COMPREHENSIVE RADIOLOGICAL SURVEY
OFF-SITE PROPERTY H'
NIAGARA FALLS STORAGE SITE
LEWISTON, NEW YORK

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INTRODUCTION

Beginning in 1944, the Manhattan Engineer District and its successor, the Atomic Energy Commission (AEC), used portions of the Lake Ontario Ordnance Works (presently referred to as the Niagara Falls Storage Site (NFSS) and off-site properties), approximately 3 km northeast of Lewiston, New York, for storage of radioactive wastes. These wastes were primarily residues from uranium processing operations; however, they also included: contaminated rubble and scrap from decommissioning activities, biological and miscellaneous wastes from the University of Rochester, and low-level fission-product waste from contaminated liquid evaporators at the Knolls Atomic Power Laboratory (KAPL). Receipt of radioactive waste was discontinued in 1954, and, following cleanup activities by Hooker Chemical Co., 525 hectares of the original 612 hectare site were declared surplus. This property was eventually sold by the General Services Administration to various private, commercial, and governmental agencies.[1]

SCA Chemical Services, Inc. (SCA) is the current owner of a tract from the NFSS, identified as off-site property H′ (see Figure 1). A radiological survey of that tract, conducted in June and July 1982, is the subject of this report.

Site Description

Figure 2 is a plot plan of off-site property H′. The property is rectangular in shape (approximately 180 m by 90 m) and occupies an area of approximately 1.6 hectares. It is bounded on three sides by roads - Wesson Road on the west, M Street on the south, and 5th Street on the east. The northern boundary is an out-of-service railroad track. The land is level with the exception of several drainage ditches near the center of the property and low areas or shallow depressions south of the railroad track and at scattered locations throughout the site. Portions of the tract are below the level of adjacent properties, suggesting possible surface excavation. Most of the low areas were covered by standing water at the time of the survey. Several small areas of dense brush are also present.

The property is not being used by SCA. There are no buildings on the site, but several small concrete pads or foundations are located on the eastern section. A portion of a railroad spur crosses the northwest corner of the property.

Radiological History

There is no evidence of contaminated waste burials on the property H′. It is suspected, however, that waste incineration operations were performed on a pad on the eastern portion of the site prior to 1954.[2] A 1971-72 survey by the Oak Ridge Operations Office of the AEC identified radiation levels of 20-50 μR/h on this portion of the property, and during the 1972 decontamination efforts, contaminated scrap was removed from the site.

In October 1978, an aerial radiological survey was conducted by EG&G. This survey did not identify significant gamma radiation levels on property H′.[3] A mobile scan of accessible roads, performed by Oak Ridge National Laboratory in November 1980, confirmed the earlier AEC findings of above background radiation levels along M Street, Wesson Road, and 5th Street.[4]

SURVEY PROCEDURES

The comprehensive survey of NFSS off-site property H′ was performed by the Radiological Site Assessment Program of Oak Ridge Associated Universities (ORAU), during the periods of June 2-11 and July 7-21, 1982. The survey was in accordance with a plan dated March 19, 1982, approved by the Department of Energy′s Office of Operational Safety. The objectives and procedures from that plan are presented in this section.

Objective

The objective of the survey was to provide a comprehensive assessment of the radiological conditions and associated potential health effects, if any, on property H'. Radiological information collected included:

1. direct radiation exposure rates and surface beta-gamma dose rates,

2. locations of elevated surface residues,

3. concentrations of radionuclides in surface and subsurface soil,

4. concentrations of radionuclides in surface and ground water, and

5. contamination levels on pads previously used for storage or incineration of contaminated wastes.

Procedures

1. Site Preparation

   a. Brush and weeds were cleared as needed to provide access for gridding and surveying. This operation was performed under subcontract by Modern Disposal Co., Model City, NY.

   b. A 20 m grid system was established by McIntosh and McIntosh of Lockport, NY, under subcontract. This grid system is shown on Figure 2.

2. Gamma exposure rate measurements were made at the surface and at 1 m above the surface at each accessible grid line intersection. Measurements were performed using portable gamma NaI (Tl) scintillation survey meters. Conversion of these measurements to exposure rates in microroentgens per hour (μR/h) was in accordance with cross calibration with a pressurized ionization chamber.

3. Beta-gamma dose rate measurements were performed 1 cm above the surface at each accessible grid line intersection. These measurements were conducted using thin-window (7mg/cm^2) G-M detectors and portable scaler/ratemeters. Measurements were also obtained with the detector shielded to evaluate contributions of non-penetrating beta and low-energy photon radiations. Meter readings were converted to dose-rate in microrads per hour (μrad/h), based on cross calibration with a thin-window ionization chamber using soil samples from the property.

4. Surface (0-15 cm) soil samples of approximately 1 kg each were collected at or near each accessible grid line intersection.

5. Walkover surface scans were conducted at 1-2 m intervals over all accessible areas of the property. Portable gamma scintillation survey meters were used for these scans. Locations of elevated contact radiation levels were noted and surface exposure rates were measured at these locations.

6. At 21 of the locations of elevated surface radiation levels, beta-gamma dose rates and exposure rates at 1 m above the surface were also measured. Surface soil samples were obtained from these locations and, following sampling, the surface exposure levels were remeasured to evaluate the effectiveness of shallow sampling on removal of the radiation source. The 21 locations where these additional measurements and samples were obtained are indicated on Figure 3.

7. Detection Sciences Group of Carlisle, MA, performed ground penetrating radar surveys. The purpose of these radar scans was to identify the presence of underground piping or utilities which would preclude borehole drilling. Ground radar would also identify other subsurface objects or anomalies which might be indicative of waste burials on the site.

8. Boreholes were drilled to provide a mechanism for logging subsurface direct radiation profiles and collecting subsurface soil and water samples. Fifteen boreholes were drilled to ground water depth (2-6 m). These holes were drilled by Site Engineers, Inc., of Voorhees, NJ, using a truck-mounted 20 cm diameter hollow-stem auger. Thirteen shallower (0.5-1.5 m deep) boreholes were drilled by the ORAU radiological survey team using a portable motorized auger. These shallow boreholes were primarily at locations where direct radiation measurements and ground-penetrating radar had indicated possible residues. The locations of these boreholes are shown on Figure 4.

A gamma scan of each borehole was performed to identify elevated radiation levels, which would indicate subsurface residues. Radiation profiles in the boreholes were determined by measurements of gamma radiation at 30-50 cm intervals between the surface and ground water (deep holes) or the hole bottom (shallow holes). A collimated gamma scintillation detector and portable scaler were used for these measurements.

Ground water samples of approximately 3.5 liters each were collected from all deep boreholes, where it was available. Collection was performed using a hand bailer. Soil samples of approximately 1 kg each were collected from various depths in the deep holes by scraping the sides of the borehole with a specially constructed sampling tool.

Samples from the shallow boreholes were obtained using a post-hole digger, after the hole was drilled to the desired sampling depth and then cleaned of drilling debris. Subsurface sampling locations were at depths where gamma logging indicated possible contaminated residues and at additional random depths to adequately characterize the subsurface distribution and levels of radionuclides.

9. Samples of surface water were collected from two drainage ditches and one area of standing water shown on Figure 5.

10. Sediment samples of approximately 1 kg each were obtained at the two drainage ditch locations where surface water samples were collected (see Figure 5).

11. Twenty soil samples and four water samples were collected from the Lewiston area (but not on the NFSS or associated off-site properties) to provide baseline concentrations of radionuclides for comparison purposes. Direct background radiation levels were measured at locations where baseline soil samples were collected. The locations of the baseline samples and background measurements are shown on Figure 6.

Sample Analyses and Interpretation of Results

Soil and sediment samples were analyzed by gamma spectrometry. Radium 226 was the major radionuclide of concern, although spectra were reviewed for Cs-137, U-235, U-238, and other gamma emitters. Several samples with high Cs-137 concentrations were analyzed for Sr-90, since the presence of high Cs-137 indicated possible wastes from KAPL or the University of Rochester. One sample having high Ra-226 and U-238 levels was also analyzed for Pu-239.

Water samples were analyzed for gross alpha and beta concentrations. Isotopic analyses were performed on water samples exceeding the EPA drinking water standards for gross activity. Additional information concerning analytical equipment and procedures is contained in Appendix A.

Results of this survey were compared to applicable guidelines for formerly utilized radioactive materials handling sites as presented in Appendix B.

RESULTS

Background Levels and Baseline Concentrations

Background exposure rates and baseline radionuclide concentrations in soil, determined for 20 locations in the vicinity of the former LOOW site, are presented in Table 1-A. Exposure rates ranged from 6.8 to 8.8 μR/h (typical levels for this area of New York). Concentrations of radionuclides in soil were: Ra-226, <0.09* to 1.22 pCi/g (picocuries per gram); U-235, <0.14 to 0.46 pCi/g; U-238, <2.20 to 6.26 pCi/g; Th-232, <0.32 to 1.18 pCi/g; and Cs-137, <0.02 to 1.05 pCi/g. These concentrations are typical of the radionuclide levels normally encountered in surface soils.

Radioactivity levels in baseline water samples are presented in Table 1-B. The gross alpha and gross beta concentrations ranged from 0.55 to 1.87 pCi/l (picocuries per liter) and 0.63 to 14.3 pCi/l, respectively. These are typical of concentrations normally occurring in surface water.

Direct Radiation Levels

Direct radiation levels, systematically measured at grid line intersections, are presented in Table 2. The gamma exposure rates at 1 m above the surface ranged from 6.2 to 18 μR/h (average 9.1 ± 4.5 μR/h). At surface contact the rates ranged from 5.7 to 22 μR/h with an average of 9.4 ± 5.6 μR/h. Dose rate measurements performed with the detector shielded averaged approximately 20% less than those with the unshielded detector. This indicates only a small portion of the surface dose rate is due to nonpenetrating beta or low-energy photon radiations.

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* *The less than symbol (<) indicates that the concentration measured was less than the minimum statistical detection limit of the procedure.*

The walkover survey identified numerous small isolated areas with elevated surface radiation levels. These locations are indicated on Figure 7. Exposure rates in contact with these elevated areas ranged up to 365 μR/h. Direct radiation levels at the 21 locations selected for further investigation are presented in Table 3. Gamma exposure rates at contact and 1 m above the surface at these locations ranged from 18 to 365 μR/h and 12 to 33 μR/h, respectively. Contact beta-gamma dose rates ranged from 110 to 5580 μrad/h. Contact exposure rates were not reduced by soil sampling at most of these locations. At many of the points, exposure rates actually increased following sampling. These results indicate that the contamination at some locations extends greater than 15 cm below the surface and is diffused rather than in discrete particles.

Direct radiation levels at grid line intersections on property H′ were generally higher on the southeastern and eastern portion of the site and along "M" Street and 5th Street. Areas of surface contamination, identified as elevated contact radiation levels, were also concentrated in these portions of the property. Measurements on the concrete pads or foundations did not indicate contamination of these structures.

Radionuclide Concentrations in Surface Soil

Tables 4 and 5 list the concentrations of radionuclides, measured in surface soil from the grid line intersections and from selected locations of elevated radiation levels on property H′. The samples from grid line intersections (see Table 4) contained Ra-226 concentrations ranging from 0.51 to 15.7 pCi/g. The highest level was in sample 19 from grid point 20N, 160E. Approximately half of these samples contained Ra-226 concentrations exceeding those in the baseline soil samples. Several of these samples contained elevated U-235 and U-238 concentrations. The highest U-235 level was 1.14 pCi/g, the highest U-238 level was 14.7 pCi/g. Concentrations of Th-232 and Cs-137 were not significantly different from those in baseline samples.

Twenty-one surface soil samples from locations of elevated contact radiation levels (refer to Table 5) all contained Ra-226 concentrations above those in baseline samples. The highest Ra-226 concentration, 1750 pCi/g, was in sample B6 (grid point 52N, 141E). This sample consisted primarily of a black material resembling an ash residue from incineration. Sample B2 (at 63N, 140E) contained 1480 pCi/g of U-238 and 66 pCi/g of U-235, but only 2.14 pCi/g of Ra-226. Several additional samples contained elevated levels of U-235 and U-238. Cesium-137 concentrations were also elevated in many of these samples. Samples B6 (at 52N, 141E) and B18 (at 14N, 178E) contained the highest Cs-137 levels of 27.1 pCi/g and 33.0 pCi/g, respectively. Strontium-90 concentrations in these samples were 9.71 pCi/g and 1.29 pCi/g, respectively. Thorium-232 levels were either in the range of the baseline samples or were below the detection sensitivities of the analytical procedure. Sample B18 (at 14N, 178E) also contained 13.3 pCi/g of Co-60; none of the other samples contained detectable levels of this radionuclide. Sample B18 was also analyzed for Pu-239; the concentration of this radionuclide was 0.30 $\pm$ 0.26 pCi/g. Because of the large error associated with the result, this analysis should not be considered evidence that Pu-239 is present in the residues on property H′.

Ground Penetrating Radar Findings

The subcontractor′s report, summarizing the ground penetrating radar survey results for property H′ is provided as Appendix C. (This report also includes the findings on property E′, since the two properties were surveyed simultaneously.) This survey identified evidence of old building foundations or concrete pads. Other anomalies, indicating the possible presence of small buried objects or small subsurface deposits of electrically "active" material were also noted at several locations on the southeastern portion of the property. These anomalies were at a depth of approximately 0.6 to 1.7 m below the surface. Pages 17 and 19 and Figure 8 of Appendix C provides additional information concerning these findings. The ground radar at some proposed borehole drilling locations did identify possible utility services, requiring slight relocations of these boreholes.

Borehole Gamma-Logging Measurements

The results of gamma scintillation measurements performed in boreholes indicate that contamination is confined to the upper 0.5 to 1.0 m of soil. The gamma count rates determined by the borehole measurements were reliable indicators of elevated subsurface radionuclide levels. However, the gamma logging data was not useful in quantifying radionuclide concentrations in the subsurface soil, because of the varying ratios of Ra-226, U-235, U-238, and Cs-137 occurring in soils from this site.

Radionuclide Concentrations in Subsurface Soil

Table 6 presents the radionuclide concentrations measured in soil samples from boreholes. Of the six boreholes (H1-H6), located to provide a representative coverage of the property, only H3 contained elevated subsurface radionuclide concentrations. The sample from the 0.15 m depth at this location contained 9.2 pCi/g of Ra-226 and also small concentrations of U-235 and U-238.

Boreholes H7-H16 were at locations where the walkover scan survey had identified probable surface contamination. Subsurface soil samples from most of these boreholes contained elevated Ra-226 concentrations. The maximum concentration was 18.1 pCi/g at the 0.5 m depth in borehole H8. All of these boreholes indicated that Ra-226 soil contamination is primarily in the upper 0.5 m. Boreholes H8 and H16 contained uranium soil contamination at 0.5 m. The U-235 and U-238 levels in borehole H8 were 1.43 pCi/g and 23.3 pCi/g, respectively; levels of these two radionuclides in borehole H16 were 4.85 pCi/g and 101 pCi/g.

Only one of the remaining boreholes, drilled in the general vicinity of elevated direct radiation levels or radar anomalies, contained subsurface radionuclide contamination. Borehole H22, contained 24.8 pCi/g of Ra-226 at 0.5 m. There were no significantly elevated uranium levels measured in soils from these boreholes.

None of the subsurface samples contained elevated concentrations of Th-232 or Cs-137. No other gamma emitting radionuclides were identified in the borehole samples.

Radionuclide Concentrations in Water

Surface Water

Sample W1 from standing water on property H' (refer to Table 7) contained a gross alpha concentration of 30 pCi/l. This sample contained 22.8 pCi/l of gross beta and 0.16 pCi/l of Ra-226. The other two surface water samples from the drainage ditches, had gross alpha and gross beta concentrations which were above the baseline levels but well within the EPA drinking water criteria of 15 pCi/l and 50 pCi/l respectively.

Subsurface Water

Most of the subsurface water samples obtained from boreholes contained elevated gross alpha and gross beta concentrations (see Table 7). The maximum levels were measured in sample W13 from borehole H8. Gross alpha and gross beta concentrations in this sample were 799 pCi/l and 363 pCi/l, respectively. This sample was also analyzed for Sr-90 and contained 2.76 pCi/l of that radionuclide. None of the samples analyzed for Ra-226 contained levels of that radionuclide exceeding the 3 pCi/l EPA drinking water criteria. It should be noted that high concentrations of dissolved solids in many of these samples resulted in residues, which adversely affected the detection sensitivities of the gross alpha procedure.

Radionuclide Concentrations in Sediment From Drainage Ditches

Sediment samples from the drainage ditches did not contain radionuclide levels significantly different from the levels in baseline soil (refer to Table 8).

COMPARISON OF SURVEY RESULTS WITH GUIDELINES

The guidelines applicable to cleanup of the off-site properties at NFSS are presented in Appendix B. The maximum gamma exposure rate measured at 1 m above the surface is 33 μR/h total or about 25 μR/h above background; the average level is 9 μR/h. These levels are well below the 60 μR/h Nuclear Regulatory Commission criteria for open land areas.

The results of the walkover surface scan and analysis of surface soil samples from selected locations of elevated direct radiation levels indicate numerous isolated areas of Ra-226 soil contamination well in excess of 5 pCi/g. As with the direct radiation levels, the surface contamination is concentrated in the southern and southeastern portions of the site. Several of the samples from that area also contain uranium concentrations above criteria which have been used at other formerly utilized sites (approximately 40 pCi/g). Portions of the property where Ra-226 or U-238 soil concentrations exceed criteria are indicated on Figure 8. Cesium-137 and Sr-90 concentrations on this property are within guidelines suggested by Healy; i.e. 80 pCi/g of Cs-137 and 100 pCi/g of Sr-90.[5]

Borehole sampling indicates several areas of subsurface soil with Ra-226 concentrations exceeding 15 pCi/g. Most of this contamination is within 0.5 m of the surface. Although ground-penetrating radar identified several areas of subsurface anomalies, borehole logging and sampling in the vicinity of some of these anomalies did not identify evidence of buried contaminated residues.

Standing surface water, from the general area of concentrations of Ra-226 contaminated soil, exceeded 15 pCi/l of gross alpha; water from the drainage ditches was well within that level. Subsurface water from four boreholes also exceeded 15 pCi/l gross alpha. One of the samples at 799 pCi/l gross alpha, was well above this level. Other borehole water samples indicated that contaminated residues on this property are not producing general ground water concentrations exceeding the EPA Interim Drinking Water Standards.

An evaluation of the potential health effects associated with radiation levels and residual contamination on the property H′ is presented in Appendix D. This section compares these levels with background exposures in the Niagara, New York, area and the scientifically based guidelines established for the protection of radiation workers and the general public.

SUMMARY

A comprehensive survey of off-site property H′ at the Niagara Falls Storage Site was conducted during June and July 1982. The survey included surface radiation scans, measurements of direct radiation levels, and analysis for radionuclide concentrations in surface and subsurface soil samples, and in surface and subsurface water samples. Ground penetrating radar was also used to identify subsurface anomalies which might suggest buried radioactive residues.

The results of the survey indicate numerous isolated areas of surface soil contamination. The major contaminant is Ra-226; however, several areas of high uranium contamination were also noted. Cesium-137, Sr-90, and Co-60 were also identified in some of the samples, but the concentrations were well below the guideline levels. The area where the Ra-226 or uranium surface contamination exceeds the guideline levels covers approximately 6000 m^2 (see Figure 8). Subsurface sampling and measurements indicate that this contamination is limited to the top 50 cm of soil, averaging about 25 cm deep. Approximately 1500 m^3 of soil would thus have to be removed to bring this property into compliance with the criteria for unrestricted use.

Although the contaminated residues on portions of this property exceed the guidelines established for release of the site for unrestricted use by the general public, under present conditions of usage the contaminants do not pose potential health risks. There is no evidence that migration of the radioactive materials is adversely affecting adjacent properties or the ground water.

