.7	0.5 - 1.4	0.8
N - Jowdy Residence		0.4 - 0.9	0.6
O - Daul Residence		0.3 - 0.6	0.4
E - Lew Port School	0.7	0.2 - 0.7	0.4

[a] Latest measurement ending April 5, 1979.

Table I-8. Radon flux on spoil pile at Lake Ontario Ordnance Works site during November 13-14, 1978 (ref. I-6)

Sampling location	Canister number	Radon flux, ($pCi \cdot m^{-2} \cdot sec^{-1}$)
A1	B-9-2	104
A2	D-14-2	68
A3	Z-19-1	156
A4	105-14-2	311
A5	B-13-3	118
A6	B-8-3	37
A7	106-57-4	51
A8	B-11-4	233
A9	E-8-2	26
A10	B-10-4	76
A11	B-13-4	19
A12	B-10-3	12
A13	B-11-3	6
A14	Z-19-2	68
A15	13-D-4	213
A16	B-12-1	275
A17	107-12-3	1,626
A18	D-15-1	1,524
A19	Z-12-1	257
A20	D-15-2	79
A21	107-12-4	67
A22	E-10-1	336
A23	106-21-2	20
A24	D-13-3	23
A25	Z-12-2	11
A26	A-8-2	23
A27	108-1-1	11
A28	105-14-1	8
A29	B-12-2	36
A30	E-12-2	21
B1	C-7-3	4,360
B2	D-9-4	1,790
B3	108-8-2	732
B4	Z-11-2	72
B5	D-11-4	78
B6	D-11-3	24
B7	Z-8-1	20
B8	Z-10-2	18
B9	Z-7-1	30
B10	D-12-1	22
B11	108-8-1	34
B12	Z-8-2	28
B13	107-53-2	14
B14	108-1-2	44

Table I-8. (continued)

Sampling location	Canister number	Radon flux ($pCi \cdot m^{-2} \cdot sec^{-1}$)
B15	D-10-2	109
B16	Z-11-1	208
B17	D-12-2	409
B18	Z-7-2	2,020[a]
B19	A-14-4	315
B20	107-53-1	322
B21	Z-5-1	143
B22	D-7-2	26[a]
B23	Z-10-1	55
B24	Z-5-2	213
B25	E-10-2	52
B26	E-8-1	33
B27	106-2-1	148
B28	D-10-1	193
B29	D-14-1	29
B30	106-57-3	48

[a]Possibly reversed.

Table I-9. Radon flux on spoil pile at Lake Ontario Ordnance Works site during November 20-21, 1978 (ref. I-6)

Sampling location	Canister number	Radon flux ($pCi \cdot m^{-2} \cdot sec^{-1}$)
Z-1	107-53-2	34
Z-2	B-10-4	1,670
Z-3	108-8-2	435
Z-4	Z-8-1	512
Z-5	D-9-4	159
Z-6	B-9-2	297
Z-7	A-14-4	50
Z-8	B-12-1	9
Z-9	Z-11-2	15
Z-10	D-11-4	(charcoal leaked)
Z-11	Z-11-1	29
Z-12	D-13-4	22
Z-13	Z-5-2	19
Z-14	B-11-3	6
Z-15	Z-8-2	26
Z-16	106-57-3	15
Z-17	A-8-2	29
Z-18	D-14-2	20
Z-19	Z-12-1	53
Z-20	106-21-2	178
Z-21	107-12-4	1,260
Z-22	D-15-1	31
Z-23	B-19-1	145
Z-24	D-10-1	218
Z-25	D-12-1	58
Z-26	D-14-1	148
Z-27	B-10-3	1,620
Z-28	107-53-1	825
Z-29	D-12-2	346
Z-30	Z-10-1	200
Y1	Z-19-2	102
Y2	105-14-2	1,980
Y3	Z-5-1	249
Y4	E-10-1	132
Y5	D-7-2	207
Y6	D-13-3	154
Y7	107-12-3	55
Y8	B-8-3	22
Y9	Z-7-2	17
Y10	B-12-2	9
Y11	106-57-4	13
Y12	106-21-1	7
Y13	Z-12-2	7

Table I-9. (continued)

Sampling location	Canister number	Radon flux ($pCi \cdot m^{-2} \cdot sec^{-1}$)
Y14	E-8-1	22
Y15	105-14-1	16
Y16	B-13-4	27
Y17	B-13-3	12
Y18	E-10-2	8
Y19	E-12-2	134
Y20	108-1-1	86
Y21	Z-10-2	1,260
Y22	B-11-4	1,380
Y23	D-11-3	28
Y24	D-10-2	200
Y25	C-7-3	40
Y26	108-8-1	1,230
Y27	Z-8-2	12
Y28	108-1-2	18
Y29	D-15-2	221
Y30	Z-7-1	180

APPENDIX II

DESCRIPTION AND TECHNIQUE USED FOR EXTERNAL GAMMA SURVEY AND MEASUREMENT OF RADON AND RADON DAUGHTER CONCENTRATIONS

EXTERNAL GAMMA SURVEY METER

External gamma exposure rates are measured by a "Phil" dosimeter[II-1] (Fig. II-A). The probe is 15 cm (6 in) long with a 30 mg/cm^2 glass-walled, organic-filled Geiger-Mueller (G-M) tube. The tube is surrounded by an energy compensated shield of tin and lead. Pulses from this unit are counted with a battery-powered portable scaler. Geiger-Mueller counters are not typically used for dosimeters due to a peak response at low photon energies. However, perforated layers of tin (1.0 mm) and lead (0.1 mm) are used as energy compensation filters to flatten the peak response at photon energies below approximately 200 keV. National Bureau of Standards (NBS) traceable sealed sources of ^{137}Cs and ^{226}Ra are used for calibration. Detector response is 1 mR/hr = 3400 cpm. Each measurement represents the mean of at least three one-minute counts. Instrument background is subtracted out in final determination of exposure rate.

MEASUREMENT OF ^{222}RN CONCENTRATION IN AIR

Concentrations of radon are measured using a detector developed by Wrenn et al.[II-2] This detector operates on the principle that most of the ^{218}Po (RaA) ions are positively charged. Radon is allowed to diffuse through a foam, rubber-covered, hemispherically shaped metal screen, which filters radon daughters. As radon in the chamber decays, after diffusing into the cavity, ^{218}Po ions are attracted to a single-layer, thin (1.5×10^{-4} in.), aluminized mylar film that is stretched over a zinc sulfide scintillation detector. The potential between this a luminized mylar film and the hemispherically shaped wire screen creates

a strong electric field, which serves to attract the charged ions. The ions thus attracted remain on the surface of the mylar film and continue their radioactive decay to other radon daughters. The principal radiation detected by a radon monitor of this type is the alpha particles from ^{218}Po and ^{214}Po (RaC'). Alpha pulses are counted and integrated for a fixed period of time, usually 30 min. At the end of each timed counting period, the total count for each channel is printed automatically, the system is reset, and counting for the next period is initiated. Figure II-B is a photograph of the radon monitor and associated electronic components including NDT-COMP 8 microcomputer and printer. Figure II-C is a photograph of the interim of the radon monitor with a view of the photo-multiplier housing, screen mesh hemisphere housing, and aluminized mylar covering a ZnS scintillator.

MEASUREMENT OF ^{222}RN DAUGHTER CONCENTRATION IN AIR

An alpha spectrometry technique has been refined by Kerr[II-3,4,5] for the measurement of ^{222}Rn progeny concentrations in air. From one integral count of the ^{218}Po alpha activity and two integral counts of the ^{214}Po alpha activity, the concentrations in air of ^{218}Po, ^{214}Bi, and ^{214}Pb may be calculated.

Particulate ^{222}Rn daughters attached to airborne dust are collected on a membrane filter with a pore size of 0.4 μm. A sampling time of 5 to 10 min and a flow rate of 10 to 20 LPM are used. This filter sample is then placed under a silicon surface barrier detector and counted. The detector and counting system used for radon daughter measurements are shown in Fig. II-D. Usually, counting of this kind is performed with a vacuum between the sample and the detector, which requires a

complicated sample holder and time-consuming sample changing methods. Experiments at this laboratory have shown that ease in sample handling is obtained with little loss in resolution when helium is used as a chamber fill gas.[II-6] In this counter, helium is flowed between the diode and the filter sample, which are separated by a distance of 0.5 cm. One integral count of the ^{218}Po alpha activity is obtained from 2 to 12 min, and two integral counts of the ^{214}Po activity are obtained from 2 to 12 min and 15 to 30 min, respectively. All counting intervals are referenced to t = 0 at the end of sampling.