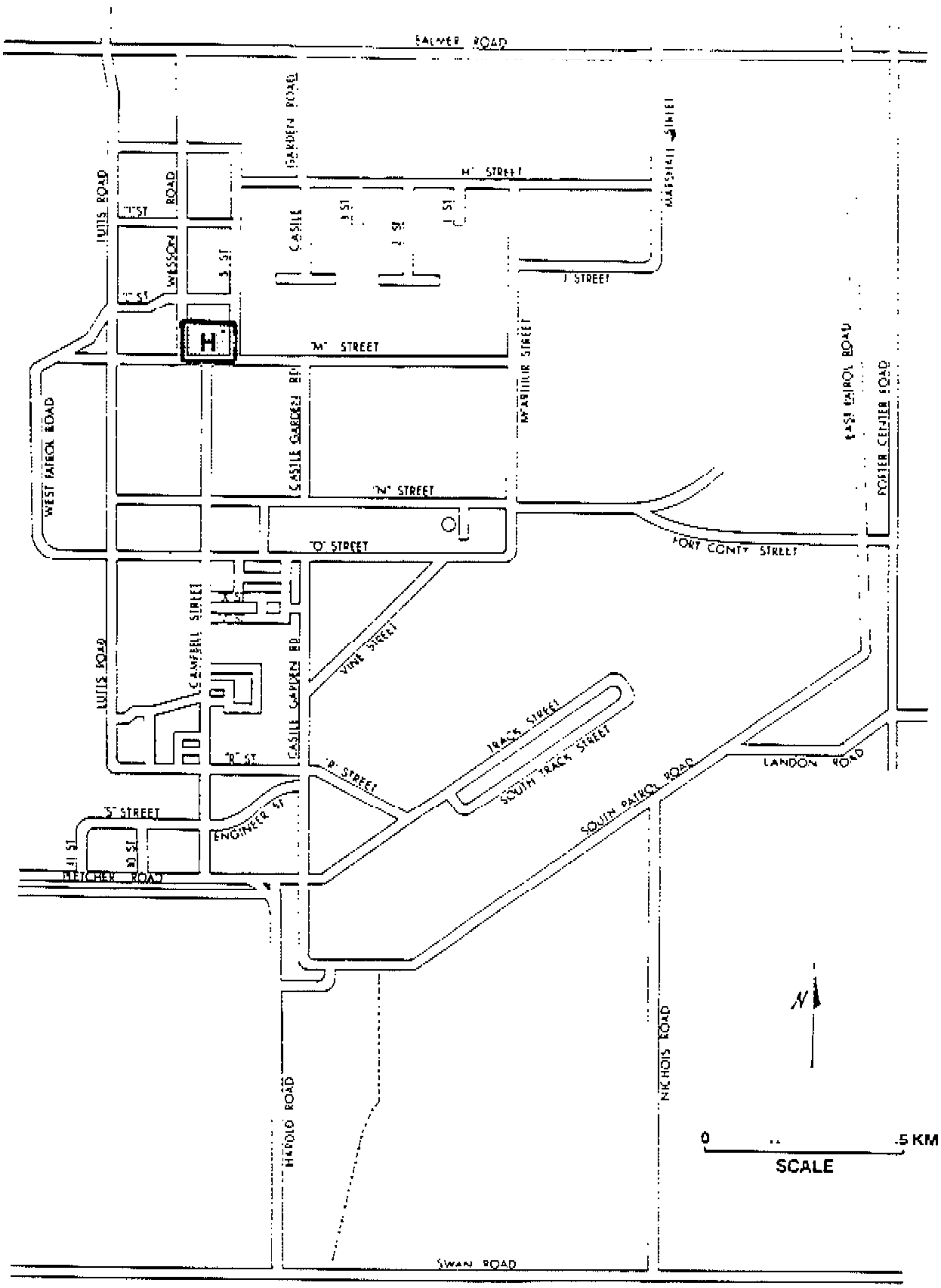

FIGURE 1. Map of the Niagara Falls Storage Site and Off-Site Properties, Lewiston, New York, Indicating the Location of Property H'.

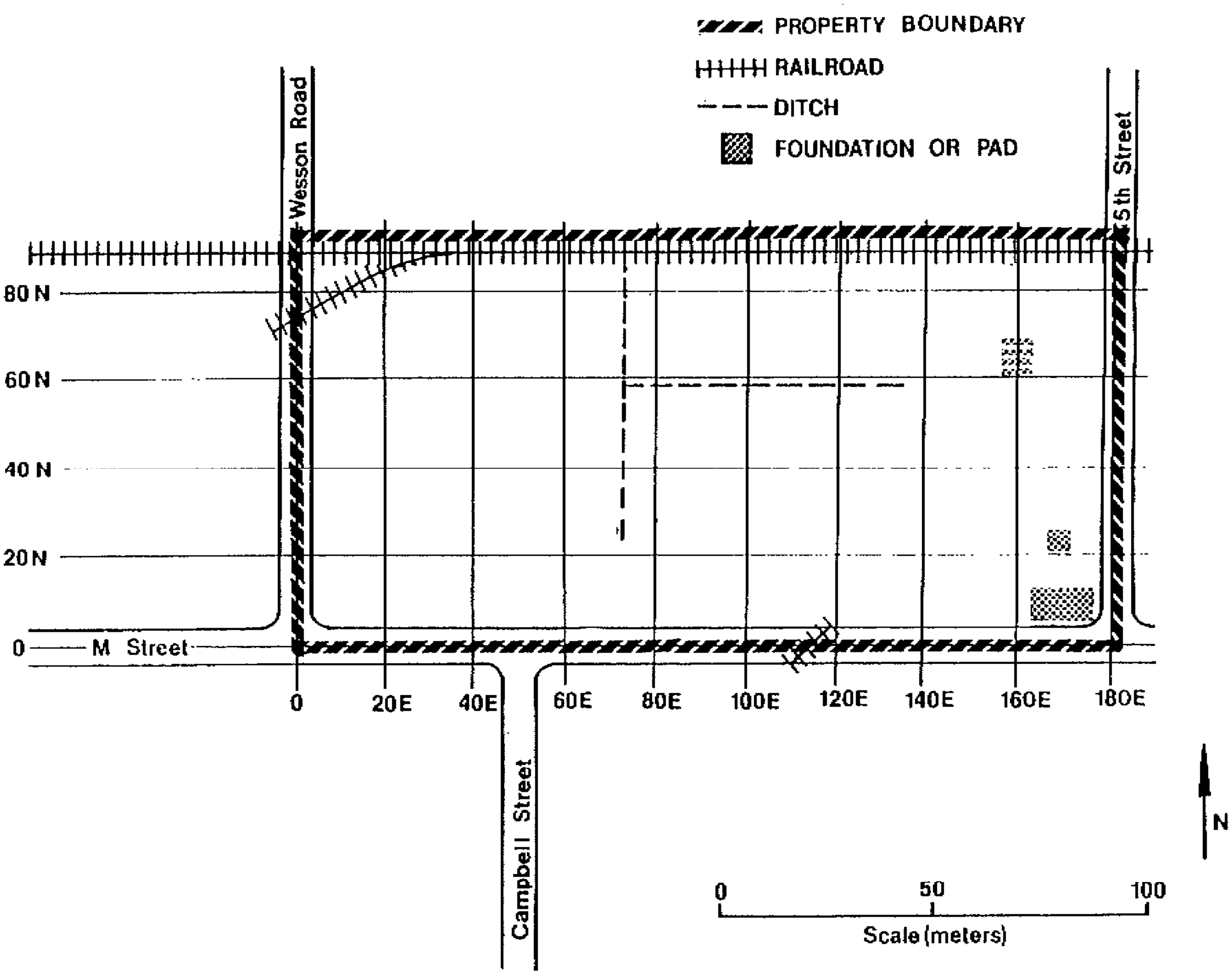

FIGURE 2. Plan View of NFSS Off-Site Property H', Indicating Prominent Surface Features and the Grid System Established for Survey Reference.

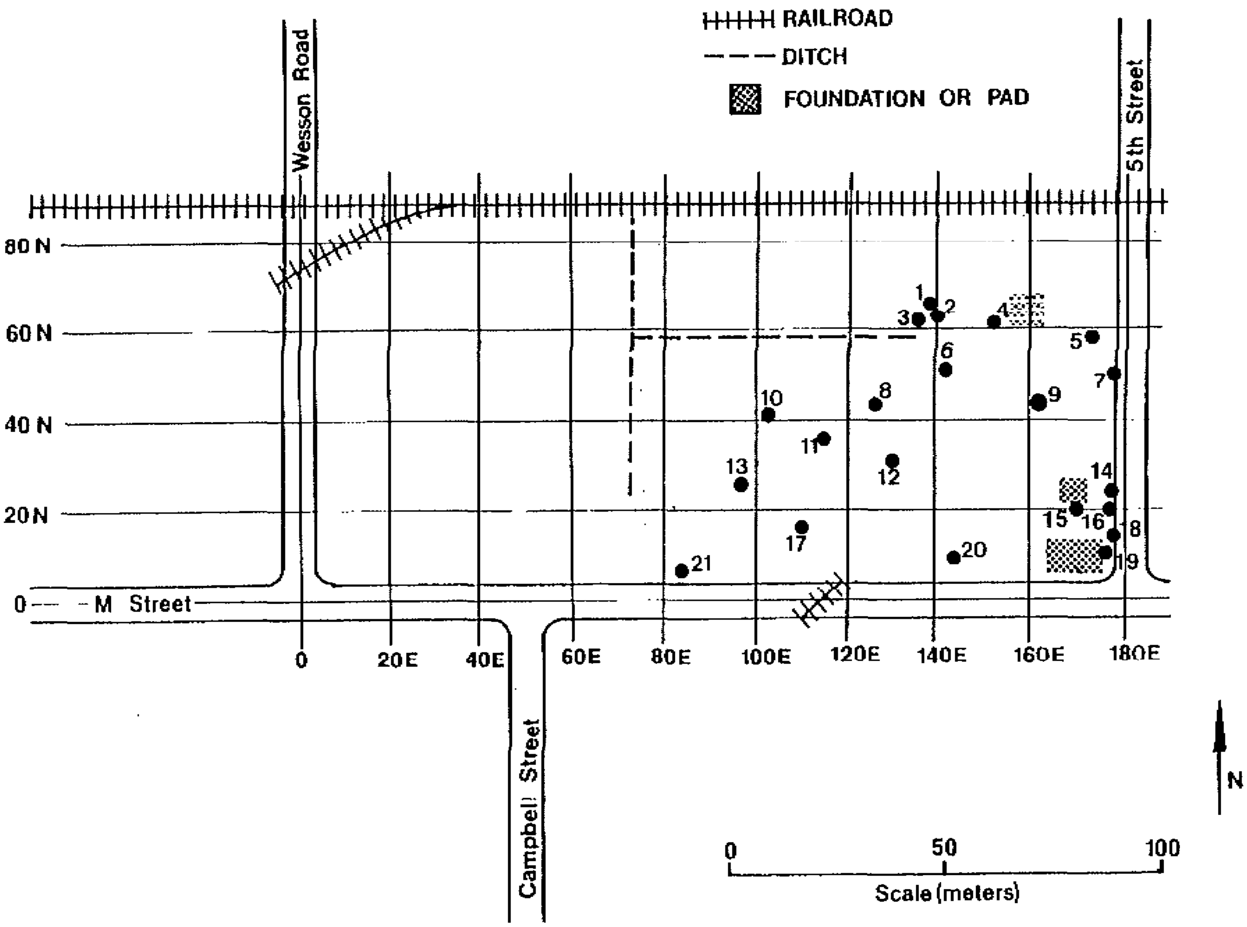

FIGURE 3. Locations of 21 Areas of Elevated Direct Radiation Levels, Selected for Further Measurements and Sampling.

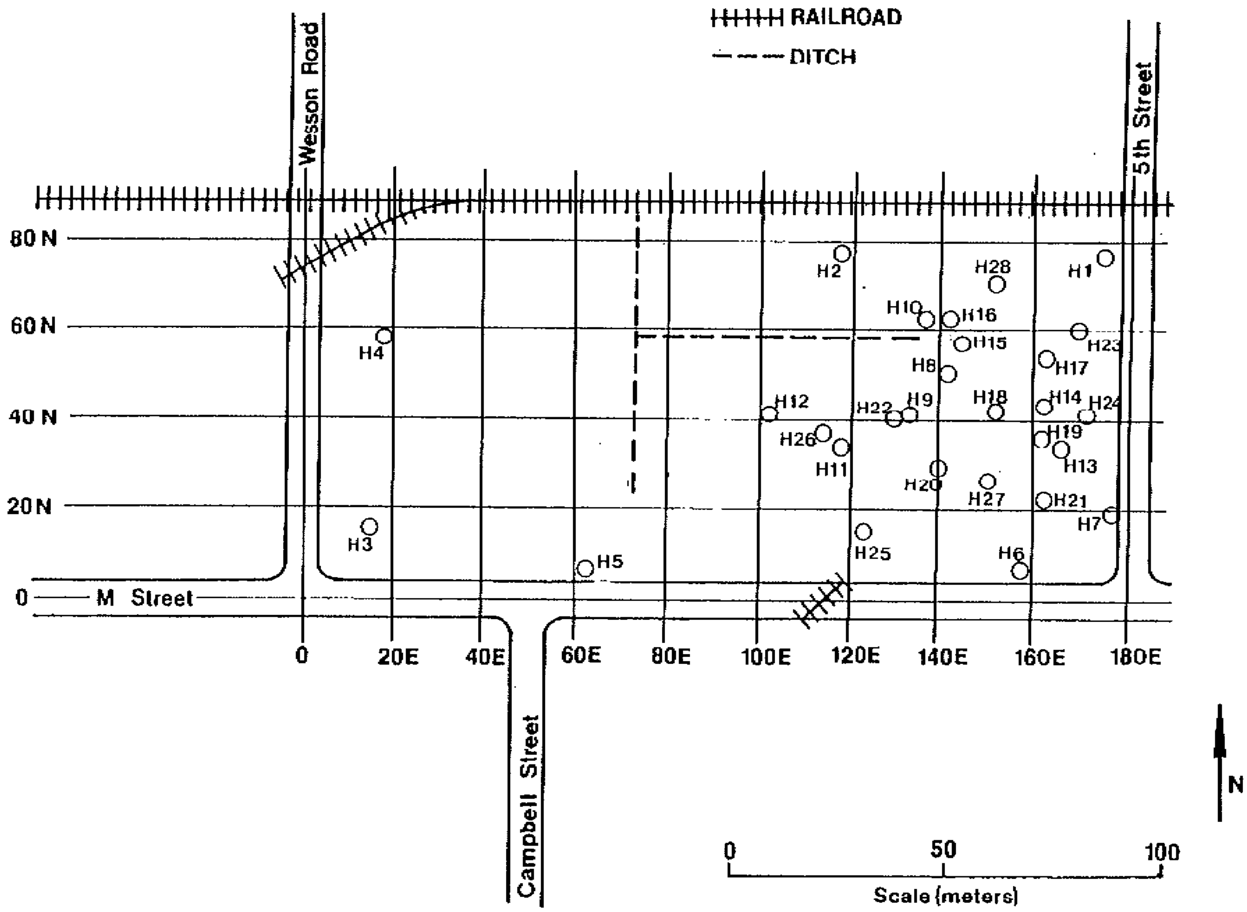

FIGURE 4. Locations of Boreholes for Subsurface Investigations

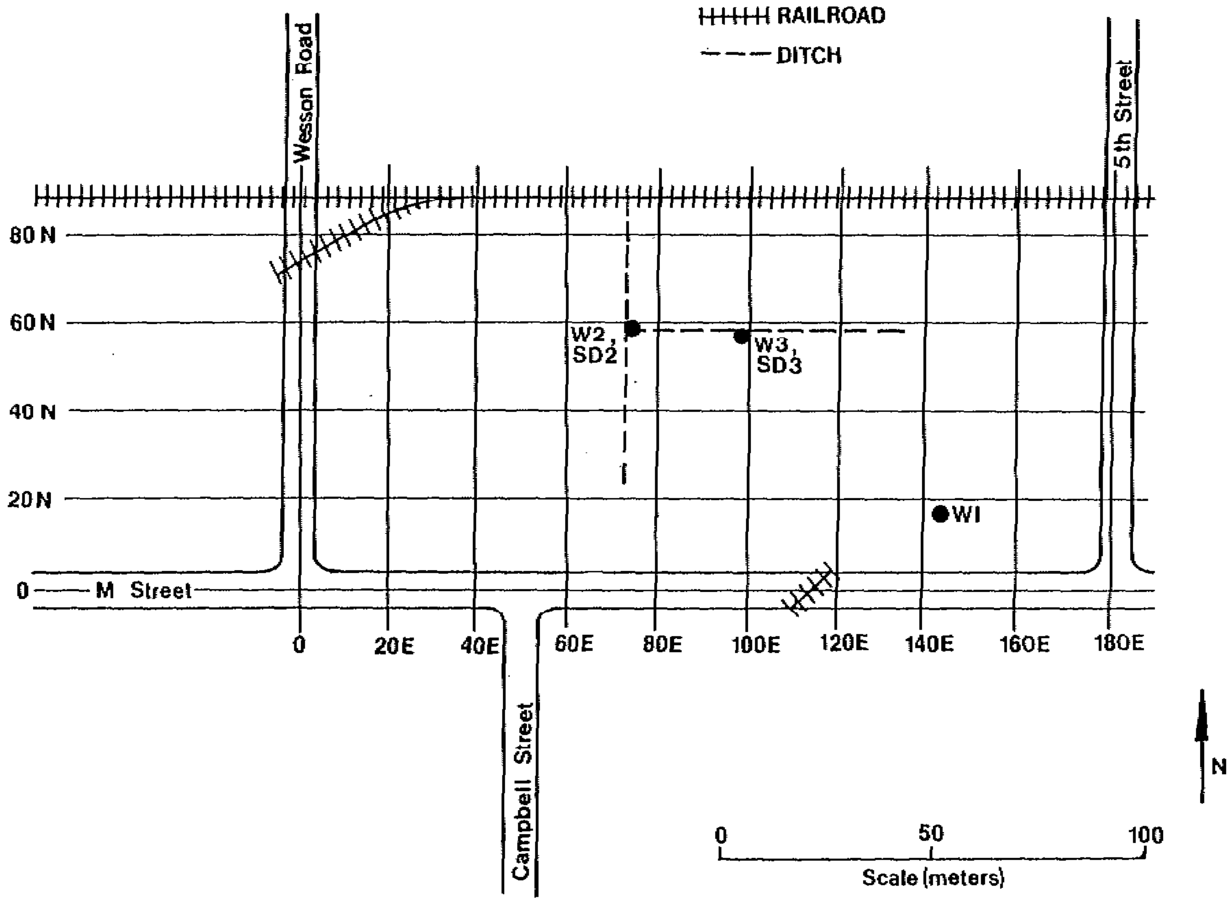

FIGURE 5. Locations of Surface Water (W1-W3) and Ditch Sediment (SD2 and SD3) Samples.