The equations describing the ^{222}Rn progeny atoms collection rates on the filter are of the form:

$$\frac{dn_i(t)}{dt} = C_i v + \lambda_{i-1}\, n_{i-1}(t)\lambda_i N_i(t) \quad , \qquad (1)$$

where

n_i = number of the i^{th} species of atom on the filter as a function of time,

λ_i = radioactive decay constant of the i^{th} species (min^{-1}),

C_i = concentration of the i^{th} species (atoms l^{-1}),

v = air sampling flow rate (liters min^{-1}).

The solution of Eq. (1) is of the form

$$y = e^{-ax}[y_0 = \int F(x)e^{ax}\, dx].$$

From the general form of the solution, specific equations can be obtained describing the number of each ^{222}Rn decay product collected on the filter as a function of time. Also by letting v = 0 in Eq. (1), a set of equations describing the decay on the filter of each ^{222}Rn

progeny can be obtained. The equations describing the decay of ^{222}Rn progeny on the filter can be integrated and related to the integral counts obtained experimentally. Values for the total activities of ^{218}Po, ^{214}Pb, and ^{214}Bi on the filter at the end of sampling are obtained by applying matrix techniques. The airborne concentrations are obtained by solving the equations describing the atom collection rates on the filter. A computer program has been written to perform these matrix operations, to calculate the air concentrations of the radon progeny, and to estimate the accuracy of the calculated concentrations.

The mobile laboratories shown in Fig. II-E are used during each formal survey to serve as a control center, and to house instruments and other equipment needed during the survey. Each lab is equipped with its own electric generator, mobile radio-telephone, and contains a wide range of well maintained and calibrated instruments. One of the mobile labs has its own microcomputer for data reduction in remote locations.

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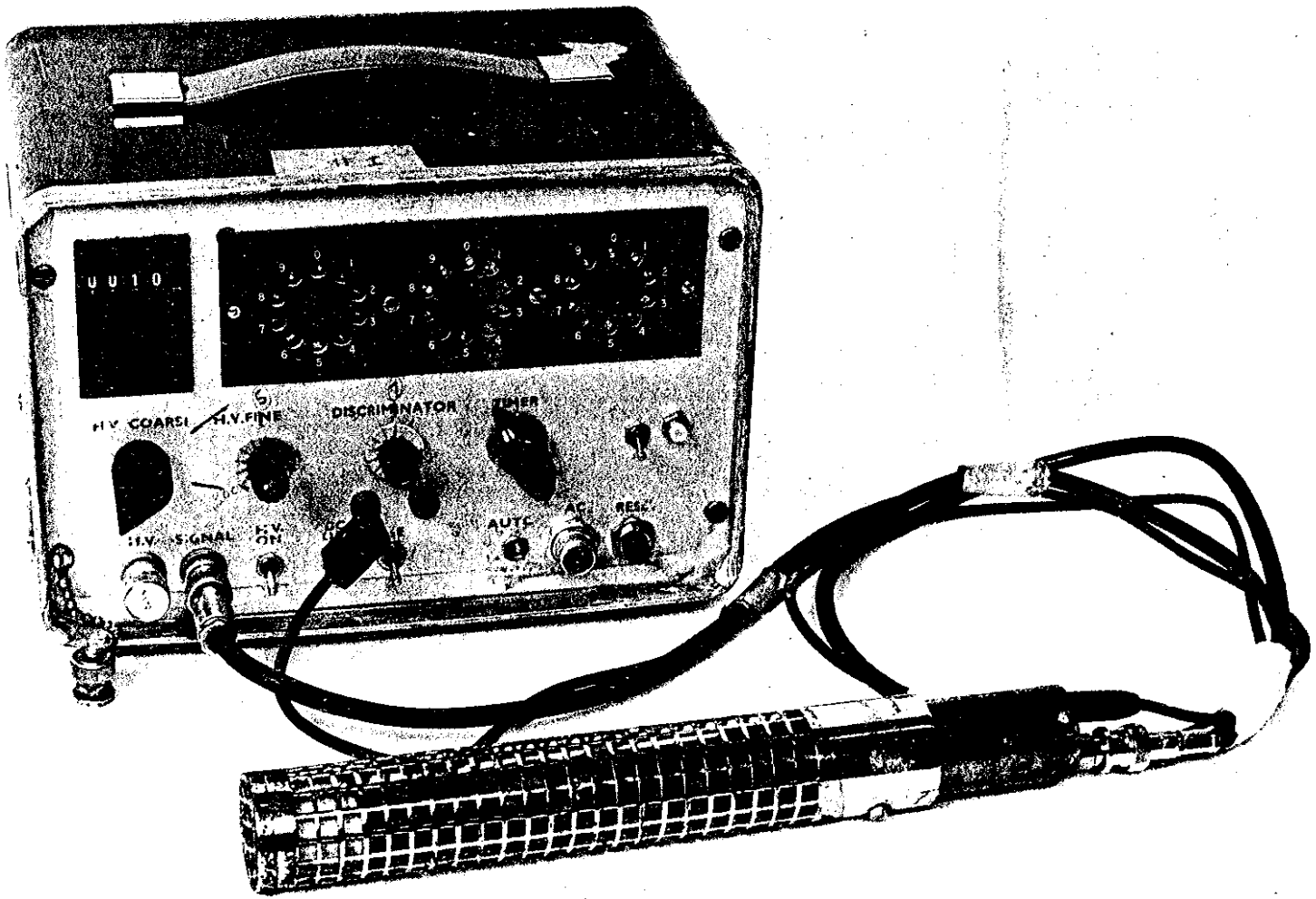