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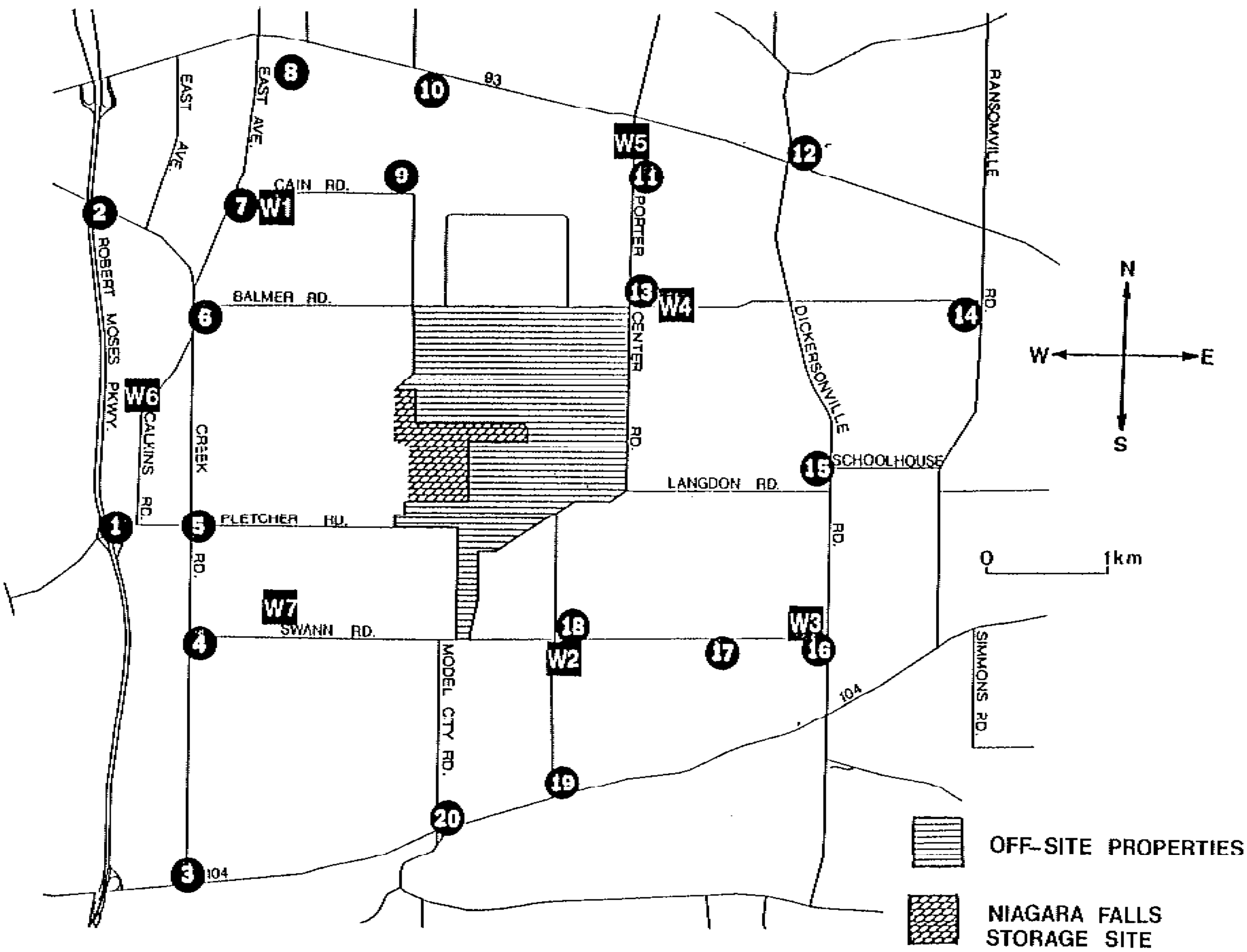

FIGURE 6. Map of Northern Niagara County, New York, Showing Locations of Background Measurements and Baseline Samples.

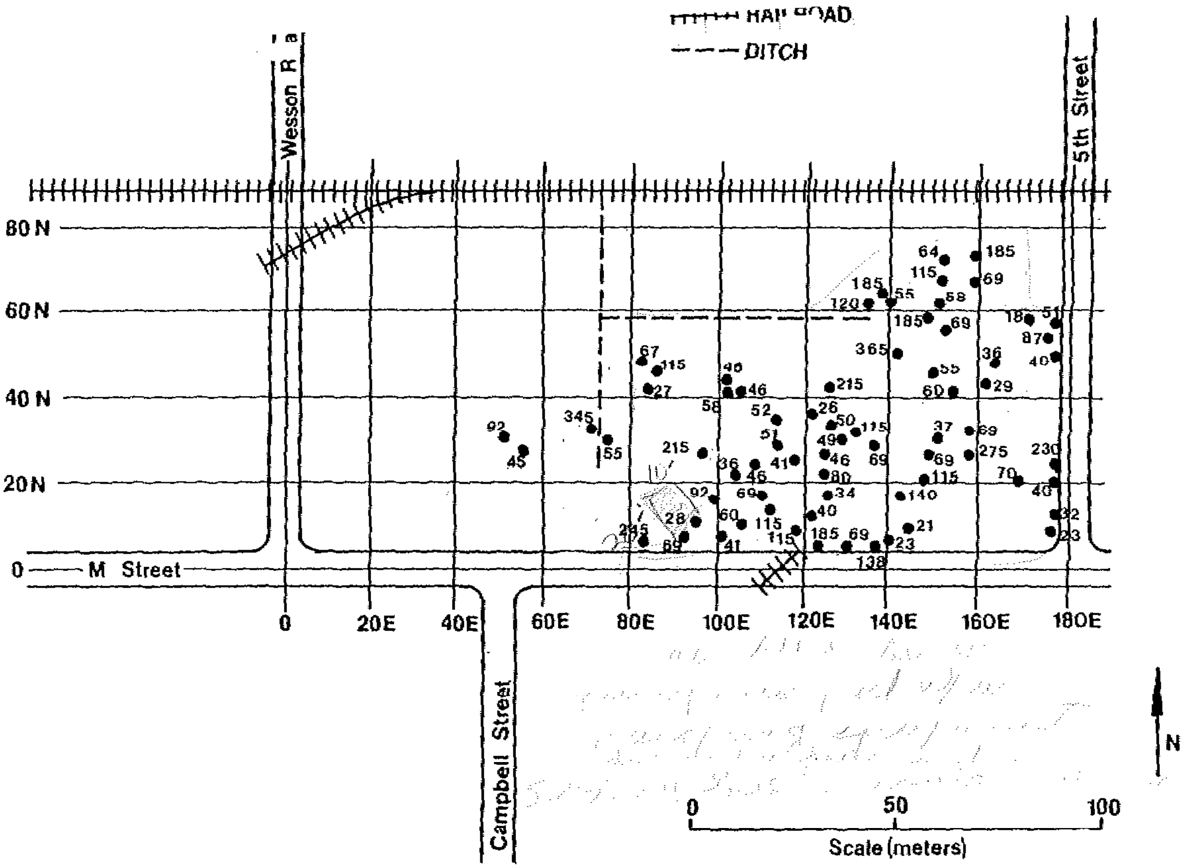

FIGURE 7. Locations of Elevated Radiation Levels (μR/h) Identified by the Walkover Scan.

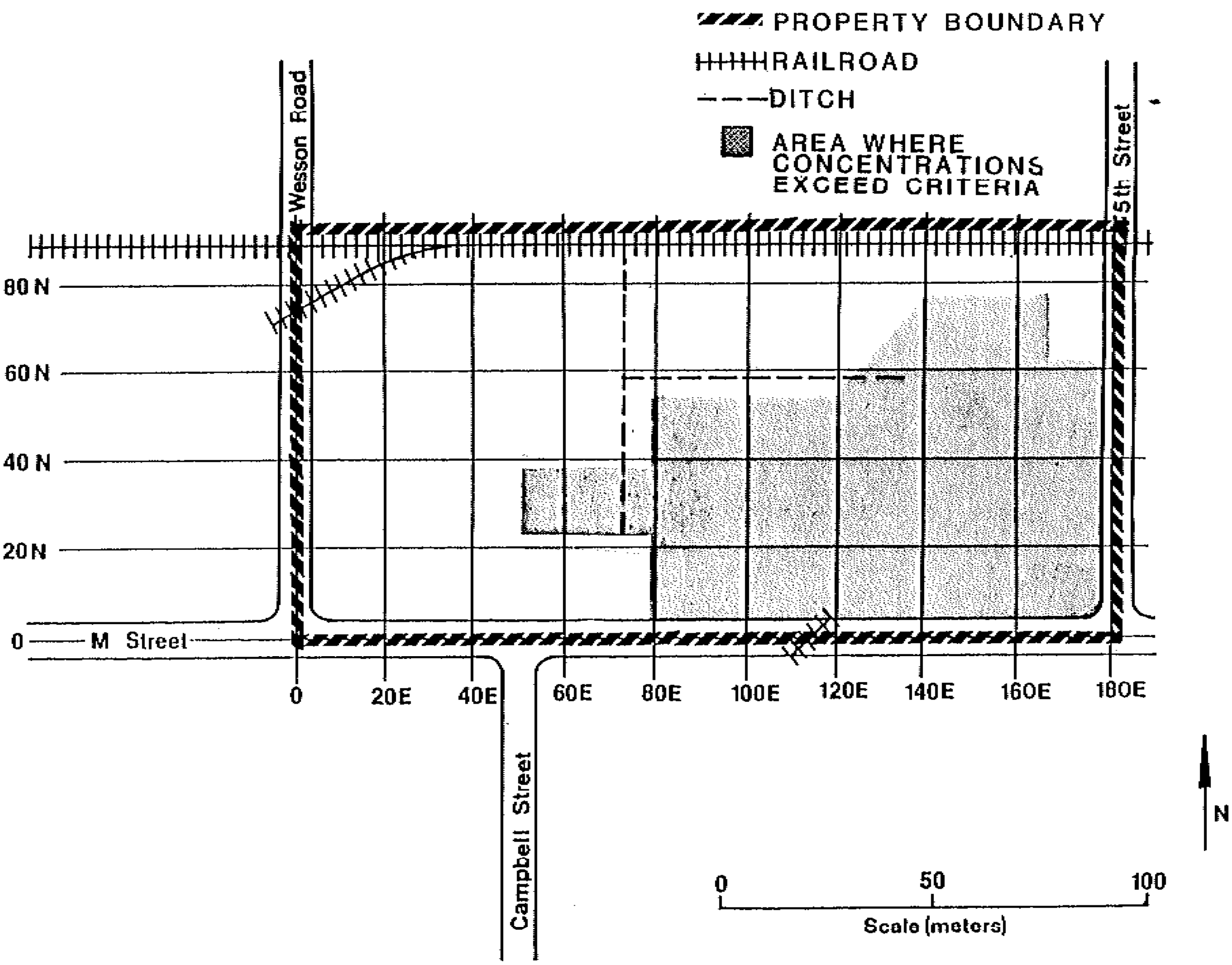

FIGURE 8. Map of NFSS Off-Site Property H', Indicating Areas Where Radionuclide Concentrations in Soil Exceed Criteria.

TABLE 1-A

BACKGROUND EXPOSURE RATES AND BASELINE RADIONUCLIDE CONCENTRATIONS IN SOIL

Location[a]	Exposure Rate[b] (μR/h)	Radionuclide Concentrations (pCi/g)				
		Ra-226	U-235	U-238	Th-232	Cs-137
1	6.6	0.74 ± 0.16[c]	<0.19	<2.09	0.70 ± 0.46	0.29 ± 0.08
2	6.8	0.75 ± 0.19	<0.19	<3.35	<0.22	0.24 ± 0.08
3	8.3	0.71 ± 0.18	0.46 ± 0.41	<3.72	0.88 ± 0.33	0.34 ± 0.09
4	7.9	0.67 ± 0.18	<0.22	<4.10	1.18 ± 0.35	0.12 ± 0.07
5	7.3	0.70 ± 0.16	<0.17	<3.34	0.68 ± 0.24	0.14 ± 0.07
6	7.7	0.50 ± 0.15	<0.16	<2.33	0.52 ± 0.38	0.17 ± 0.09
7	7.7	0.63 ± 0.13	<0.17	<2.73	0.83 ± 0.24	0.35 ± 0.08
8	7.6	0.59 ± 0.12	<0.14	<2.20	0.54 ± 0.23	<0.02
9	7.1	0.63 ± 0.20	<0.23	<4.16	0.83 ± 0.30	0.69 ± 0.11
10	7.1	0.70 ± 0.16	<0.19	<2.98	<0.18	0.69 ± 0.10
11	6.7	<0.09	<0.19	<2.83	0.49 ± 0.31	0.48 ± 0.14
12	7.1	0.48 ± 0.13	<0.16	<2.84	0.65 ± 0.26	0.68 ± 0.10
13	6.7	0.57 ± 0.14	<0.17	<2.36	0.49 ± 0.26	0.41 ± 0.08
14	6.8	0.68 ± 0.17	<0.19	<3.24	0.67 ± 0.25	0.70 ± 0.10
15	8.2	0.65 ± 0.14	<0.17	<3.20	0.72 ± 0.35	0.23 ± 0.08
16	7.4	0.91 ± 0.17	<0.71	<3.58	0.83 ± 0.28	0.61 ± 0.09
17	7.0	0.48 ± 0.14	<0.16	<2.73	0.32 ± 0.22	0.38 ± 0.08
18	7.7	0.73 ± 0.16	<0.18	6.26 ± 9.23	<0.23	0.32 ± 0.12
19	8.8	1.22 ± 0.22	<0.23	<3.79	1.08 ± 0.49	1.05 ± 0.13
20	8.6	0.83 ± 0.17	<0.21	<3.59	0.84 ± 0.29	0.08 ± 0.07
Range	6.8 to 8.8	<0.09 to 1.22	<0.14 to 0.46	<2.20 to 6.26	<0.18 to 1.18	<0.02 to 1.05

[a] Refer to Figure 6.
[b] Measured at 1 m above the surface.
[c] Errors is 2σ based on counting statistics only.

TABLE 1-B

RADIONUCLIDE CONCENTRATIONS IN BASELINE WATER SAMPLES

Location[a]	Radionuclide Concentrations (pCi/l)	
	Gross Alpha	Gross Beta
W1	0.95 ± 0.93 [b]	4.79 ± 1.15
W2	0.95 ± 0.94	9.17 ± 1.31
W3	0.55 ± 0.78	2.73 ± 1.05
W4	0.63 ± 0.89	5.37 ± 1.17
Range	0.55 to 0.95	2.73 to 9.17

a Refer to Figure 6.
b Errors are 2σ based on counting statistics.

TABLE 2

DIRECT RADIATION LEVELS
SYSTEMATICALLY MEASURED AT GRID LINE INTERSECTIONS

Grid Location	Gamma Exposure Rates at 1 m Above the Surface (μR/h)	Gamma Exposure Rates at the Surface (μR/h)	Beta-Gamma Dose Rates at the Surface (μrad/h)
3N, 0E	9.0	10	55
3N, 20E	8.9	8.9	48
3N, 40E	10	12	66
3N, 60E	9.7	10	60
3N, 80E	10	10	71
3N,100E	9.7	9.0	55
3N,120E	12	12	52
3N,140E	13	13	45
3N,160E	11	12	46
3N,180E	8.0	8.8	42
20N, 3E	8.7	8.8	38
20N, 20E	8.1	7.4	45
20N, 40E	7.7	8.0	31
20N, 60E	8.2	7.7	38
20N, 80E	8.2	8.7	42
20N,100E	10	11	46
20N,120E	11	9.0	45
20N,140E	9.7	10	48
20N,160E	10	16	71
20N,180E	18	22	100
40N, 3E	8.7	8.4	45
40N, 20E	7.7	8.4	23
40N, 40E	7.7	8.6	48
40N, 60E	7.4	7.4	31
40N, 80E	8.4	8.0	48
40N,100E	11	12	55
40N,120E	14	15	51
40N,140E	12	11	43
40N,160E	14	15	58
40N,180E	9.7	9.8	45
60N, 3E	7.4	8.8	46
60N, 20E	8.0	8.0	37
60N, 40E	8.2	7.4	25
60N, 60E	7.4	7.7	38
60N, 80E	8.6	8.2	20
60N,100E	7.7	7.7	37
60N,120E	8.8	9.5	43
60N,140E	14	12	38
60N,160E	9.5	9.8	29
60N,178E	8.8	9.5	46

TABLE 2, cont.

DIRECT RADIATION LEVELS
SYSTEMATICALLY MEASURED AT GRID LINE INTERSECTIONS

Grid Location	Gamma Exposure Rates at 1 m Above the Surface (μR/h)	Gamma Exposure Rates at the Surface (μR/h)	Beta-Gamma Dose Rates at the Surface (μrad/h)
80N, 4E	8.2	8.0	40
80N, 20E	6.4	5.7	31
80N, 40E	6.2	5.9	26
80N, 60E	6.6	5.9	38
80N, 80E	7.2	7.2	35
80N,100E	8.0	7.4	23
80N,120E	6.8	7.2	29
80N,140E	7.7	7.7	38
80N,160E	7.4	7.2	25
80N,178E	7.3	8.6	37
95N, 0E	9.7	10	42
90N, 20E	6.8	6.4	23
95N, 40E	7.4	7.0	31
98N, 60E	8.2	8.7	29
90N, 80E	12	15	60
90N,100E	8.7	9.5	35
100N,120E	7.4	7.3	35
90N,140E	6.4	6.4	40
90N,160E	a	a	a
90N,178E	9.0	10	45

[a] Measurement not performed due to presence of surface water.

TABLE 3

DIRECT RADIATION LEVELS AT SELECTED LOCATIONS IDENTIFIED BY THE WALKOVER SURFACE SCAN

Location[a]	Grid Point	Exposure Rate (μR/h)		Surface Dose Rate (μrad/h)	Soil Sample [b]	Contact Exposure Rate After Sample Removal (μR/h)
		Contact	1 m above surface			
1	64N,139E	185	28	850	B1	305
2	63N,140E	55	22	310	B2	70
3	63N,137E	120	33	620	B3	185
4	62N,152E	58	17	260	B4	70
5	58N,172E	18	13	270	B5	34
6	52N,141E	365	21	2140	B6	475
7	51N,178E	40	15	190	B7	43
8	45N,126E	215	16	5580	B8	475
9	44N,162E	29	21	130	B9	35
10	41N,101E	58	12	410	B10	84
11	35N,115E	52	15	190	B11	49
12	30N,130E	49	21	210	B12	60
13	26N, 96E	215	24	1370	B13	300
14	23N,177E	230	25	1050	B14	285
15	20N,170E	70	20	370	B15	92
16	20N,177E	40	24	170	B16	50
17	17N,110E	69	21	390	B17	115
18	14N,178E	32	15	290	B18	40
19	10N,175E	23	16	110	B19	37
20	10N,145E	21	16	190	B20	34
21	7N, 83E	245	15	2010	B21	160

[a] Refer to Figure 3.
[b] Soil concentrations presented in Table 5.

TABLE 4

RADIONUCLIDE CONCENTRATIONS IN SURFACE SOIL SAMPLES FROM GRID LINE INTERSECTIONS

Sample No.	Grid Location[a]	Radionuclide Concentrations (pCi/g)				
		Ra-226	U-235	U-238	Th-232	Cs-137
1	3N, 0E	1.72 ± 0.17[b]	<0.18	<3.26	0.62 ± 0.24	0.78 ± 0.09
2	3N, 20E	1.75 ± 0.21	0.24 ± 0.36	<3.76	0.50 ± 0.32	0.38 ± 0.08
3	3N, 40E	1.65 ± 0.19	<0.18	<3.74	0.77 ± 0.26	0.76 ± 0.09
4	3N, 60E	2.59 ± 0.24	<0.18	<4.26	0.75 ± 0.27	1.23 ± 0.12
5	3N, 80E	1.37 ± 0.17	0.24 ± 0.33	<3.56	0.62 ± 0.25	0.37 ± 0.09
6	3N,100E	1.43 ± 0.19	<0.18	<3.63	0.54 ± 0.24	0.41 ± 0.08
7	3N,120E	1.09 ± 0.16	<0.18	<3.23	0.56 ± 0.26	0.29 ± 0.06
8	3N,140E	3.81 ± 0.28	<0.18	<4.26	0.53 ± 0.31	0.62 ± 0.11
9	3N,160E	4.82 ± 0.30	<0.18	<4.35	1.06 ± 0.34	0.95 ± 0.12
10	3N,180E	1.50 ± 0.21	<0.18	<4.13	0.43 ± 0.30	0.54 ± 0.09
11	20N, 3E	0.97 ± 0.23	0.30 ± 0.30	<3.26	<0.21	0.81 ± 0.10
12	20N, 20E	0.83 ± 0.17	<0.15	<3.89	0.60 ± 0.37	0.50 ± 0.09
13	20N, 40E	0.72 ± 0.15	<0.14	<3.74	0.79 ± 0.24	0.87 ± 0.12
14	20N, 60E	1.12 ± 0.18	<0.15	<3.79	0.74 ± 0.25	1.00 ± 0.12
15	20N, 80E	1.35 ± 0.22	0.25 ± 0.35	<3.63	1.03 ± 0.35	0.57 ± 0.09
16	20N,100E	3.23 ± 0.28	0.58 ± 0.42	10.4 ± 9.9	0.88 ± 0.31	0.15 ± 0.08
17	20N,120E	1.95 ± 0.20	<0.18	<4.39	0.92 ± 0.28	0.11 ± 0.08
18	20N,137E	0.94 ± 0.17	0.18 ± 0.34	6.84 ± 6.66	1.01 ± 0.27	0.08 ± 0.05
19	20N,160E	15.7 ± 0.52	1.14 ± 0.73	<6.76	1.48 ± 0.44	0.22 ± 0.07
20	20N,180E	1.25 ± 0.17	0.30 ± 0.31	<3.73	0.92 ± 0.28	0.16 ± 0.06
21	40N, 3E	3.31 ± 0.33	<0.21	<4.65	0.45 ± 0.54	0.77 ± 0.15
22	40N, 20E	0.60 ± 0.19	<0.15	<3.86	<0.18	0.59 ± 0.11
23	40N, 40E	0.64 ± 0.14	0.12 ± 0.28	<3.95	0.59 ± 0.39	0.53 ± 0.11
24	40N, 60E	0.59 ± 0.17	<0.14	<4.19	0.73 ± 0.22	0.47 ± 0.09
25	40N, 80E	0.83 ± 0.15	<0.14	<3.31	0.83 ± 0.38	0.65 ± 0.10
26	40N,100E	2.46 ± 0.27	<0.20	<4.39	0.86 ± 0.29	0.56 ± 0.10
27	40N,120E	3.32 ± 0.26	0.55 ± 0.43	<4.19	0.85 ± 0.28	0.18 ± 0.10
28	40N,140E	2.33 ± 0.22	<0.17	<3.83	0.68 ± 0.28	0.16 ± 0.07
29	40N,160E	10.8 ± 0.44	<0.32	<6.30	0.74 ± 0.45	0.41 ± 0.11
None[c]	40N,180E	---	---	---	---	---
30	60N, 3E	1.60 ± 0.21	<0.23	<3.79	0.69 ± 0.29	1.00 ± 0.12
31	60N, 20E	0.63 ± 0.18	<0.20	<4.08	0.95 ± 0.34	1.06 ± 0.16
32	60N, 40E	0.66 ± 0.15	<0.19	<3.28	<0.21	0.45 ± 0.11
33	60N, 60E	0.97 ± 0.23	<0.23	<3.54	0.63 ± 0.51	0.87 ± 0.14
34	60N, 80E	0.65 ± 0.21	0.29 ± 0.41	<4.07	0.78 ± 0.34	0.54 ± 0.11
35	60N,100E	1.22 ± 0.21	<0.24	<3.83	0.88 ± 0.33	0.87 ± 0.13
36	60N,120E	1.94 ± 0.28	<0.31	<5.64	0.89 ± 0.41	0.76 ± 0.16
37	60N,140E	3.34 ± 0.33	0.92 ± 0.67	<5.28	0.85 ± 0.41	0.74 ± 0.14
38	60N,160E	1.82 ± 0.26	<0.27	14.7 ± 9.8	<0.25	<0.08
39	60N,178E	2.28 ± 0.30	<0.29	<3.69	0.90 ± 0.40	1.27 ± 0.16
40	80N, 4E	0.70 ± 0.16	<0.19	<3.67	0.78 ± 0.32	0.04 ± 0.05
None[c]	80N, 20E	---	---	---	---	---
None[c]	80N, 40E	---	---	---	---	---

TABLE 4, cont.

RADIONUCLIDE CONCENTRATIONS IN SURFACE SOIL SAMPLES
FROM GRID LINE INTERSECTIONS

Sample No.	Grid Location	Radionuclide Concentrations (pCi/g)				
		Ra-226	U-235	U-238	Th-232	Cs-137
None[c]	80N, 60E	---	---	---	---	---
41	80N, 80E	0.64 ± 0.17	0.45 ± 0.45	<2.66	0.77 ± 0.31	0.35 ± 0.09
42	80N,100E	0.68 ± 0.21	<0.18	<2.54	<0.20	0.42 ± 0.11
43	80N,120E	0.71 ± 0.16	<0.21	<2.64	0.84 ± 0.34	0.64 ± 0.10
44	80N,140E	0.71 ± 0.19	<0.22	<3.94	0.61 ± 0.34	0.67 ± 0.15
45	80N,160E	0.87 ± 0.18	<0.21	<3.68	<0.22	0.49 ± 0.10
46	80N,178E	1.40 ± 0.39	<0.33	<4.06	<0.26	0.99 ± 0.21
47	95N, 0E	0.51 ± 0.13	<0.16	<2.51	0.78 ± 0.28	0.04 ± 0.05
None[c]	90N, 20E	---	---	---	---	---
48	95N, 40E	0.68 ± 0.17	<0.21	<3.84	0.53 ± 0.28	0.72 ± 0.12
49	98N, 60E	4.06 ± 0.34	<0.29	8.53 ± 8.93	0.43 ± 0.32	0.65 ± 0.12
None[c]	90N, 80E	---	---	---	---	---
50	90N,100E	1.40 ± 0.26	0.54 ± 0.53	<3.15	<0.19	1.01 ± 0.16
51	100N,120E	0.59 ± 0.17	0.21 + 0.46	<4.02	0.39 ± 0.40	0.84 ± 0.16
52	90N,140E	0.63 ± 0.18	0.44 ± 0.42	<3.93	0.38 ± 0.35	1.09 ± 0.15
None[c]	90N,160E	---	---	---	---	---
53	90N,178E	1.97 ± 0.25	<0.22	<4.19	0.46 ± 0.34	0.26 ± 0.08

[a] Refer to Figure 2.
[b] Errors are 2σ based on counting statistics.
[c] No sample obtained due to presence of surface water.

TABLE 5

RADIONUCLIDE CONCENTRATIONS IN SURFACE SOIL SAMPLES FROM SELECTED LOCATIONS IDENTIFIED BY THE WALKOVER SCAN

Sample	Grid Location[a]	Radionuclide Concentrations (pCi/g)[b]				
		Ra-226	U-235	U-238 [f]	Th-232	Cs-137
B1	64N,139E	278 ± 4 [c]	11.7 ± 5.2	228 ± 97	<1.31	8.32 ± 0.96
B2	63N,140E	2.14 ± 0.43	66.0 ± 3.0	1480 ± 50	<0.26	0.56 ± 0.21
B3	63N,137E	167 ± 2	13.7 ± 3.4	202 ± 51	<0.68	3.48 ± 0.44
B4	62N,152E	53.9 ± 1.1	3.16 ± 1.76	43.8 ± 30.3	<0.42	1.44 ± 0.25
B5	58N,172E	11.6 ± 0.5	0.84 ± 0.92	<6.46	<0.28	0.17 ± 0.13
B6	52N,141E[d]	1750 ± 10	<8.24	450 ± 220	<3.48	27.1 ± 2.3
B7	51N,178E	17.0 ± 0.6	1.02 ± 0.98	<7.20	<0.26	0.66 ± 0.16
B8	45N,126E	835 ± 5	<3.57	<11.0	<1.53	13.8 ± 1.0
B9	44N,162E	18.5 ± 0.9	<0.81	<11.1	<0.43	0.70 ± 0.22
B10	41N,101E	110 ± 2	2.93 ± 2.68	<16.3	<0.54	2.63 ± 0.39
B11	35N,115E	22.8 ± 0.7	1.13 ± 1.10	<7.96	<0.30	0.58 ± 0.16
B12	30N,130E	123 ± 3	3.06 ± 4.03	<7.02	<0.90	1.98 ± 0.52
B13	26N, 96E	470 ± 5	<3.89	<9.14	<1.55	7.45 ± 0.93
B14	23N,177E	501 ± 5	<3.81	<12.5	<1.62	7.22 ± 1.13
B15	20N,170E	141 ± 2	<1.96	<4.64	<0.87	<0.23
B16	20N,177E	11.9 ± 0.5	<0.45	<6.17	<0.22	0.83 ± 0.16
B17	17N,110E	219 ± 3	<2.60	<8.47	<1.12	3.64 ± 0.83
B18	14N,178E[e]	330 ± 3	7.73 ± 4.59	134 ± 68	<1.10	33.0 ± 0.7
B19	10N,175E	18.9 ± 0.6	0.85 ± 1.02	<7.32	<0.25	0.74 ± 0.16
B20	10N,145E	38.9 ± 0.9	<0.75	28.2 ± 23.0	0.69 ± 0.67	0.60 ± 0.20
B21	7N, 83E	958 ± 7	<5.29	<17.0	<2.22	15.1 ± 1.5

[a] Refer to Figure 3.
[b] Refer to Table 2 for direct radiation levels.
[c] Errors are 2σ based on counting statistics.
[d] This sample also contained 9.71 ± 0.75 pCi/g of Sr-90 and 0.30 ± 0.26 pCi/g of Pu-239.
[e] This sample also contained 13.3 ± 1.3 pCi/g of Co-60 and 1.29 ± 0.36 pCi/g of Sr-90.
[f] Large minimum detectable activities and relative errors are the result of high continuum count rates resulting from high levels of Ra-226 in these samples.

TABLE 6

RADIONUCLIDE CONCENTRATIONS IN BOREHOLE SOIL SAMPLES

Borehole No.	Grid Location[a]	Depth (m)	Radionuclide Concentrations (pCi/g)				
			Ra-226	U-235	U-238	Th-232	Cs-137
B1	78N, 174E	0.5	0.70 ± 0.14[b]	<0.17	<3.41	0.82 ± 0.24	<0.02
		1	0.65 ± 0.16	<0.18	<2.49	0.98 ± 0.29	<0.03
		2	0.62 ± 0.18	<0.19	<3.72	1.22 ± 0.35	<0.03
		3	0.68 ± 0.17	<0.21	<3.30	0.81 ± 0.28	<0.02
		4	0.61 ± 0.14	<0.16	<2.54	0.99 ± 0.36	<0.02
B2	78N, 118E	0.5	0.50 ± 0.18	0.28 ± 0.57	<3.57	1.07 ± 0.36	<0.03
		1	0.69 ± 0.16	<0.20	<3.91	0.52 ± 0.38	<0.03
		2	0.67 ± 0.23	<0.21	<3.36	1.16 ± 0.37	<0.02
		3	0.65 ± 0.14	<0.18	<2.70	0.81 ± 0.38	<0.02
		4	0.64 ± 0.14	<0.19	<3.17	0.85 ± 0.42	<0.02
B3	15N, 15E	0.15	9.20 ± 0.43	0.69 ± 0.77	13.9 ± 11.8	<0.24	0.15 ± 0.12
		0.5	0.60 ± 0.12	<0.16	<2.63	0.46 ± 0.22	0.02 ± 0.06
		1	0.73 ± 0.16	<0.15	<3.03	<0.17	<0.02
B4	59N, 18E	0.5	0.86 ± 0.19	<0.26	<4.80	1.15 ± 0.43	<0.03
		1	0.67 ± 0.22	<0.21	<4.37	1.16 ± 0.37	<0.03
		2	0.93 ± 0.16	<0.20	<4.24	<0.22	<0.03
		3	0.52 ± 0.15	<0.14	<2.17	0.78 ± 0.26	<0.02
		4	0.56 ± 0.21	<0.20	<3.23	0.73 ± 0.28	<0.03
B5	7N, 62E	0.5	0.62 ± 0.20	<0.23	<3.92	0.79 ± 0.34	<0.03
		1	0.53 ± 0.16	<0.18	<3.57	0.78 ± 0.26	<0.02
		2	0.59 ± 0.16	<0.17	<2.70	0.49 ± 0.26	<0.02
		4	0.64 ± 0.14	<0.17	<2.70	0.98 ± 0.29	<0.02
B6	7N, 159E	0.5	0.81 ± 0.15	<0.21	<3.34	<0.24	<0.03
		1	0.61 ± 0.29	<0.20	<3.44	0.97 ± 0.39	<0.03
		2	0.85 ± 0.23	<0.24	<4.49	1.06 ± 0.46	<0.03
		3	<0.10	<0.17	<3.45	0.91 ± 0.31	<0.02
		4	0.55 ± 0.14	<0.15	<2.94	0.58 ± 0.32	<0.02
B7	20N, 177E	surface	11.9 ± 0.5	<0.45	<6.17	<0.22	0.83 ± 0.16
		0.5	1.24 ± 0.20	<0.22	<4.00	1.00 ± 0.33	<0.03
		1	1.32 ± 0.25	<0.26	<3.96	1.20 ± 0.40	<0.03
		2	1.11 ± 0.21	<0.21	<3.53	0.91 ± 0.35	<0.03
B8	52N, 141E	surface[c]	1750 ± 10	<8.24	450 ± 220	<3.48	27.1 ± 2.3
		0.5	18.1 ± 0.7	1.42 ± 1.15	23.3 ± 17.5	0.93 ± 0.78	0.35 ± 0.15
		1	1.85 ± 0.25	0.44 ± 0.49	<4.35	1.19 ± 0.42	<0.03
		2	1.33 ± 0.19	<0.20	<3.20	0.88 ± 0.33	<0.02
		3	0.92 ± 0.18	<0.18	<3.40	1.03 ± 0.28	<0.02

TABLE 6, cont.

RADIONUCLIDE CONCENTRATIONS IN BOREHOLE SOIL SAMPLES

Borehole No.	Grid Location	Depth (m)	Radionuclide Concentrations (pCi/g) Ra-226	U-235	U-238	Th-232	Cs-137
H9	41N, 136E	surface	1.76 ± 0.23	<0.23	<3.19	0.52 ± 0.37	0.16 ± 0.08
		0.5	2.86 ± 0.25	<0.26	<3.42	0.73 ± 0.37	0.05 ± 0.06
		1	0.56 ± 0.14	<0.17	9.77 ± 6.34	0.78 ± 0.31	<0.02
		2	0.63 ± 0.16	<0.18	<2.87	0.95 ± 0.31	<0.02
		3	0.68 ± 0.17	<0.19	<3.36	0.73 ± 0.27	<0.02
H10	63N, 137E	surface	167 ± 2	13.7 ± 3.4	202 + 51	<0.68	3.48 ± 0.44
		0.5	1.97 ± 0.24	0.75 ± 0.58	6.6 ± 11.7	0.94 ± 0.33	<0.03
		1	1.58 ± 0.23	0.45 ± 0.46	5.87 ± 8.10	0.65 ± 0.28	0.04 ± 0.06
		2	0.58 ± 0.11	<0.14	4.13 ± 6.34	0.55 ± 0.22	<0.02
		3	0.62 + 0.16	<0.21	<3.97	1.08 ± 0.37	<0.03
H11	35N, 118E	surface	7.39 ± 0.40	0.77 ± 0.65	<4.88	0.76 ± 0.35	0.32 ± 0.10
		0.5	1.55 ± 0.24	<0.21	<3.26	0.84 ± 0.49	<0.03
H12	41N, 101E	surface	110 ± 2	2.93 ± 2.68	<16.3	<0.54	2.63 ± 0.39
		0.5	5.56 ± 0.28	<0.28	<3.72	0.51 ± 0.26	0.14 + 0.08
H13	35N, 165E	surface	30.6 ± 0.8	1.68 ± 1.33	15.4 ± 19.3	<0.31	0.65 ± 0.18
		0.5	0.63 ± 0.15	<0.17	6.40 ± 6.35	0.66 ± 0.33	<0.02
H14	44N, 162E	surface	18.5 ± 0.9	<0.81	<11.1	<0.43	0.70 ± 0.22
		0.5	1.47 ± 0.20	0.77 ± 0.39	<3.48	0.77 ± 0.26	<0.03
H15	56N, 146E	surface	29.3 ± 0.87	<0.72	12.3 ± 21.6	<0.34	0.68 ± 0.21
		0.5	3.95 ± 0.31	0.85 ± 0.64	7.61 ± 8.90	0.81 ± 0.39	0.05 ± 0.06
H16	63N, 140E	surface	2.14 ± 0.43	66.0 ± 3.0	1480 ± 50	<0.26	0.56 ± 0.21
		0.5	0.48 ± 0.17	4.85 ± 0.82	101 ± 16	0.80 + 0.30	<0.04
H17	53N, 163E	0.5	<0.14	<0.21	<3.16	<0.24	<0.03
		1	0.58 ± 0.15	<0.18	10.3 ± 6.7	0.82 ± 0.33	<0.02
H18	41N, 152E	0.5	0.69 ± 0.15	<0.19	<3.77	<0.18	0.04 ± 0.06
		1	0.46 ± 0.11	<0.16	4.84 ± 4.65	0.64 + 0.22	<0.02
H19	38N, 162E	0.5	0.74 ± 0.20	<0.22	9.2 ± 10.5	1.02 ± 0.37	<0.03
		1	0.63 ± 0.16	0.37 ± 0.46	<4.14	<0.20	<0.03
H20	30N, 140E	0.5	0.77 ± 0.21	<0.21	<4.23	1.00 ± 0.41	<0.03
		1	0.64 + 0.18	<0.20	<4.26	<0.23	<0.07

TABLE 6, cont.

RADIONUCLIDE CONCENTRATIONS IN BOREHOLE SOIL SAMPLES

Borehole No.	Grid Location	Depth (m)	Radionuclide Concentrations (pCi/g)				
			Ra-226	U-235	U-238	Th-232	Cs-137
H21	21N, 161E	0.5	1.00 ± 0.18	<0.20	<3.32	0.73 ± 0.35	<0.02
		1	0.69 ± 0.19	<0.19	<3.01	0.84 ± 0.28	<0.03
H22	40N, 136E	0.5	24.8 ± 0.7	1.16 ± 1.12	13.4 ± 18.6	<0.29	0.43 ± 0.17
		1	1.31 ± 0.19	0.37 ± 0.48	<4.20	0.92 ± 0.34	<0.03
H23	60N, 168E	0.5	0.68 ± 0.19	<0.19	<3.63	0.88 ± 0.29	<0.02
		1	0.61 ± 0.17	0.28 ± 0.36	<3.24	<0.19	<0.02
		2	0.63 ± 0.14	<0.17	<3.18	0.59 ± 0.37	<0.02
		3	0.68 ± 0.15	<0.16	<2.87	0.47 ± 0.29	<0.02
		4	0.60 ± 0.17	<0.16	<2.92	0.82 ± 0.25	<0.02
H24	41N, 170E	0.5	0.72 ± 0.15	0.22 ± 0.49	<2.72	0.65 ± 0.31	<0.02
		1	0.64 ± 0.18	<0.20	<3.49	<0.21	<0.03
		2	0.72 ± 0.16	<0.19	<3.45	0.78 ± 0.25	<0.02
		3	0.85 ± 0.17	<0.19	<2.71	0.81 ± 0.45	<0.03
H25	16N, 122E	0.5	0.28 ± 0.25	<0.05	<3.80	0.77 ± 0.52	<0.03
		1	1.48 ± 0.35	<0.26	9.66 ± 13.3	<0.27	0.06 ± 0.11
		2	0.70 ± 0.15	<0.20	<3.25	1.06 ± 0.29	<0.03
		3	0.79 ± 0.19	<0.20	<4.23	<0.22	<0.03
		4	0.81 ± 0.21	0.38 ± 0.48	<3.35	1.12 ± 0.35	<0.03
H26	38N, 115E	0.5	0.92 ± 0.15	0.17 ± 0.32	<2.54	0.01 ± 0.28	<0.02
		1	1.56 ± 0.20	<0.21	<3.66	0.81 ± 0.29	<0.03
		2	1.07 ± 0.20	<0.21	<3.62	1.11 ± 0.32	<0.03
		4	1.11 ± 0.17	<0.18	<3.03	0.52 ± 0.36	<0.02
H27	29N, 149E	0.5	0.89 ± 0.21	<0.23	<4.36	0.92 ± 0.36	<0.03
		1	<0.14	0.36 ± 0.40	<3.56	1.06 ± 0.37	<0.03
		2	0.72 ± 0.14	<0.16	<2.92	<0.17	<0.02
		3	0.57 ± 0.13	<0.16	<2.93	0.67 ± 0.30	<0.02
H28	69N, 152E	0.5	0.63 ± 0.19	<0.18	<3.48	1.00 ± 0.35	<0.03
		1	0.60 ± 0.14	<0.17	<2.96	0.83 ± 0.29	<0.02

[a] Refer to Figure 4.
[b] Errors are 2σ based on counting statisitcs.
[c] This sample also contained 9.71 ± 0.75 pCi/g of Sr-90 and 0.30 ± 0.26 pCi/g of Pu-239.