Fig. II-A. Gamma-ray, Geiger-Mueller (G-M) dosimeter ("Phil").

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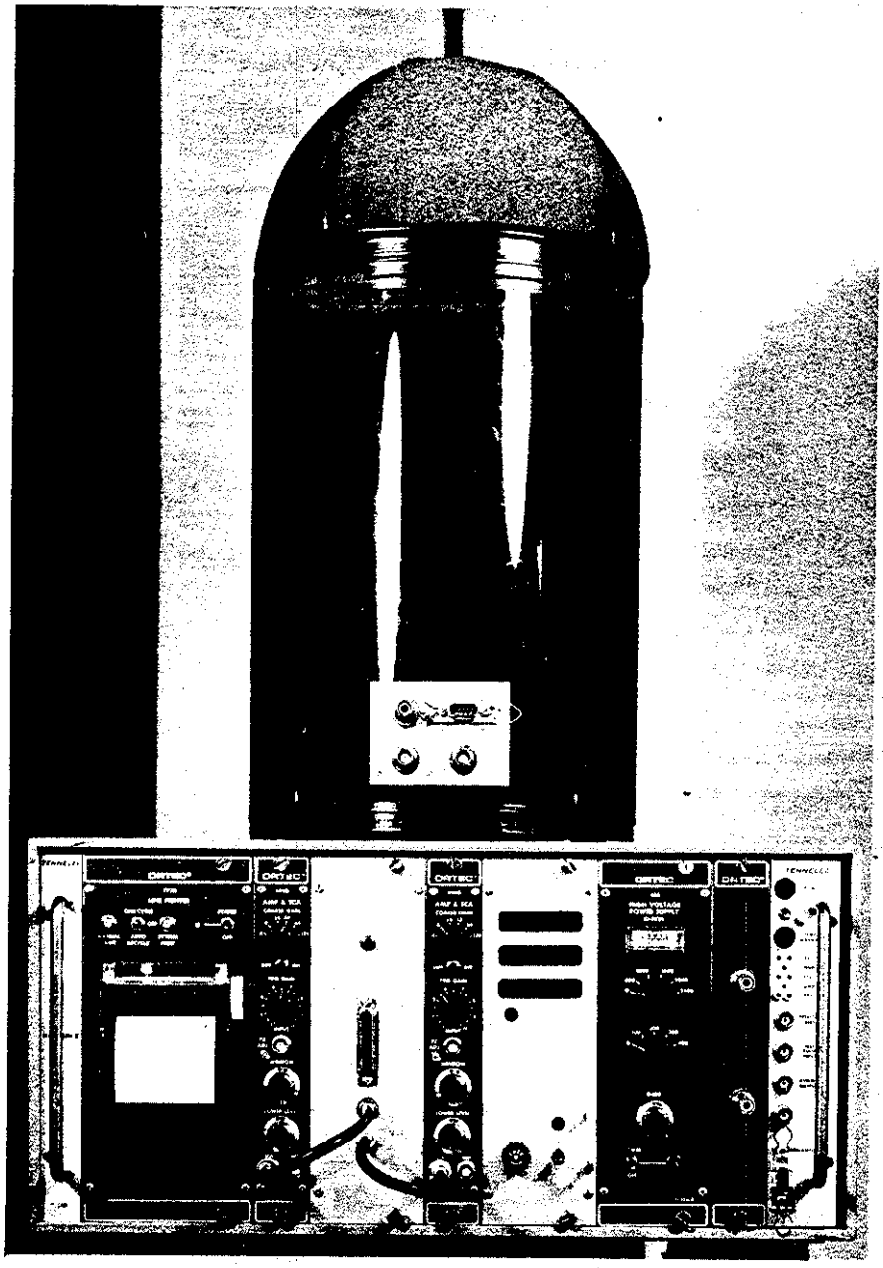