TABLE 7

RADIONUCLIDE CONCENTRATIONS IN WATER SAMPLES

Sample Identification	Sample Type	Grid Location[a]	Radionuclide Concentrations (pCi/l)			
			Gross Alpha	Gross Beta	Ra-226	Sr-90
W1	Surface Water	16N, 143E	30.0 ± 9.2[b]	22.8 ± 9.0	0.16 ± 0.11	----
W2	Surface Water	60N, 73E	1.22 ± 1.10	4.73 ± 1.36	----[c]	----
W3	Surface Water	56N, 97E	6.97 + 5.79	8.64 ± 7.44	----	----
W4	Subsurface Water	78N, 174E	<4.49	7.95 ± 8.23	----	----
W5	Subsurface Water	78N, 118E	<5.04	<5.52	----	
W6	Subsurface Water	15N, 15E	9.87 ± 8.59	<5.51	----	----
W7	Subsurface Water	59N, 18E	7.50 ± 9.93	6.12 ± 8.48	----	----
W8	Subsurface Water	7N, 62E	17.8 ± 17.9	12.5 ± 14.4	0.77 ± 0.18	----
W9	Subsurface Water	7N, 159E	17.8 ± 9.5	5.55 ± 8.17	0.53 ± 0.18	----
W10	Subsurface Water	60N, 168E	10.8 ± 7.7	6.32 ± 8.06	<0.08	----
W11	Subsurface Water	41N, 170E	8.85 ± 7.24	7.49 + 8.09	----	----
W12	Subsurface Water	20N, 177E	<4.98	<5.51	----	----
W13	Subsurface Water	52N, 141E	799 ± 41	363 ± 21	0.38 ± 0.14	2.76 ± 2.00
W14	Subsurface Water	16N, 122E	<5.82	8.27 ± 8.56	----	----
W15	Subsurface Water	36N, 115E	7.31 ± 7.63	9.04 ± 8.33	----	----
W16	Subsurface Water	63N, 137E	37.9 ± 11.0	23.0 ± 9.2	0.25 ± 0.12	----
W17	Subsurface Water	29N, 149E	9.78 ± 7.56	8.93 ± 8.23	----	----

[a] Refer to Figures 2 and 5.
[b] Errors are 2σ based on counting statisitics.
[c] Dashes indicate analysis not performed.

TABLE 8

RADIONUCLIDE CONCENTRATIONS IN SEDIMENT SAMPLES
FROM DRAINAGE DITCHES

Sample No.	Grid Location[a]	Radionuclide Concentration (pCi/g)				
		Ra-226	U-235	U-238	Th-232	Cs-137
SD1	60N, 73E	0.98 ± 0.18	<0.19	<3.19	<0.19	0.74 ± 0.10
SD3	56N, 97E	0.96 ± 0.19	<0.20	<3.42	0.93 ± 0.45	0.29 ± 0.10

[a] Refer to Figure 5.
[b] Error is 2σ based on counting statistics.

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1. E.A. Vierzba and A. Wallo, A Background Report and Evaluation of Resurvey Requirements for the Former Atomic Energy Commission Portion of the Lake Ontario Ordnance Works (draft), Aerospace Corp., April 1981.

2. Oak Ridge Operations, U.S. Atomic Energy Commission, Radiation Survey and Decontamination Report of the Lake Ontario Ordnance Works Site, Oak Ridge, TN, January 1973.

3. EG&G, Inc., Summary Report - Aerial Radiological Survey, Niagara Falls Area, New York, WAMD-010, November 1971.

4. T.E. Myrick, et. al., Preliminary Results of the Ground-Level Gamma-Ray Scanning Survey of the Former Lake Ontario Ordnance Works Site - Draft Report, ORNL, Oak Ridge, TN, 1981.

5. J.W. Healy et al, Interim Soil Limits for D&D Projects. Los Alamos Laboratory, Los Alamos, NM. LA-UR-79-1865 rev. (Sept. 1979).

APPENDIX A

INSTRUMENTATION AND ANALYTICAL PROCEDURES

APPENDIX A

Instrumentation and Analytical Procedures

Gamma Scintillation Measurements

Walkover surface scans and measurements of gamma exposure rates were performed using Eberline Model PRM-6 portable ratemeters with Victoreen Model 489-55 gamma scintillation probes containing 3.2 cm x 3.8 cm NaI(Tl) crystals. Count rates were converted to exposure levels (μR/h) using factors determined by comparing the response of the scintillation dectector with that of a Reuter Stokes model RSS-111 pressurized ionization chamber at several locations on property H′.

Beta-Gamma Dose Rate Measurements

Measurements were performed using Eberline "Rascal," Model PRS-1, portable ratemeters with Model HP-260 thin-window, pancake G-M, beta probes. Dose rates (mrad/h) were determined by comparison of the response of a Victoreen Model 440 ionization chamber survey meter to that of the G-M probes for a composite of soil samples from the site, which were high in Ra-226 content.

Borehole Logging

Borehole gamma radiation measurements were performed using a Victoreen Model 489-55 gamma scintillation probe, connected to a Ludlum Model 2200 portable scaler. The scintillation probe was shielded by a 1.25 cm thick lead shield with four 2.5 cm x 7 mm holes evenly spaced around the region of the scintillation crystal. The probe was lowered into each hole using a tripod holder with a small winch. Measurements were performed at 30-50 cm intervals in all holes. The logging data was used to identify regions of possible residues and guide the selection of subsurface soil sampling locations. Due to the varying ratios of Ra-226, U-238, and Cs-137 there was no attempt to estimate soil radionuclide concentrations directly from the logging results.

Soil and Sediment Sample Analysis

Gamma Spectrometry

Soil samples were dried at 120° C, mixed, and a portion placed in a 0.5 liter Marinelli beaker. The quantity placed in each beaker was chosen to reproduce the calibrated counting geometry and ranged from 400 to 600 g of soil. Net soil weights were determined and the samples counted using a 23% Ge(Li) detector (Princeton Gamma Tech) coupled to a Nuclear Data model ND-680 pulse height analyzer system. Background and Compton stripping, peak search, peak identification, and concentration calculations were performed using the computer capabilities inherent in the analyzer system. Energy peaks used for determination of radionuclides of concern were:

Ra-226 - 0.609 MeV from Bi-214 (secular equilibrium assumed)
U-235 - 0.143 MeV
U-238 - 1.001 MeV from Pa-234 (secular equilibrium assumed)
Th-232 - 0.911 MeV from Ac-228 (secular equilibrium assumed)
Cs-137 - 0.662 MeV
Co-60 - 1.332 MeV

Other Analyses

Samples were analyzed for Sr-90 following standard procedures specified in "Radiochemical Analytical Procedures for Analysis of Environmental Samples," EMSL-LV-0539-17, March 1979. An outside laboratory performed the analysis for Pu-239 using wet chemistry and alpha spectroscopy procedures.

Water Sample Analysis

Water samples were rough-filtered through Whatman No. 2 filter paper. Remaining suspended solids were removed by subsequent filtration through 0.45 μm membrane filters. The filtrate was acidified by addition of 20 ml of concentrated nitric acid. Fifty milliliters of each sample was evaporated to dryness and counted for gross alpha and gross beta using a Tennelec Model LB 5100 low-background proportional counter.

Analysis for Ra-226 was performed using the standard technique EPA 600/4-75-008 (revised). Analysis for Sr-90 was performed according to methods described in "Radiochemical Analytical Procedures for Analysis of Environmental Samples," EMSL-LV-0539-17, March 1979.

APPENDIX B

SUMMARY OF RADIATION GUIDELINES APPLICABLE TO OFF-SITE PROPERTIES AT THE NIAGARA FALLS STORAGE SITE

SUMMARY OF RADIATION GUIDELINES
APPLICABLE TO OFF-SITE PROPERTIES AT THE NIAGARA FALLS STORAGE SITE

Mode of Exposure	Exposure conditions	Guideline value	Guideline source
1. External gamma radiation	Continuous exposure to individual in general population (whole body)	60 μR/hr	Nuclear Regulatory Commission (NRC) Standards for Protection Against Radiation (10 CFR 20.105)
	Indoor gamma radiation (above background)	20 μR/h	EPA Standards for Uranium Mill Tailings (40 CFR 192)
2. Surface alpha contamination[a]	Ra-226 contamination fixed on surfaces	100 dpm/100 cm^2	*NRC Guidelines for Facilities* and Equipment Prior to Release for Unrestricted Use or Termination of Licenses for By-product, Source, or Special Nuclear Material (Adapted from NRC Reg. Guide 1.86)
	Removable Ra-226	20 dpm/100 cm^2	
3. Surface beta contamination[a]	Removable beta-gamma	1000 dpm/100 cm^2	Same as number 2
4. Beta-gamma dose rate	Average dose rate on an area no greater than 1 m^2	0.2 mrad/h	Same as number 2
	Maximum dose rate in any 100 cm^2 area	1.0 mrad/h	Same as number 2
5. Exposure to radon	Maximum permissible concentration of Rn-220 in air in unrestricted areas	3.0 pCi/l	NRC 10 CFR 20.103, Appendix B, Table II
	Average annual radon daughter concentration (including background)	0.030 WL maximum 0.020 WL preferrable	EPA Standards for Mill Tailings

SUMMARY OF RADIATION GUIDELINES
APPLICABLE TO OFF-SITE PROPERTIES AT THE NIAGARA FALLS STORAGE SITE, cont.

Mode of Exposure	Exposure conditions	Guideline value	Guideline source
6. Radionuclides in water	Maximum contaminant level for combined Ra-226 and Ra-228 in drinking water	5 pCi/l	EPA Interim Drinking Water Standards (40 CFR 141)
	Maximum permissible concentration of the following radionuclides in water for unrestricted area:		NRC (10 CFR 20.103 Appendix B, Table II)
	Ra-226	30 pCi/l	
	U-238	40,000 pCi/l	
	Th-230	2,000 pCi/l	
	Pb-210	100 pCi/l	
7. Radionuclides in soil	Concentration above background-averaged over an area of 100 m^2		
	Ra-226	5 pCi/g (surface) 15 pCi/g (subsurface)	EPA Standards for Uranium Mill Tailings
	U-238 Th-232 Sr-90 Cs-137	40 pCi/g 20 pCi/g 100 pCi/g 80 pCi/g	Interim Soil Limits for D&D Projects, LA-UR-79-1865-Rev, J.W. Healy et al.
	U-enriched in U-235	30 pCi/g	NRC Branch Technical Position Paper (Federal Register, October 23, 1981)

[a] Applicable to building and equipment surfaces only.

APPENDIX C

REPORT OF GROUND-PENETRATING RADAR SURVEY OF PROPERTIES E′ AND H′ AT THE NIAGARA FALLS STORAGE SITE

DETECTION SCIENCES GROUP

496 HEALD ROAD CARLISLE, MASSACHUSETTS 01741 (617) 369-7999

FINAL REPORT

GROUND-PENETRATING RADAR SURVEY OF AREAS E' AND H' AT THE FORMER LAKE ONTARIO ORDNANCE WORKS LEWISTON, NEW YORK

Prepared for

OAK RIDGE ASSOCIATED UNIVERSITIES, INC
Oak Ridge, Tennessee 37830

Purchase Order No. C-25303
Letter Release No. 1
Dated May 28, 1982

Report No. J132A-81-F2

September 14, 1982

RADARVISION

TABLE OF CONTENTS

Illustrations

INTRODUCTION AND SUMMARY

This Final Report describes the ground-penetrating radar survey performed by Detection Sciences Group during the weeks of July 5 and 12, 1982, at the former Lake Ontario Ordnance Works, Lewiston, New York. The survey covered selected locations within specific areas of the property designated as Area E' and Area H'. The survey was performed in accordance with Oak Ridge Associated Universities, Inc. (ORAU) Purchase Order No. C-25303, Letter Release No. 1, dated May 28, 1982, under the direction of Mr. Bill Helton and Mr. Less Cole.

The ground-penetrating radar survey had two purposes. The first purpose was to search for evidence of buried materials. The second purpose was to inspect boring locations for potential obstacles.

The inspection of the boring locations was accomplished by running the radar in an "X" pattern, or cross-pattern, over the proposed location of each boring. The cross-pattern consisted of a north-south run and an east-west run, each crossing the site of the proposed boring. If the radar charts showed any indication of a buried utility or other potential obstruction (i.e., a discrete buried object), the charts were then searched for an alternate location which did not show any potential obstacle. Taking a conservative approach, the proposed boring was always relocated unless the radar chart was completely clear of discrete radar reflectors (other than geologic strata). The choice of alternate locations was selected as near as practical to the original location. Table I lists the grid coordinates of the biased borings and shows the coordinates of all borings that were relocated. Table II shows the same information for the unbiased borings.

The search for buried materials was conducted by running the radar in grid patterns, using the in-place grid established by ORAU personnel. Figure 1 shows the three radar search grids and all boring locations in Area E'. Figure 2 shows the radar grid and the boring locations in Area H'. Figure 3, Figure 4, and Figure 5 provide detailed maps of the three radar survey grids in Area E'. Figure 6 is a detailed map showing the radar survey lines in Area H'.

We did not observe any indications of buried material in the portions of Area E' that were searched by radar. The observed radar signatures are consistent with the industrial use of the land. We saw no evidence of excavations filled with foreign material, nor did we observe any obvious breaks in the ground strata other than the trenches that are normally observed above buried pipes. In Area H', there are a number of radar anomalies that are not consistent with the prevailing radar signatures observed in the general area. These anomalies are cited in Table III.

This Final Report provides a narrative description of all work performed in accordance with Letter Release No. 1. The narrative description covers the methodology of the radar survey, a description of the equipment and the principals of operation, and a discussion on the interpretation of the radar data. Copies of all field logs are included in the APPENDIX. In addition to the material contained in this report, all of the radar graphic charts (vertical profiles) have been bound in book form and supplied to ORAU.

DESCRIPTION OF THE SURVEY

Area Surveying

The ground-penetrating radar survey covered portions of Area E' and Area H' using a 5-meter grid pattern except where buildings or other structures made it necessary to deviate from the 5-meter spacing. Each radar survey line, or transect, is recorded in a Field Log. The survey lines are sequentially numbered in the exact order in which they were done. The survey line number is simply a "bookkeeping" number and bears no direct relation to the designation of the grid line itself. The radar charts are also numbered in the strict sequence in which the radar survey was performed, and therefore are keyed to the Field Logs. Thus, radar chart #11, for example, will be the 11th entry in the Field Log. Among other items entered into the Field Log are the grid line identification, and the starting and stopping points for the particular survey line. All of the Field Logs for Area E' and Area H' are bound in the **APPENDIX.**

In Area E', the ground-penetrating radar survey was conducted by hand-pulling the 120 MHz radar antenna on a grid with 5 meter spacings. **Figure** 1 shows the 5-meter radar grid (heavy, dark lines) superimposed on the 20-meter O.R.A.U. grid (lighter grid lines), together with the location of the borings and the major surface features.

In Area H', portions of the radar grid were surveyed by towing the 120 MHz radar antenna with the survey van, but most of the survey lines were run by hand-pulling the antenna. **Figure** 2 shows the radar grid lines with 10 meter spacing (heavy, dark lines) superimposed on the 20-meter O.R.A.U. grid, together with locations of borings and the major surface features.

Figure 3 shows in detail the radar survey lines in Area E' between 540E and 620E, running from 0N to 40N. All north-south lines are on 5-meter increments, but the locations of buildings made it necessary to use 4-meter and 2-meter spacings in the east-west direction.

Figure 4 shows the details of the radar survey lines in Area E' between 640E and 700E, running from 0N to 40N.

Figure 4 shows the details of the radar survey lines along the railroad spurs in Area E' between 680E and 790E, running from 37N to 44N. (The respective radar transect lines ran along the center of the south spur; along the center of the stip between the two spurs; along the center of the north spur; and, along the north side of the north spur).

Borehole Surveying

Each proposed borehole location was surveyed with a 6 meter cross-pattern running north-south and east-west. The centerpoint of the cross lines are at the borehole location. These locations are marked on **Figure** 1 and **Figure** 2 with a cross symbol. The grid locations of the biased borings are tabulated in **Table** I. The grid locations for the unbiased borings are tabulated in **Table** II.

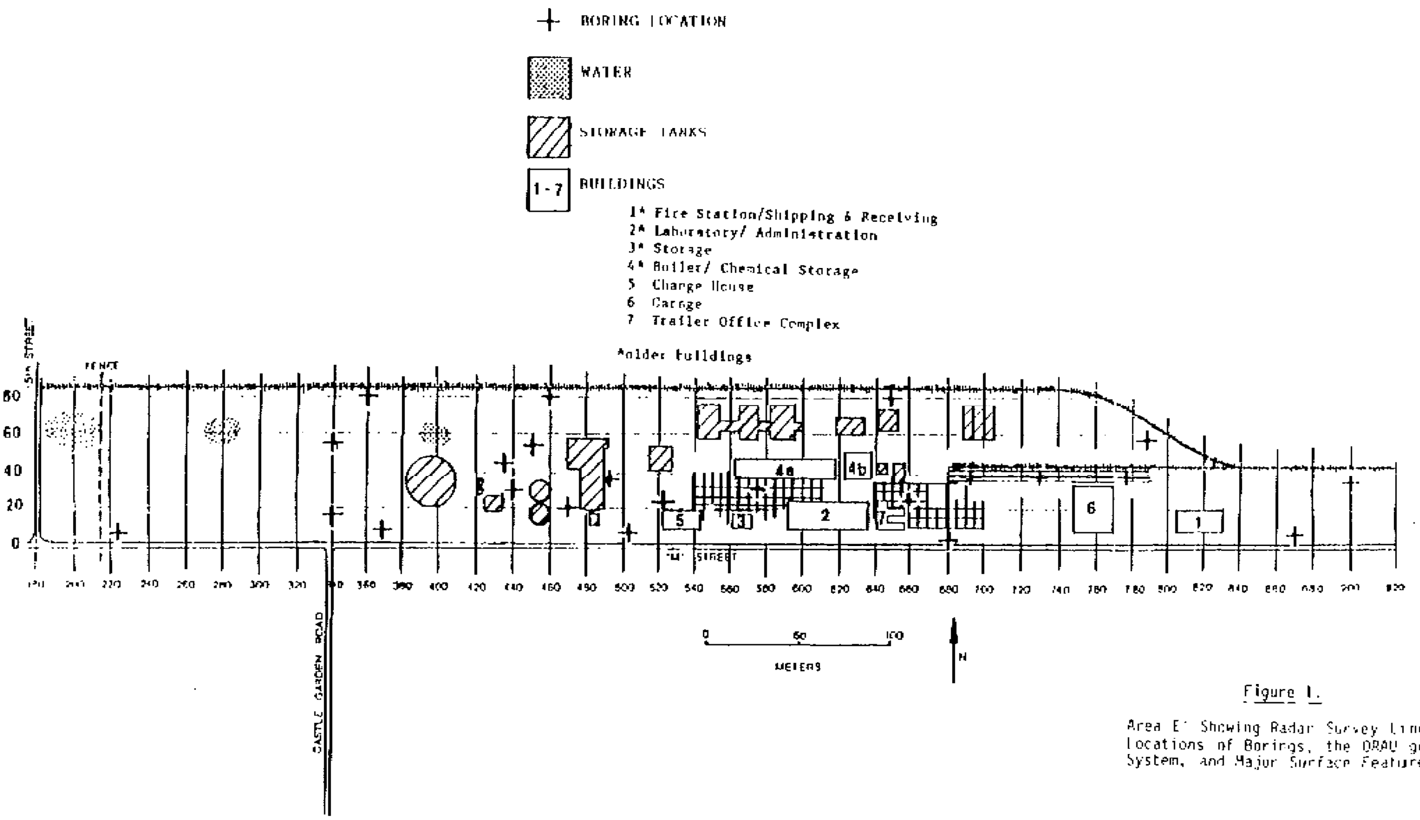


Figure 1.

Area E Showing Radar Survey Lines, Locations of Borings, the ORAU grid System, and Major Surface Features.

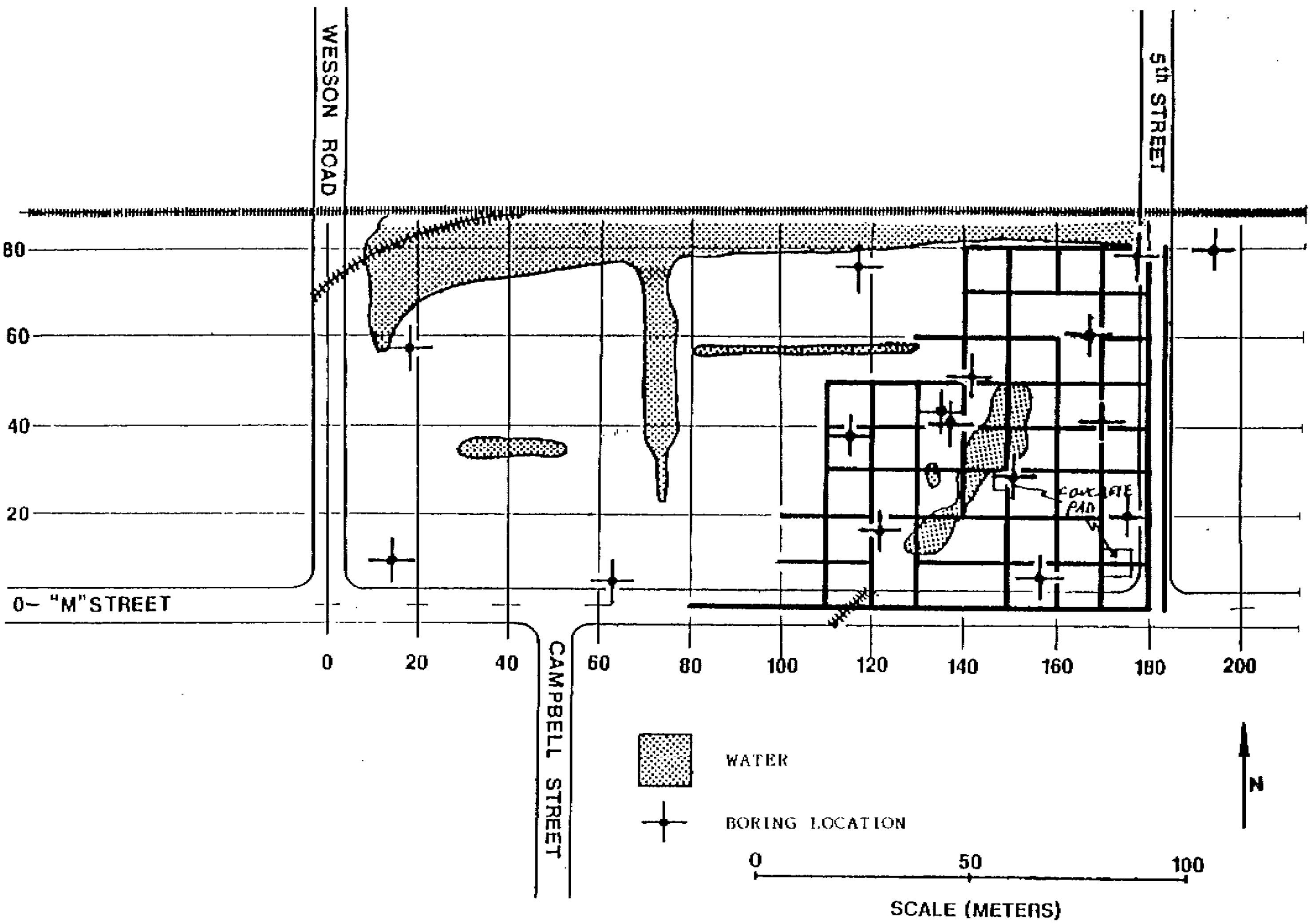
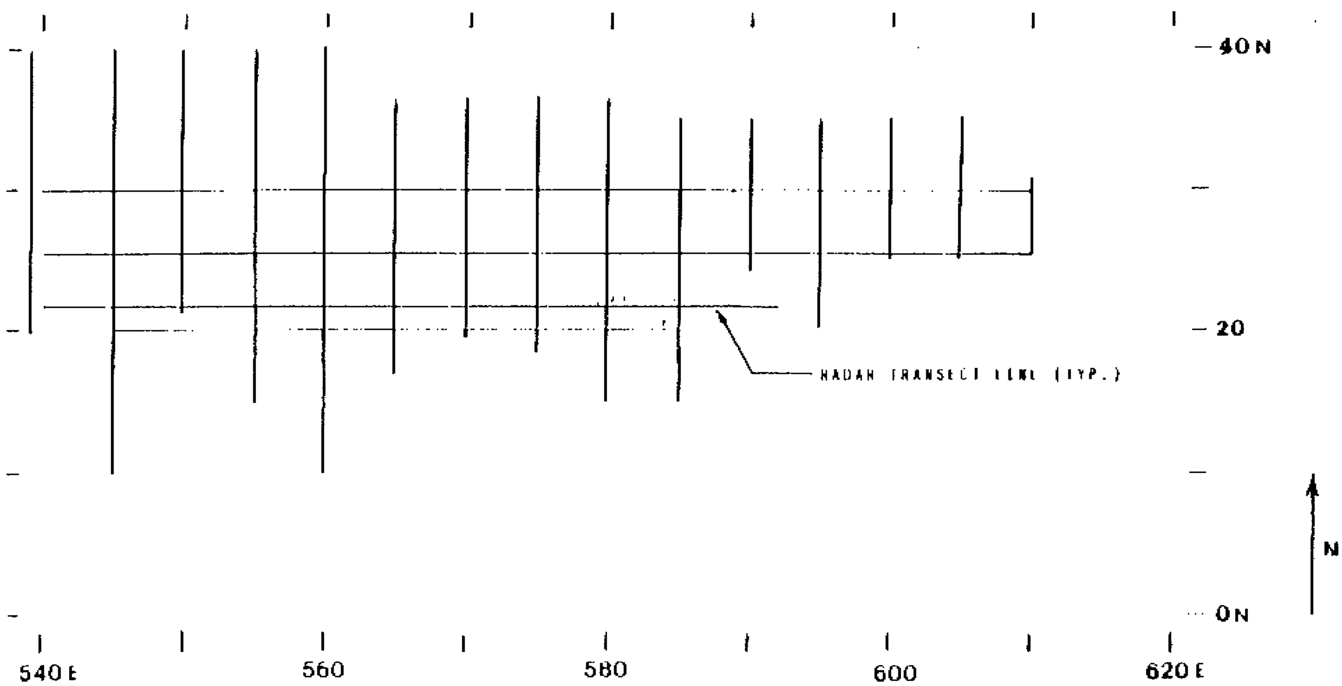


Figure 2. Area H' Showing Radar Survey Lines, Locations of Borings, the Grid System, and Major Surface Features.



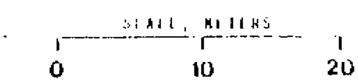


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Figure 3. Detail of Radar Transects in Area C', 540E to 620E, 0N to 40N

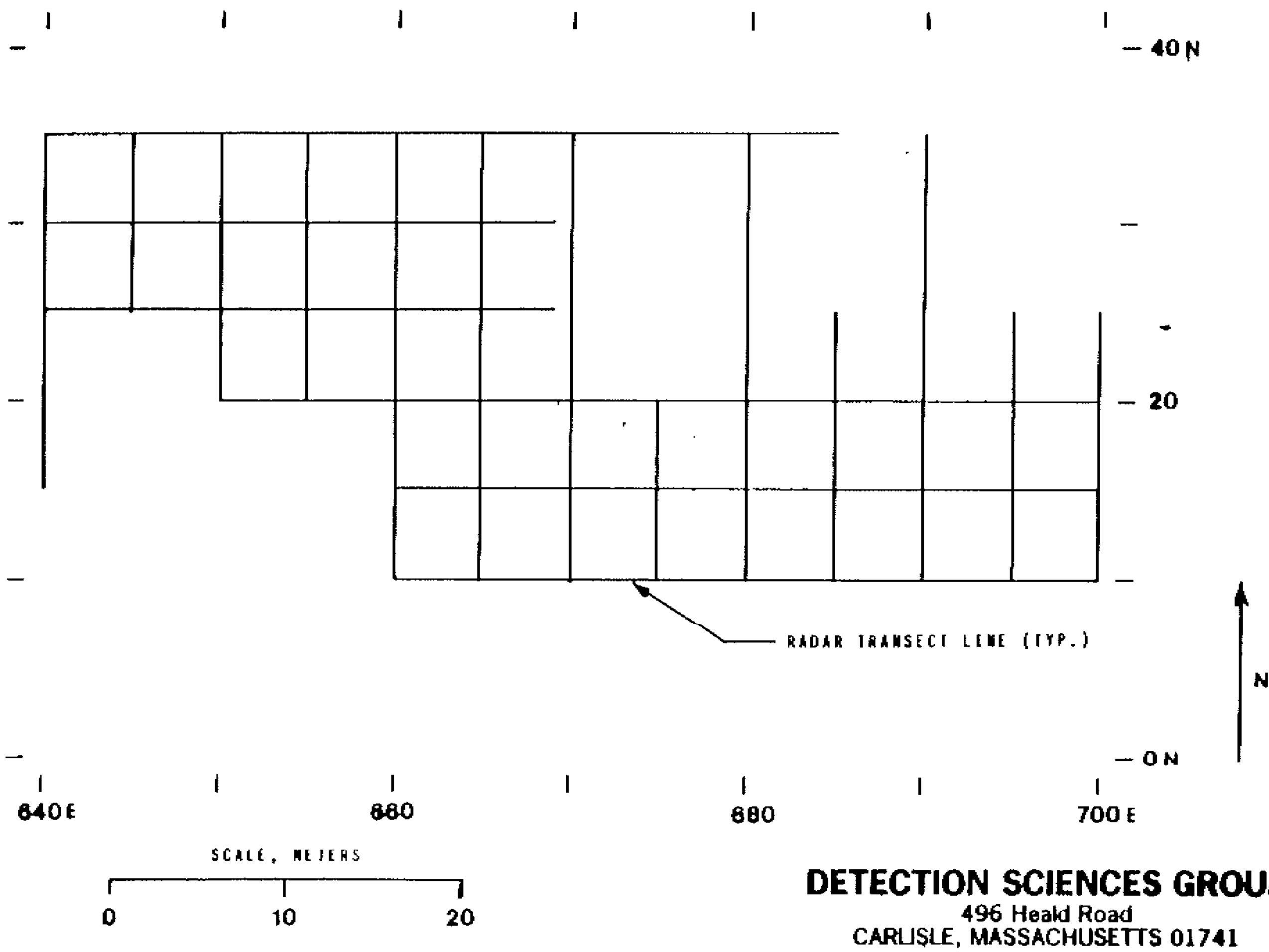

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Figure 4. Detail of Radar Transects in Area E', 640E to 700E; 0N to 40N

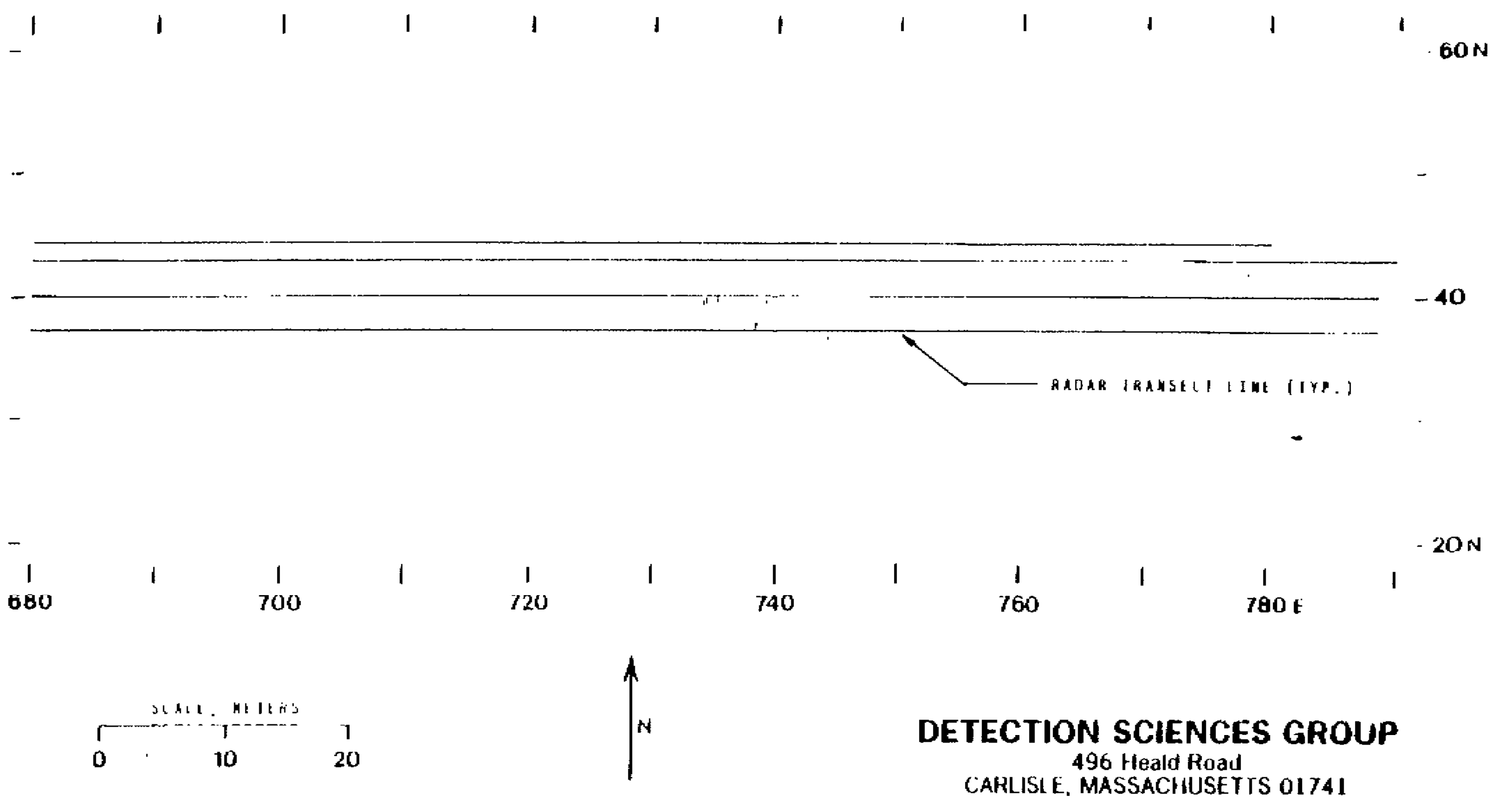

Figure 5. Detail of Radar Transects in Area F',
Railroad Spurs, 680E to 790E

TABLE I.

BORING LOCATIONS DETERMINED BY RADAR — BIASED BORINGS

Boring Number	Direction of Relocation	Proposed Location	Final Location
B1	—	60.5N, 167.5E	60.5N, 167.5E
B2	—	41N, 170E	41N, 170E
B3	—	20N, 176E	20N, 176E
B4	—	52N, 142E	52N, 142E
B5	—	40.5N, 137.5E	40.5N, 137.5E
B6	[Move 4m North Move 7m West]	16N, 122E	20N, 115E
B7	[Move 2m North Move 4m West]	38N, 116E	40N, 112E
B8	Move 3m East	42.5N, 137E	42.5N, 140E
B9	—	29N, 150E	29N, 150E
B9'	Not accessable	55N, 340E	55N, 340E
B10	Not accessable	15N, 340E	15N, 340E
B11	Move 3m South	45N, 435E	42N, 435E
B12	Move 2m North	55N, 450E	57N, 450E
B13	Move 2m South	30N, 440E	28N, 440E
B14	Move 1m South	20N, 470E	19N, 470E
B15	—	36N, 492E	36N, 492E
B16	Move 3m West	23N, 523E	23N, 520E
B17	Move 7m West	30N, 575E	30N, 568E
B18	[Move 5m South Move 5m East]	25N, 660E	20N, 655E
B19	Move 7m East	Between tracks, 693E	Between tracks, 700E
B20	Move 5m East	Between tracks, 730E	Between tracks, 735E
B21	Move 8.5m West	Between tracks, 775E	Between tracks, 766.5E

TABLE II.

BORING LOCATIONS DETERMINED BY RADAR

UNBIASED BORINGS

Boring Number	Direction of Relocation	Proposed Location	Final Location
1	—	80N, 195E	80N, 195E
2	Move 4m West	78N, 178E	78N, 174E
3	Move 3m North	76N, 118E	79N, 118E
4	Move 5m North	10N, 15E	15N, 15E
5	—	58N, 18E	58N, 18E
6	Move 3m West	5N, 63E	5N, 60E
7	Move 2m North	7N, 157E	9N, 157E
8	Move 2m West	37N, 900E	37N, 898E
9	Move 4m West	5N, 870E	5N, 866E
10	Move 3m West	3N, 680E	3N, 677E
11	Move 4m East	5N, 503E	5N, 507E
12	Move 4m North	7N, 368E	11N, 368E
13	Move 3m North	80N, 360E	83N, 360E
14	—	80N, 460E	80N, 460E
15	—	6N, 225E	6N, 225E
16	—	80N, 650E	80N, 650E
17	Move 4m South	61N, 788E	57N, 788E

PRINCIPALS OF OPERATION

The ground-penetrating radar sytem is an echo-location system which emits a brief impulse of radio energy lasting only a few billionths of a second. The time that it takes for the echoes to return to the radar antenna corresponds to the depth below the surface. By recording these depth-dependent echoes on a scanning time-based chart recorder, a vertical profile of the ground is generated which shows the longitudinal distribution of subsurface strata and other features over which the radar antenna has passed.

The radar impulse travels into the ground at an average speed of about 40 percent of the speed of light in air. The exact speed depends on the nature of the material through which the impulse is traveling. The slowest medium is water, where the speed is about 11 percent of the speed of light. The fastest material is dry sand, where the speed is about 50 percent of the speed of light. In air, such as an underground cavity, the radar impulse travels exactly at the speed of light, taking one nanosecond (one billionth of a second) to travel one foot.

The ground-penetrating radar equipment is designed to measure and display the time-based echoes down to a fraction of a nanosecond. To convert to depth, it is necessary to know the exact velocity of the radar impulse as it travels through the ground. By using published tables for various materials, it is normally possible to estimate the velocity to within 10 percent. The radar system can also be calibrated by external means, such as a boring or a test trench. Other methods involve triangulation and geometric relationships that are time-consuming to perform in the field but are inherently accurate.

At the interface of two materials, the radar impulse typically undergoes an abrupt change in velocity. It is this change in velocity which causes some of the radar energy to be reflected back to the surface of the ground, where it is detected by the antenna. The amount of energy that is reflected, or the reflection coefficient, depends on the contrast between the two materials; i.e., the difference between their respective radar velocities.

All materials with the exception of metals are relatively transparent to the passage of radar energy. Metals reflect all of the energy striking the surface, so that buried metal objects like pipes or metal containers make excellent targets. The fact that most materials are relatively transparent means that the radar impulse can continue to send back reflection after reflection as it propagates downward into the ground, thus revealing the various subsurface strata and profiles.

In effect, the radar functions as a "difference meter", by drawing a boundary at the interface of two different materials. The strength of the reflected signal is a measure of the difference between the two materials, but the radar system does not provide any kind of physical assay as to the nature of the two materials. Experience in interpreting radar charts is helpful, as the "texture" of the material can sometimes provide clues as to the nature of the material. Glacial till, moisture-laden organic material, clay and gravel are examples of materials that have radar signatures that are relatively easy to recognize. On the other hand, interspersed layers of organic silt, silty sand, etc., are impossible to identify without direct inspection by means of a test trench or core sample. What is important here is that test borings or other test methods can be used as an aid to the identification of subsurface materials, and the radar can show the distribution of the material over the length of the path traversed by the radar antenna. In this regard, it is useful to think of the radar system as a means of making closely spaced "electronic borings", corresponding to each sequence of echoes processed by the radar. Operating at a speed of 52 vertical soundings per second, the radar is capable of generating millions of these "electronic boreholes" in the course of a day.

The penetration depth of the radar system depends on the operating frequency and the electrical conductivity of the ground. For shallow penetration of a few feet, the optimum choice is an operating frequency of 600 MHz. This small, lightweight antenna can penetrate to a depth of about 5 feet under the most adverse ground conditions, and as much as 25 to 30 feet under good conditions. "Adverse" refers to highly conductive materials having a resistivity of less than 20 ohm-meters. Good radar conditions would be resistivities of several hundred ohm-meters or more.

Shifting to a lower operating frequency provides greater penetration, the improvement being the square root of the ratio of the respective wavelengths. An operating frequency of 120 MHz is a good general-purpose frequency for reaching depths that are beyond the capability of the 600 MHz antenna. There is a corresponding loss of detail, or spatial resolution, due to the longer wavelength. The optimum is to use as high an operating frequency as possible, consistent with the operating depth requirements, thus providing the best possible detail under the operating conditions. The useful range of ground-penetrating radar frequencies is limited to about 10 MHz at the lower end, and about 1000 MHz (1 GHz) at the upper end. The penetration of the 1 GHz antenna is limited to a few inches. The 10 MHz antenna can penetrate hundreds of feet into the ground, but the corresponding loss of detail limits its usefulness to large features, such as geologic strata.