Fig. II-B. Continuous radon monitor and associated electronic components with printer.

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Fig. II-C. View of ionization chamber in ORNL radon monitor. Shown in the photo is the photo-multiplier housing, screen mesh hemisphere housing, and aluminized mylar covering the ZnS scintillator.

ORNL-Photo 6708-76

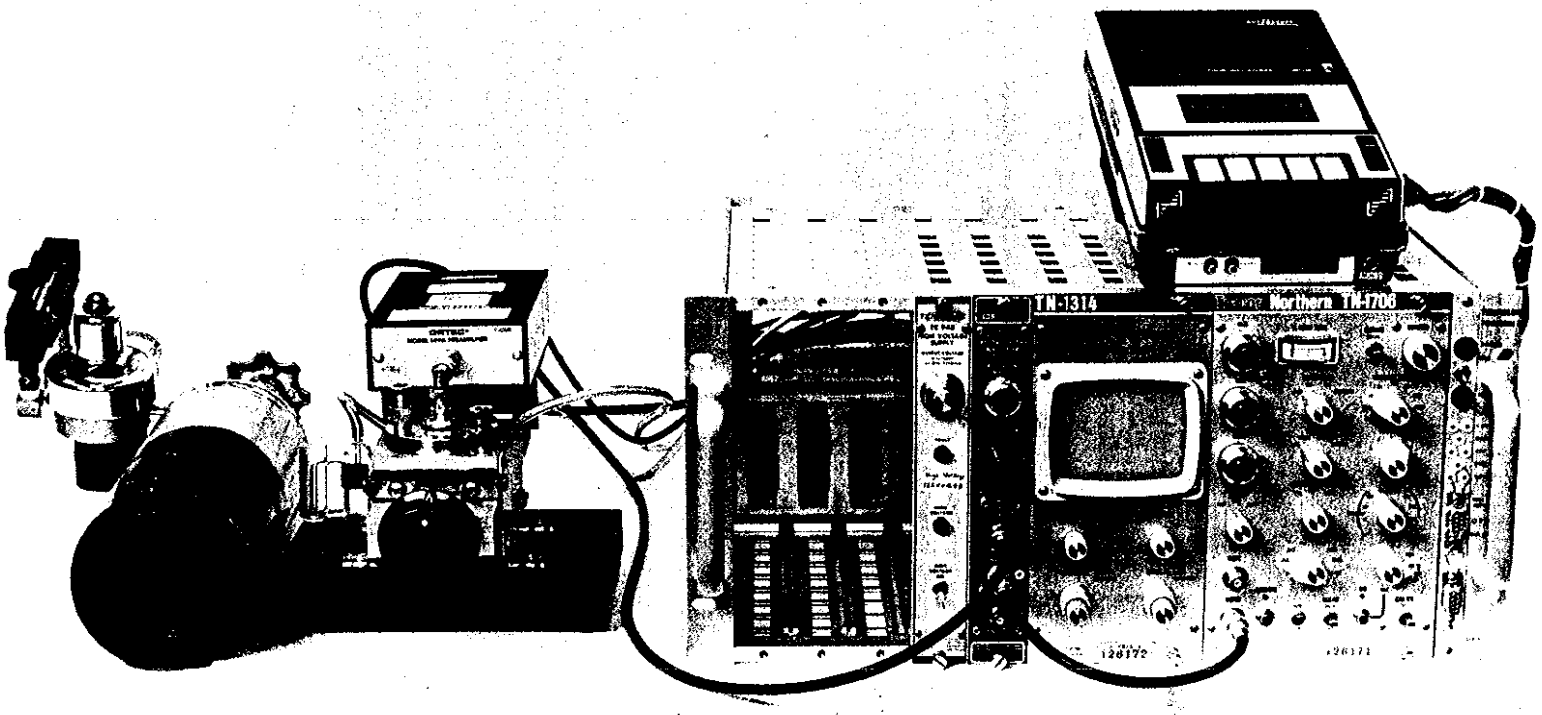

Fig. II-D. System used for measurement of ^{222}Rn daughter concentrations.

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Fig. II-E. Mobile labs used for logistic support during surveys.

APPENDIX III

DESCRIPTION OF GE(LI) DETECTOR AND SOIL COUNTING PROCEDURES

DESCRIPTION OF Ge(Li) DETECTOR SYSTEM

A holder for twelve 30-cm^3 polyethylene bottles (standard containers for liquid scintillation samples) and a background shield have been designed for use with a 50-cm^3 Ge(Li) detector system (see Figs. III-A, III-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-cm^3 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% or less.

Pulses are sorted by a 4096-channel analyzer (see Fig. III-C), 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, which is accessible through a remote terminal, relies on a library of radioisotopes, which contains approximately 700 isotopes and 2500 gamma-rays and which 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.

ORNL-Photo 2172-75

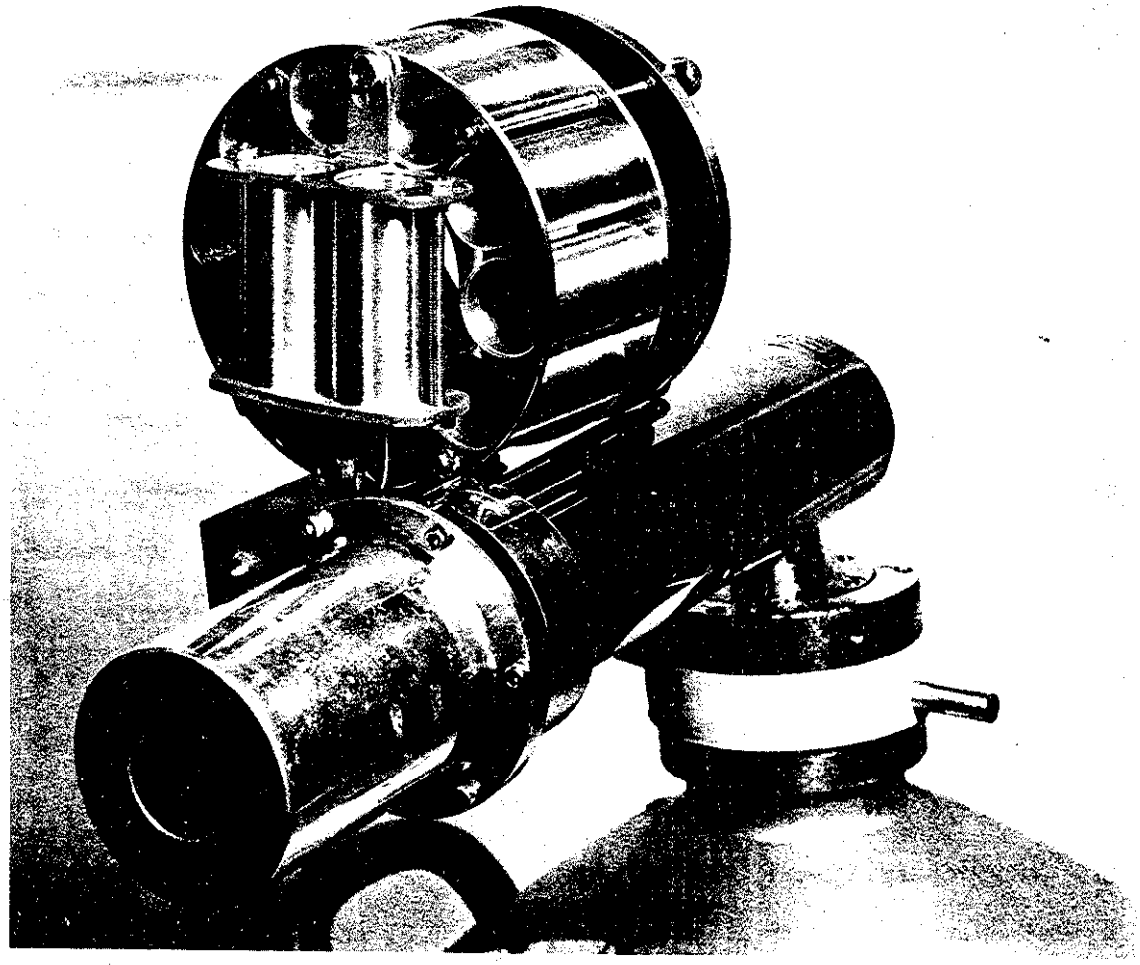

Fig. III-A. Holder for Ge(Li) detector system samples.