The discussion regarding penetration depth assumes that all antennas have the same power. The penetration depth at any given frequency can be improved with increased power, but the improvement suffers from inverse-square losses as a function of depth, so that a quantum jump in power is necessary to gain any significant improvement. For this reason, Detection Sciences Group has focused its research efforts on improving the sensitivity of the radar receiver and reducing the internal noise of the receiver. These efforts have paid off by more than doubling the penetration depth of our equipment compared to standard, commercially-available systems. The present electronics are now operating close to the theoretical limits for the sensitivity of non-crogenically cooled electronics. This improved capability allows Detection Sciences Group to obtain data under conditions that were previously impossible for the operation of ground-penetrating radar.

SURVEY METHODOLOGY

The ground-penetrating radar equipment is carried in a survey van, which provides 12 volt dc power for the solid state inverter used to power the 120 volt ac recording equipment. Figure 6 shows the recording equipment mounted in the survey van.

The most efficient method of data gathering is to use the survey van to tow the radar antenna over the surface of the ground. The radar equipment is capable of high-speed recording, and will provide good spatial resolution at speeds up to about 10 kph. When the terrain does not permit the vehicle to be driven along the survey path, it is necessary to pull the radar antenna by hand. With the vehicle parked near the center of a survey line, there is sufficient electrical cable to allow a range of about 150 meters either side of the centerpoint; this approach makes it possible to hand-survey a line about 300 meters in length without having to relocate the vehicle. Figure 7 shows a 600 MHz radar antenna being hand-pulled along a survey line. The normal speed is a walking pace, or about 5 kph.

Detection Sciences Group has made a number of innovations to facilitate the survey process, improve the performance of the equipment, and allow more efficient data gathering. We have:

- weatherized the equipment to allow it to be used in dusty conditions, fog, heavy rain, or snow, and under temperature extremes.
- developed a radiation shield to eliminate reflections from above-ground objects (power lines, parked vehicles, metal drums, trees, buildings, etc.) without degrading the performance of the antennas.
- constructed a "fifth wheel" odometer which attaches to the bumper of the survey van and automatically marks the radar graphic record with incremental distance along the radar survey path.
- built an automatic stop-start relay system to allow the operator to control the radar equipment while stationed at the antenna.
- made proprietary electronic modifications which provide a factor of 2.4 greater penetration than the standard, commercial equipment under equivalent operating conditions.

The following section lists all of the radar equipment.

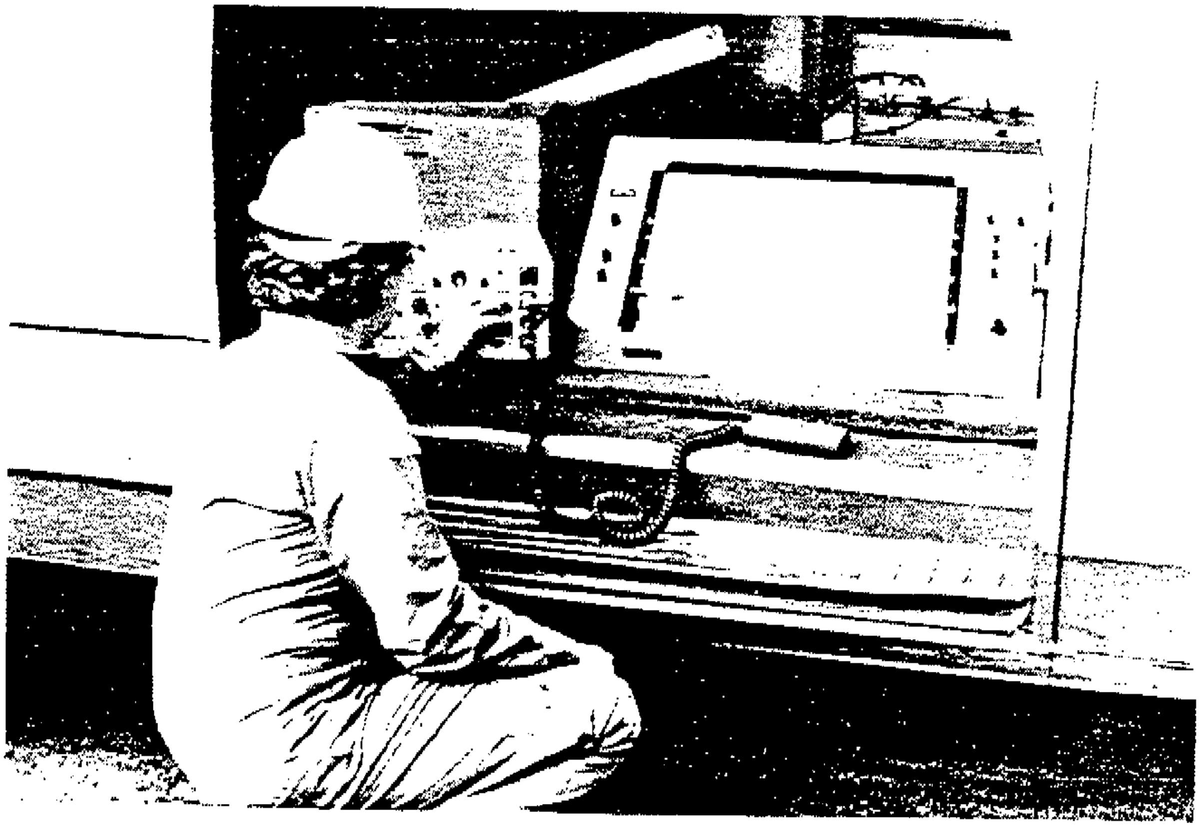

Figure 6.

CHART RECORDER AND RADAR CONTROLS

The radar equipment is carried in a van, where the operator is adjusting the controls. To the right of the operator is the chart recorder which generates vertical profiles of the ground. The power supply and the four-track tape recorder are not shown. Normally, the van is used to tow the radar antenna over the ground, but the antenna can also be pulled along by hand.

Figure 7.

600 MHz RADAR ANTENNA

The operator is guiding the 600 MHz radar antenna along the surface of the ground to generate vertical profile charts. The handle has an electrical button which electronically annotates the ground locations on the radar charts. Extending from the left of the antenna unit is an electrical cable (up to 500 feet in length) which connects with the rest of the radar system.

EQUIPMENT

Detection Sciences Group owns a modified SIR SYSTEM-8 radar system with an integral Motorola M6800 microprocessor unit. Our proprietary modifications to the radar system have provided increased range and sensitivity, as well as improving the overall efficiency of the data-gathering process. Detection Sciences Group has also developed special auxiliary equipment to facilitate our radar surveys. The individual components of the radar equipment are:

- **GSSI Model 4800 Control Unit.** The control unit contains the bulk of all the radar electronics and system controls, and has an oscilloscope display.
- **Motorola Model M68MM01A/1A2 Monoboard Microcomputer.** The microcomputer has real-time processing capability for background removal, digital filtering, running averages, and other radar signal-processing algorithms.
- **Hewlett-Packard Model 3964A Instrumentation Tape Recorder.** This high quality, four channel tape recorder provides master tapes of all data recorded in the field.
- **EPC Laboratories, Inc. Model 2800 Chart Recorder.** This scanning chart recorder generates the hard-copy radar graphic charts (vertical profiles) used to interpret the radar data.
- **GSSI Radar Antenna Units.** The radar antennas operate at different frequencies; the depth requirements of the survey determine the operating frequency selected for the survey:

  [ ] 900 MHz [ ] 600 MHz [ ] 300 MHz [x] 120 MHz [ ] 80 MHz [ ] 10 MHz

- **Sears 500VA Solid State Inverter.** This power supply unit provides both 120 volt ac power as well as 12 volt dc power for operating all field equipment from the survey vehicle's electrical system.
- **Remote Stop/Start Unit.** The remote stop/start feature allows the operator to control the radar system from the antenna location.
- **Odometer Wheel Assembly.** This "fifth wheel" attached to the survey vehicle provides automatic logging of incremental distance traveled along the survey path, and automatically logs the ground stations on the radar charts.
- **Support Equipment.** The various support equipment includes the Microcomputer Control Box, the Remote Control/Marker Unit, Hand-held Marker Unit, towing sleds, towing harnesses and miscellaneous electrical cables and connectors.

RESULTS OF THE SURVEY

The survey began in Area E', at location 540E. The specific locations surveyed in Area E' are shown by **Figure** 3, **Figure 4** and **Figure** 5. The location of the initial survey lines were laid out by **Detection Sciences Group** so as to avoid buildings and other obstacles. Thereafter, all survey lines were along grid lines laid out by ORAU personnel at intervals of 10 meters. In some instances, the radar survey line ran with an offset to the grid line. The exact location of all radar survey lines was recorded in the **Field Logs** (refer to the **APPENDIX**).

Area E' at 540E, 25N.

The results of the survey in Area E' showed chemically-contaminated soil in various locations, as evidenced by zones of high electrical conductivity (low resistivity). At location 570E, 25N, the contamination can be attributed to current operations by the present occupant of the site, SCA Chemical Services Company. Crystallized salts that have accumulated on electric pump motors and their flotation platforms are being removed by hand-scraping these encrusted units in a location adjacent to a maintenance shop. The residue from this maintenance operation is allowed to fall on the ground, where rain water will carry water-soluable material into the ground. Water-soluable salts are ionic, which modifies the electrical properties of the ground. This, in turn, appears in the radar data as an area having a lighter-than-normal contrast, indicating higher rate of signal attenuation due to higher electrical conductivity. Detection Sciences Group makes no representations about the enviornmental effect that this maintenance operation may have on the site; this information is provided only for the purpose of reporting to ORAU the observations made during the radar survey.

Railroad Spurs.

A similar situation was observed along the railroad spurs at the northeast sector of Area E'. Radar survey lines adjacent to each of the two sets of tracks shows evidence of chemical contamination. Radar survey lines down the center of each track show little evidence of contamination. The absence of contamination in the center of the tracks, combined with contamination along the edges of the tracks, suggests that the contamination is due to spillage while freight cars were being loaded or unloaded. Detection Sciences Group makes no representation as to the nature of these spills, or to the effect, if any, that such spills may have on the enviornment. This observation is presented to ORAU for information purposes only.

Buried Utility Lines.

Buried utilitiy lines were in evidence in various areas covered by the survey. If there were any need to do so, a map could be prepared to show the location of the utilities observed by the radar. The job description (Purchase Order No. C-25303, Letter Release No. 1) does not call for a utility map. Therefore, a utility map has not been prepared.

The observation of radar targets indicating the presence of buried pipes or utility lines was considered in the placement of biased and unbiased borings, as described in the next paragraph.

Boring Locations.

The proposed location for each boring to be done in Areas E' and H' were examined by running radar survey lines over each proposed location. The exceptions are biased boring locations B9' and B10, which were not accessable. The radar graphic charts were analyzed in the field, in real time, to make a determination as to whether the proposed boring locations might harbor buried obstacles, such as pipes, utility lines or buried boulders. Where there was reason to suspect that there may be a buried obstacle, the proposed location was moved to a clear location which was kept as close as possible to the proposed location. Table I shows the proposed location and final location of all biased borings in Areas E' and H'. Biased borings are designated by the letter "B" preceeding the boring number.

Table II tabulates the proposed location and final location of all unbiased borings. Unbiased borings are listed numerically, without the letter "B" which designates the biased borings. The information tabulated in both Table I and Table II was provided in hand-written form to ORAU personnel in the field at the time of the survey. Inclusion of these tables in this report provides confirmation of the hand-written information generated in the field by Detection Sciences Group.

Area H'.

In general, the radar charts of Area H' are consistent with the industrial history of the site. We observe characteristic radar signatures of buried concrete slabs containing rebars, and linear features presumed to be the remains of building foundations or other structures. In other cases, there are unexplained radar signatures which depart significantly from the prevailing ground signatures found at this site. These abnormal radar signatures, or anomalies, are plotted in Figure 8. The use of the term "anomalies" indicates that the radar signature shows a significant, localized departure from the prevailing, or normal, radar signatures observed at the site.

In the case of the metallic reflectors (narrow, dashed-line symbol), the radar signatur exhibits a characteristic "ringing", or resonance, which is unique to buried metal objects, including electrical cables.

The dark reflector (medium dashed-line symbol) is an area where the dielectric constant is significantly higher than the prevailing dielectric constant found at the site. A wet, saturated area can have a radar signature that is darker than the norm, but the characteristic structure within the wet saturated area is usually no different than the characteristic structre found throughout the site. For example, in glacial till, the radar signals are very "busy" and have a great deal of fine detail (large rocks, etc.) and is generally lacking in distinct strata. Wet, saturated areas in glacial till have the same "busy" character, but are simply darker due to the higher dielectric constants. In Area H' we have ruled out what appears to be the wet areas, and are left with the dark anomalies.

The jittery reflectors suggest electrically active zones that are interacting with the radar signal. It is suggested that ground samples be taken at these locations to seek an answer as to the source of these unusual radar signals.

The information plotted in Figure 8 is also presented in tabular form in Table III.

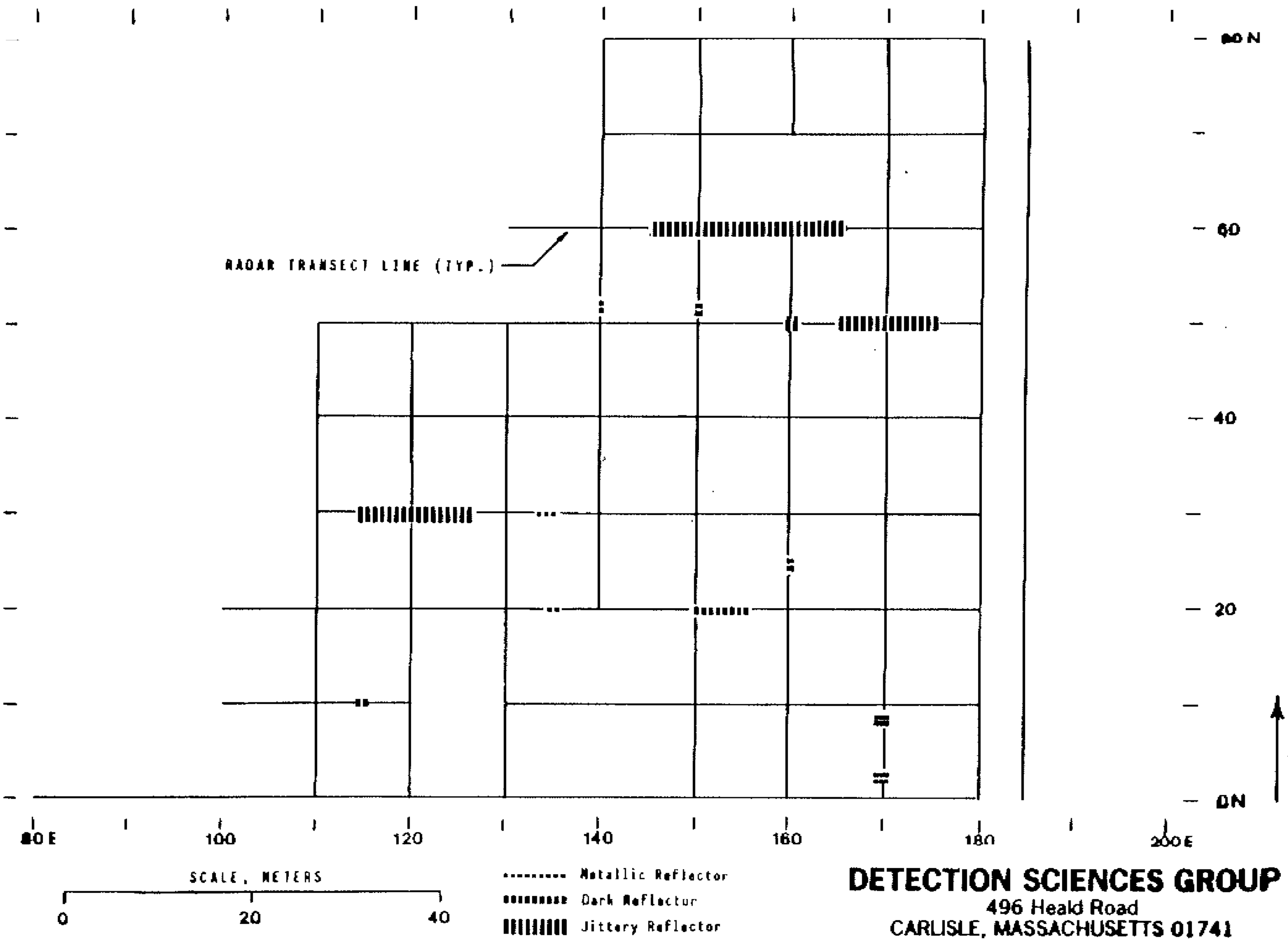

Figure 8. Radar Anomalies in Area II'

TABLE III

RADAR ANOMALIES IN AREA H'

Chart Number	Radar Line	Location (Meters)	Depth (Cm.)	Comments
80	60N	145E to 160E	168	Dark, jittery reflector
81	50N	164E to 175E	-	Jittery reflections
83	30N	115E to 127E	-	Jittery reflector
85	10N	115E	117	Dark, isolated reflector
90	170E	8N and 3N	100	Dark, jittery reflectors
91	160E	50N	116	Jittery, disturbed spot
92	150E	52N	98	Very dark location
99	20N	150E to 155E	100	Darkened area
101	160E	25N	98	Dark, isolated reflector
118	B.H.#17	3N of B.H.#17	61	Dark, isolated reflector

APPENDIX

DETECTION SCIENCES GROUP 496 HEALD ROAD CARLISLE, MASSACHUSETTS 01741
(617) 369-7999

RADARVISION

TAPE NO.: 8242 LOCATION: SCA CHEMICAL SERVICES COMPANY LEWISTON NY CLIENT: O.R.A.U.

DATE: 7/7/82

RANGE ADJ	RANGE MULTIPLY X1	RANGE MULTIPLY X2	RANGE MULTIPLY X4	RANGE GAIN	FILTER H	FILTER M	FILTER L	SENSITIVITY	SCAN SETTING 51.2	25.6	12.8	6.4	3.2	SLOW	TAPE SPEED 15	3 3/4	15/16	TAPE CHANNEL 1	2	4	COMMENTS
350	▨			9+1.5 • 0		▨		250			▨					▨			▨		J132-82

GRID NO.	GRID LINE	MARKER CODE	TAPE COUNT START	TAPE COUNT FINISH	FIRST MARK	LAST MARK	COMMENTS
1	26N	—	000	149	540E	610E	2@ 20M 1 @ 2M W→E
2	30N	2#0	149	281	540E	610E	" "
3	22N	3#0	281	372	"	592E	" "
4	539E	4#0	372	407	40 N	20N	1@ 2M 2@ 40N N→S
5	545E	5#0	407	447	40N	~20N	2@ 40 N 1 @ 5M "
6	550E	6#0	447	482	40N	25N	MARK EVERY 5 M LINE ENDED ~ 22M "
7	555E	7#0	482	526	40N	20N	MISSING MARKS "
8	560E	8#0	526	566	40N	20N	2 @ 40N 1 @ 5M "

FIELD LOGS

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RADARVISION

TAPE NO.: 8242 LOCATION: SCA CHEMICAL SVS. CO. CLIENT: O.R.A.U.
DATE: 7/8/82 LEWISTON NY

RANGE ADJ	RANGE MULTIPLY X1	X2	X4	RANGE GAIN	FILTER H	M	L	SENSITIVITY	SCAN SETTING 51.2	25.6	12.8	6.4	3.2	SLOW	TAPE SPEED 15	3¾	15/16	TAPE CHANNEL 1	2	4	COMMENTS
350	▨			9+ 1.5 / • 0		▨		250			▨					▨			▨		J132-82

GRID NO.	GRID LINE	MARKER CODE	TAPE COUNT START	TAPE COUNT FINISH	FIRST MARK N 33N	LAST MARK	COMMENTS	
9	565E	2#0	566	592	FIRE HYDRANT	17N	1@5M	N→S
10	570E	3#0	592	615	33N	19N	1@5M	"
11	575E	4#0	615	642	"	18N	"	"
12	580E	5#0	642	674	34N	15N	"	"
13	585E	6#0	674	702	35N	"	25N/13 60CM N + 40CM W	"
14	590E	7#0	702	726	35N	24N	" " " 80 CM N	"
15	595E	8#0	726	751	"	20N	1@5M	"
16	600E	2#0	751	769	"	25N	"	"
17	605E	3#0	769	787	"	"	"	"
18	610E	4#0	787	803	31N	"	"	"
19	20N	5#0	803	850	545E	585E	"	"
20	640E	6#0	850	880	35N	15N	"	"
21	645E	7#0	880	901	35N	25N	STOP 22N	
22	651N	8#0	901	926	35N	20N	STOP 19N	

FIELD LOGS

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(617) 369-7999

RADARVISION

TAPE NO.: 8242 LOCATION: ScA CHEMICAL SERVICE Co., LEWISTON, NY CLIENT: O.R.A.U.