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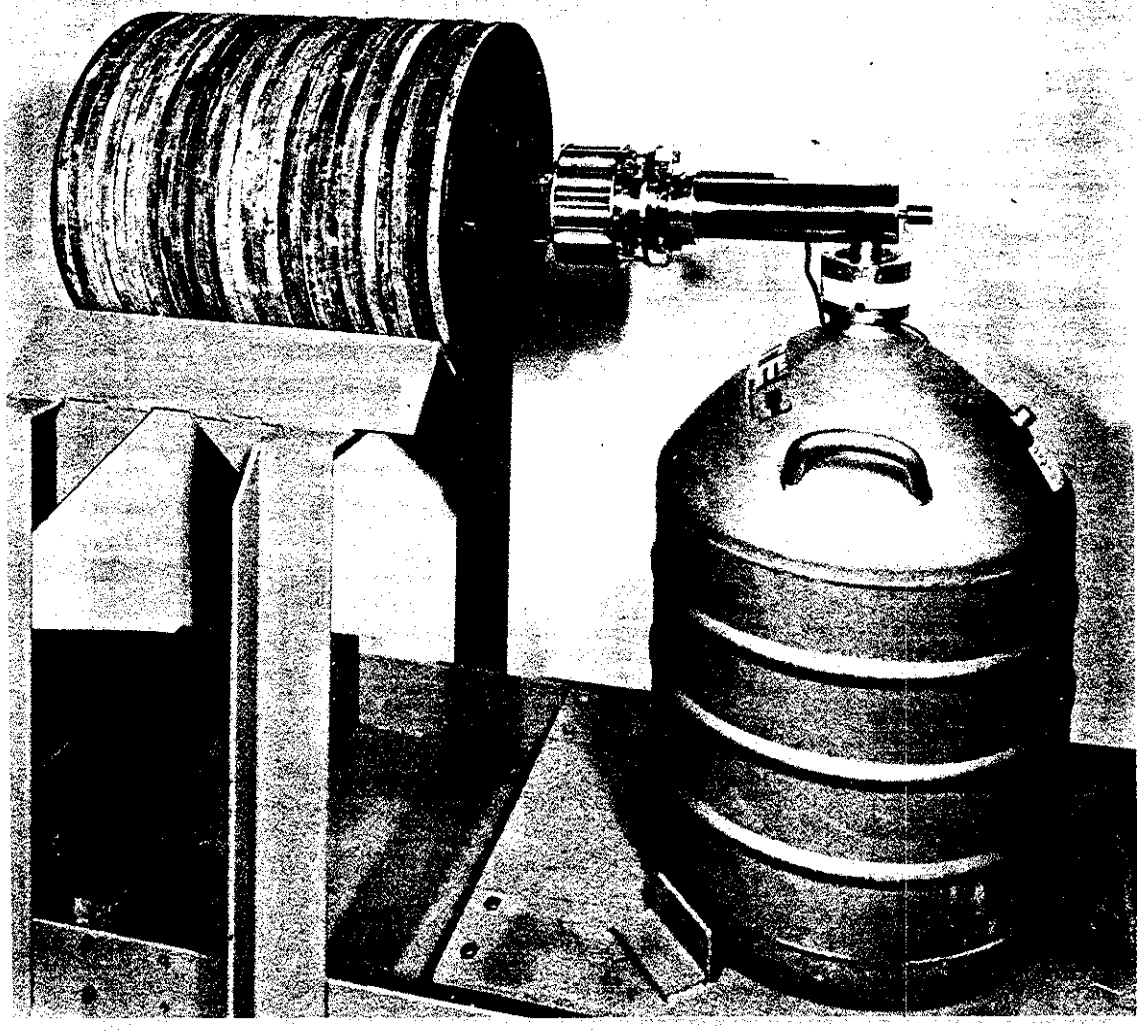

Fig. III-B. Ge(Li) detector system.

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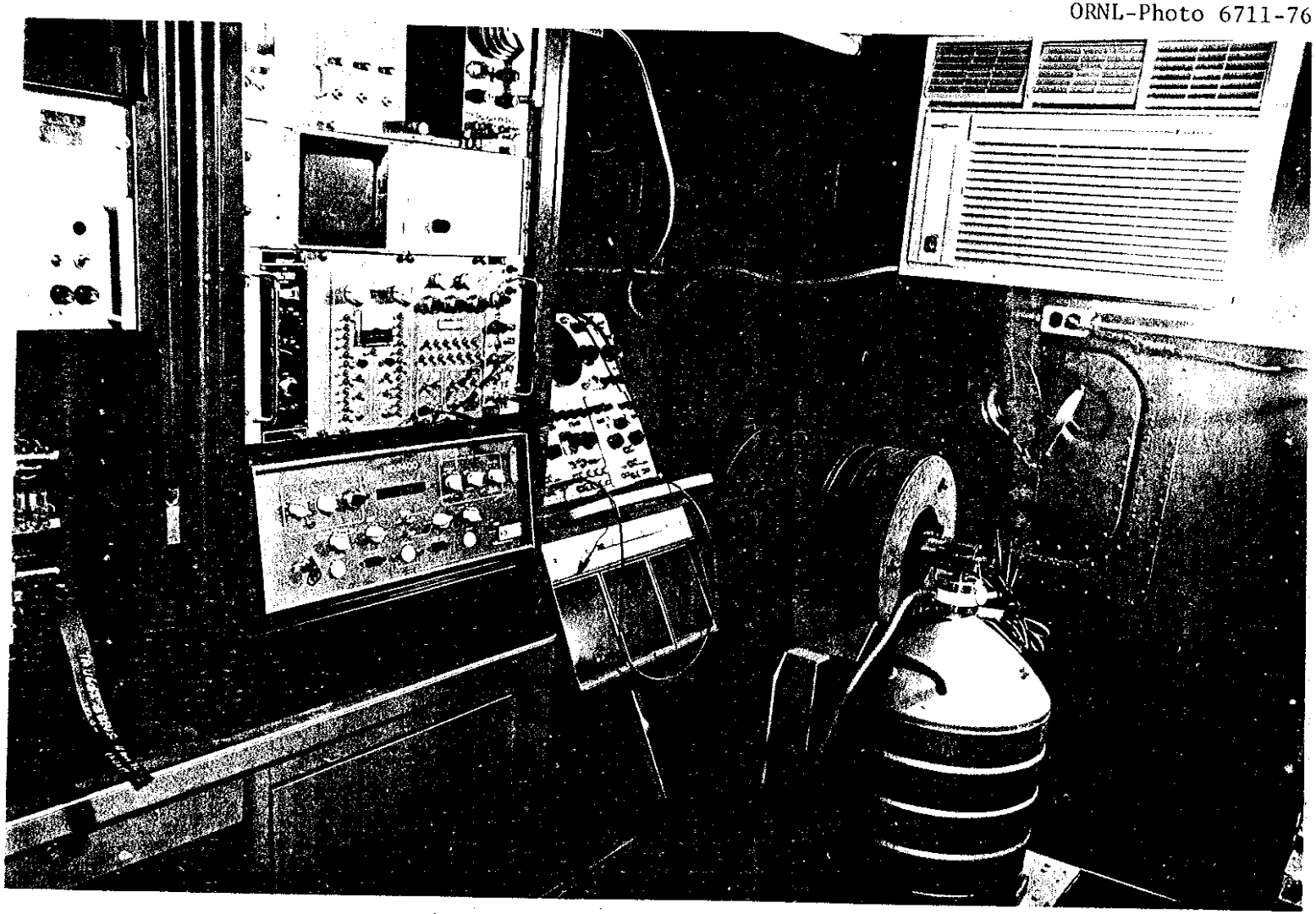

Fig. III-C. 4096-channel analyzer.

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