DATE: 7/8/82

RANGE ADJ	RANGE MULTIPLY			RANGE GAIN	FILTER			SENSITIVITY	SCAN SETTING						TAPE SPEED			TAPE CHANNEL			COMMENTS
	X1	X2	X4		H	M	L		51.2	25.6	12.8	6.4	3.2	SLOW	15	3¾	15/16	1	2	4	
350	▨			4 1.5 0		▨		250			▨					▨			▨		J132-82

GRID NO.	GRID LINE	MARKER CODE	TAPE COUNT START	TAPE COUNT FINISH	FIRST MARK	LAST MARK	COMMENTS	
23	655E	3#0	926	953	35N	20N	1@ 5H	N→S
24	660E	2#0	953	980	35N	10N	"	"
25	665E	3#0	980	1007	"	"	"	"
26	35N	4#0	1007	1052	640E	685E	"	W→E
27	30N	5#0	1052	1078	640E	669E	"	"
28	25N	6#0	1078	1108	640E	"	"	"
29	20N	7#0	1108	1132	650E	670E	"	"
30	"	8#0	1132	1165	670E	700E	"	"
31	15N	4#0	1165	1206	660E	"	"	"
32	RRN	2#0	1206	1284	680E	740 ±E	"	"
33	RR S	3#0	1284	1355	680E	740E	"	"
34	BETWEEN RR	4#0	1355	1414	683E	738E	"	"
35	RR 44N	5#0	1414	1478	680	740E	"	"
36	RRS	6#0	1478	1531	740E	788E	"	"

FIELD LOGS

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RADARVISION

TAPE NO.: 8242 LOCATION: SCA CHEMICAL SVS. CO. LEWISTON, NY CLIENT: O.R.A.U.

DATE: 7/8/82

RANGE ADJ	RANGE MULTIPLY X1	X2	X4	RANGE GAIN	FILTER H	M	L	SENSITIVITY	SCAN SETTING 51.2	25.6	12.8	6.4	3.2	SLOW	TAPE SPEED 15	3 3/4	15/16	TAPE CHANNEL 1	2	4	COMMENTS
350	▨			14 1.5 / 6 0		▨		250			▨					▨			▨	▨	J132-82

GRID NO.	GRID LINE	MARKER CODE	TAPE COUNT START	TAPE COUNT FINISH	FIRST MARK	LAST MARK	COMMENTS
37	BETWEEN RR	7#0	1531	1582	741E	788E	1@5M W→E
38	RR N	8#0	1582	1643	740E	790E	" "
							CHANNEL 4
39	RR 44N	—	000	174	746E		1@5M W→E
40	10N	2#0	174	257	660E	700E	" "

FIELD LOGS

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(617) 369-7999

RADARVISION

TAPE NO.: 8242 LOCATION: SCA CHEMICAL SVS. CO. LEWISTON, NY CLIENT: ORAU.

DATE: 7/9/82

RANGE ADJ	RANGE MULTIPLY X1	X2	X4	RANGE GAIN	FILTER H	M	L	SENSITIVITY	SCAN SETTING 51.2	25.6	12.8	6.4	3.2	SLOW	TAPE SPEED 15	3¾	15/16	TAPE CHANNEL 1	2	4	COMMENTS
350		(shaded)		9+ 1.5 • 0		(shaded)		250			(shaded)					(shaded)				(shaded)	J132-82

GRID NO.	GRID LINE	MARKER CODE	TAPE COUNT START	TAPE COUNT FINISH	FIRST MARK	LAST MARK	COMMENTS
41	670E	3#0	257	310	35N	10N	N→S 1@5 24' DEEP
42	675E	4#0	310	335	20N	11N	" " "
43	680E	5#0	335	378	35N	"	" " "
44	685E	6#0	378	407	25N	"	" " "
45	690E	6#0	407	449	35N	10N	" " "
46	695E	7#0	449	477	25N	"	" " "
47	700E	8#0	477	512	25N	10N	" " "
48	B1	2#0	512	563	-6W	+6E	1@2M 2@ B1 350 X 1 W→E
49	"	3#0	563	591	+2N	-6S	" " N→S
50	B2	4#0	591	628	-6W	+6E	" 2@ B2 W→E
51	"	5#0	628	669	+6N	-6S	" " N→S
52	B3	6#0	669	695	-4W	+6E	" 1@ B3 N→E
53	"	7#0	695	726	+4N	-6S	" 2@ B3 N→S
54	B4	8#0	726	760	-6W	+6E	" 2@ B4 W→E

FIELD LOGS

DETECTION SCIENCES GROUP
496 HEALD ROAD CARLISLE, MASSACHUSETTS 01741
(617) 369-7999

RADARVISION

TAPE NO.: 8242 LOCATION: SCA CHEMICAL SVC. CO. LEWISTON, NY CLIENT: O.R.A.U.

DATE: 7/9/82

RANGE ADJ	RANGE MULTIPLY X1	RANGE MULTIPLY X2	RANGE MULTIPLY X4	RANGE GAIN	FILTER H	FILTER M	FILTER L	SENSITIVITY	SCAN SETTING 51.2	25.6	12.8	6.4	3.2	SLOW	TAPE SPEED 15	3¾	15/16	TAPE CHANNEL 1	2	4	COMMENTS
350	▨			9+ 1.5 / • 0		▨		250			▨					▨				▨	J132-82

GRID NO.	GRID LINE	MARKER CODE	TAPE COUNT START	TAPE COUNT FINISH	FIRST MARK	LAST MARK	COMMENTS
55	B4	3#0	760	795	+6 N	-6 S	1@ 2H 2 @ BORING N → S
56	B5	2#0	795		-4W	+6E	1@ 2H 2 @ " W → E
57	"	3#0		851	+6N	-6S	" " N → S
58	B6	4#0	851		-6W	+6E	" " W → E
59	"	5#0		912	+6N	-6S	" " N → S
60	B7	6#0	912		-6W	+6E	" " W → E
61	"	7#0		973	+6N	-6S	" " N → S

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RADARVISION

TAPE NO.: 8242 LOCATION: SCA CHEMICAL SVS. CO. CLIENT: ORAU.
DATE: 7/10/82 LEWISTON, NY

RANGE ADJ	RANGE MULTIPLY X1	RANGE MULTIPLY X2	RANGE MULTIPLY X4	RANGE GAIN	FILTER H	FILTER M	FILTER L	SENSITIVITY	SCAN SETTING 51.2	25.6	12.8	6.4	3.2	SLOW	TAPE SPEED 15	3 3/4	15/16	TAPE CHANNEL 1	2	4	COMMENTS
350	▨			9+ 1.5		▨		250			▨					▨				▨	J132-82

GRID NO.	GRID LINE	MARKER CODE	TAPE COUNT START	TAPE COUNT FINISH	FIRST MARK	LAST MARK	COMMENTS
62	B8	8#0	973		-4W	+4E	1@2m 2@ BORING W→E
63	"	4#0		1028	+6N	-2S	" " N→S
64	B9	2#0	1028		-6W	+6E	" " W→E
65	"	3#0		1087	+6N	-6S	" " N→S

FIELD LOGS

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RADARVISION

TAPE NO.: 8242 LOCATION: SCA CHEMICAL SVS. CO. CLIENT: O.R.A.U.
DATE: 7/12/82 LEWISTON, NY

RANGE ADJ	RANGE MULTIPLY X1	RANGE MULTIPLY X2	RANGE MULTIPLY X4	RANGE GAIN	FILTER H	FILTER M	FILTER L	SENSITIVITY	SCAN SETTING 51.2	25.6	12.8	6.4	3.2	SLOW	TAPE SPEED 15	3 3/4	15/16	TAPE CHANNEL 1	2	4	COMMENTS
350	▨			97 1.5 / • 0		▨		250			▨					▨				▨	J132-82

GRID NO.	GRID LINE	MARKER CODE	TAPE COUNT START	TAPE COUNT FINISH	FIRST MARK	LAST MARK	COMMENTS
66	B10	4#0	1087		-6 W	+6 E	1@ 2M 2@ BORING W→E
67	"	5#0		1128	3 N	-6 S	" " N→S
68	B11	6#0	1128		-6W	+6E	? 12.5 • 0 " W→E
69	"	7#0		1184	+6 N	-6 S	" " N→S
70	B12	8#0	1184		-2 W	+5E	" " W→E
71	"	5#0		1223	+6 N	-6 S	" " N→S
72	B13	2#0	1223		-6 W	+6 E	" " W→E
73	"	3#0		1263	+6 N	-6 S	" " N→S
74	B14	4#0	1263		-6W	+6E	" " W→E
75	"	5#0		1305	+6N	-6S	" " N→S
76	B15	6#0	1305		-6W	+6W	" " W→E
77	"	7#0		1347	+6N	-6S	" " N→S
78	80 N	8#0	1347	1368	180 E	140E	VEHICLE SURVEY 1@ 10 N 1st/S E→W (25.6)
79	90N	5#0	1368	1389	"	"	" "

FIELD LOGS

DETECTION SCIENCES GROUP 496 HEALD ROAD CARLISLE, MASSACHUSETTS 01741
(617) 369 7999

RADARVISION

TAPE NO.: 8242 LOCATION: SCA CHEMICAL SVS. CO. LEWYSTON, NY CLIENT: O.R.A.U.
DATE: 7/12/82

RANGE ADJ	RANGE MULTIPLY			RANGE GAIN	FILTER			SENSITIVITY	SCAN SETTING						TAPE SPEED			TAPE CHANNEL			COMMENTS
	X1	X2	X4		H	M	L		51.2	25.6	12.8	6.4	3.2	SLOW	15	3 3/4	15/16	1	2	4	
350	///			8.5 12.5 • 0		///		250		///						///				///	J132-82

GRID NO.	GRID LINE	MARKER CODE	TAPE COUNT START	TAPE COUNT FINISH	FIRST MARK	LAST MARK	COMMENTS VEHICLE SURVEY
80	60N	2#0	1389	1414	180 E	130 E	1@ 10M 1.5MS E→W
81	50N	3#0	1414	1449	180 E	110 E	ANTENNA ~~SNAG~~ RESTART " "
82	40N	4#0	1449	1471	160 E	110 E	7@ 10M 1.5MS E→W
83	30N	5#0	1471	1491	150 E	110 E	" " "
84	20N	6#0	1491	1508	130 E	100 E	" " "
85	10N	7#0	1508	1527	120 E	100 E	" 1.5 MN "
86	0N	8#0	1527	1557	180 E	80 E	" ON LINE "

FIELD LOGS

DETECTION SCIENCES GROUP — 496 HEALD ROAD CARLISLE, MASSACHUSETTS 01741 — (617) 369-7999

RADARVISION

TAPE NO.: 8242 & 8243 LOCATION: SCA CHEMICAL SVS. CO. LEWISTON, NY CLIENT: O.R.A.U.

DATE: 7/13/82

RANGE ADJ	RANGE MULTIPLY X1	X2	X4	RANGE GAIN	FILTER H	M	L	SENSITIVITY	SCAN SETTING 51.2	25.6	12.8	6.4	3.2	SLOW	TAPE SPEED 15	3 3/4	15/16	TAPE CHANNEL 1	2	4	COMMENTS
350	(shaded)			8.5 • 12.5 O		(shaded)		250			(shaded)					(shaded)		(shaded)		(shaded)	J132-82

GRID NO.	GRID LINE	MARKER CODE	TAPE COUNT START	TAPE COUNT FINISH	FIRST MARK	LAST MARK	COMMENTS (HAND PULL)
87	184E	2 #0	1557	1640	80 N	0 N	1 @ 10M N→S
88	180 E	3 #0	1640	—	"	"	TAPE RAN OUT
=							NEW TAPE CHANNEL 1
89	180E	—	000	170	80 N	0 N	1 @ 10M N→S 1M E OF LINE
90	170E	2 #0	170	311	"	"	" "
91	160E	3 #0	311	374	80N / 60N	70N / 30N	" "
92	150E	4 #0	374	465	80 N	28 N	" "
93	140E	5 #0	465	560	80 N	20 N	" "
94	130E	6 #0	560	636	50 N	0 N	" "
95	120E	7 #0	636	705	50N	0 N	" "
96	110E	8 #0	705	765	"	"	" "
97	40N	2 #0	765	804	180E	160E	" E→W 1M S OF LINE
98	30N	3 #0	804	863	180 E	150E	" "
99	20N	4 #0	863	936	180 E	130E	" "

FIELD LOGS

DETECTION SCIENCES GROUP 496 HEALD ROAD CARLISLE, MASSACHUSETTS 01741
(617) 369-7999

RADARVISION

TAPE NO.: 8243 LOCATION: SCB CHEMICAL SVS. CO. LEWISTON, NY CLIENT: D.R.A.U.

DATE: 7/13/82

RANGE ADJ	RANGE MULTIPLY			RANGE GAIN	FILTER			SENSI-TIVITY	SCAN SETTING						TAPE SPEED			TAPE CHANNEL			COMMENTS
	X1	X2	X4		H	M	L		51.2	25.6	12.8	6.4	3.2	SLOW	15	3 3/4	15/16	1	2	4	
350	▨			8.5 • 12.6 0		▨		250			▨					▨		▨			J132-82

GRID		MARKER CODE	TAPE COUNT		FIRST MARK	LAST MARK	COMMENTS
NO.	LINE		START	FINISH			
100	10N	5#0	936	1017	180E	130E	1 @ 10N E→W 1M N of LINE
101	160E	6#0	1017	1080	30N	0N	" N→S 1M E of LINE
102	150E	7#0	1080	1127	"	"	" " "

FIELD LOGS

DETECTION SCIENCES GROUP 496 HEALD ROAD CARLISLE, MASSACHUSETTS 01741
(617) 369-7999

RADARVISION

TAPE NO.: 8243 LOCATION: SCA CHEMICAL SVS. CO. CLIENT: O.R.A.U.
DATE: 7/14/82 LEWISTON, NY

RANGE ADJ	RANGE MULTIPLY X1	X2	X4	RANGE GAIN	FILTER H	M	L	SENSITIVITY	SCAN SETTING 51.2	25.6	12.8	6.4	3.2	SLOW	TAPE SPEED 15	3 3/4	15/16	TAPE CHANNEL 1	2	4	COMMENTS
350	X			8.5 12.5 • O		X		250			X					X		X			J132-82

GRID NO.	GRID LINE	MARKER CODE	TAPE COUNT START	TAPE COUNT FINISH	FIRST MARK	LAST MARK	COMMENTS
103	H11	8 #0	1127		-6W	+6E	1 @ 2 M 2 @ BORING [10] • [12.5] O W→E
104	"	3 #0		1180	+6N	-6S	" " N→S
105	H12	2 #0	1180		-6W	+6E	" " W→E
106	"	3 #0		1224	+6N	-6S	" " N→S
107	H13	4 #0	1224		-6W	+6E	" " W→E
108	"	5 #0		1266	+6N	-6S	" " N→S
109	H14	6 #0	1266		-6W	+4E	" " W→E
110	"	7 #0		1304	+6N	-6S	" " N→S
111	H15	8 #0	1304		-1W	+6E	" " W→E
112	"	4 #0		1343	+6N	-6S	" " N→S
113	H16	2 #0	1343		-6W	4E	" " W→E
114	"	3 #0		1378	+6N	-4S	" " N→S
115	B16	4 #0	1378		4W	+6E	" " W→E
116	"	5 #0		1416	+6N	-6S	" " N→S

FIELD LOGS

DETECTION SCIENCES GROUP 496 HEALD ROAD CARLISLE, MASSACHUSETTS 01741
(617) 369-7999

RADARVISION

TAPE NO.: 8243 LOCATION: SCA CHEMICAL SYS. CO. CLIENT: O.R.A.U.
DATE: 7/14/82 LEWISTON, NY

RANGE ADJ	RANGE MULTIPLY X1	X2	X4	RANGE GAIN	FILTER H	M	L	SENSITIVITY	SCAN SETTING 51.2	25.6	12.8	6.4	3.2	SLOW	TAPE SPEED 15	3¾	15/16	TAPE CHANNEL 1	2	4	COMMENTS
350	▨			8.5 12.5 • 0		▨		250			▨					▨		▨			J132-82

GRID NO.	GRID LINE	MARKER CODE	TAPE COUNT START	TAPE COUNT FINISH	FIRST MARK	LAST MARK	COMMENTS
117	B17	6#0	1416	1437	+6W	+6E	1@2M 2@ BORING W→E
118	"	7#0	1437	1458	+6N	-6S	" " N→S

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FIELD LOGS

APPENDIX D

EVALUATION OF RADIATION EXPOSURES ON OFF-SITE PROPERTY H' AT THE NIAGARA FALLS STORAGE SITE LEWISTON, NEW YORK

APPENDIX D

Evaluation of Radiation Exposures
on Off-Site Property H′
at the Niagara Falls Storage Site
Lewiston, New York

INTRODUCTION

The U.S. Department of Energy has completed a radiological survey and determined that portions of the SCA Chemical Services, Inc. (SCA) property, Lewiston, New York, are contaminated with low-level radioactive residues resulting from previous uses of this property. This property is part of the Former Lake Ontario Ordnance Works (now known as the Niagara Falls Storage Site) where radioactive wastes from Manhattan Engineer District and Atomic Energy Commission operations were handled and stored. These wastes were primarily residues from uranium processing operations. However, they also included contaminated rubble and scrap from decommissioned facilities, biological and miscellaneous wastes from the University of Rochester, and low-level fission product waste from contaminated-liquid evaporators at the Knolls Atomic Power Laboratory (KAPL) in Schenectady, New York. Receipt of additional wastes was discontinued at the site in 1954. Although some storage of radioactive materials on a portion of the site continues under the control of the Department of Energy, work involving handling of radioactive waste has not been performed on the off-site properties for approximately 25 years.

In 1954 a preliminary cleanup of the site was performed by Hooker Chemical Company. Approximately 1298 acres of the original 1511-acre site were then declared excess and eventually sold by the General Services Administration to various private, commercial, and governmental agencies. SCA Chemical Services, Inc. is the current owner of a 4-acre tract, identified as off-site property H′. This property is not occupied or in use.

This property was surveyed by Oak Ridge Associated Universities, Oak Ridge, Tennessee, during June and July 1982, and was found to contain radioactive contamination. The survey indicated radionuclides from the naturally occurring uranium and actinium decay series and small quantities of Cs-137, Sr-90, and Co-60.

Cesium-137, Sr-90, and Co-60 are man-made radionuclides created through the fission process such as in a nuclear reactor. Cesium-137 and Sr-90 both have half-lives* of approximately 30 years and Co-60 has a half life of approximately 5.2 years. Cesium-137 and Co-60 emit beta and gamma radiation, Sr-90 emits only beta radiation. The naturally occurring decay series, known as the uranium and actinium series, are believed to have been created when the earth was formed, and they are still present today because of their very long half-lives. These series are presented in Tables C-1 and C-2.

As a radionuclide decays it changes into another substance. In the case of U-238, for example, the decay produces Th-234. Thorium-234 is called the "daughter" of U-238, U-238 is the "parent" of Th-234. In turn, Th-234 is the "parent" of Pa-234. Radioactive decay started by U-238, U-235, or Th-232 continues as shown in the tables until a stable nuclide is formed.

The radionuclides in these decay series are present in small quantities throughout the environment. Concentrations of them normally occur in soil, air, water, food, etc., and are referred to as baseline concentrations. Radiation exposures resulting from this environmental radioactivity are referred to as background exposures. These background exposures are not caused by any human activity, and to a large extent, can be controlled only through man's moving to areas with lower background exposures. Each and every human receives some background exposure daily.

The use of radioactive materials for scientific, industrial, or medical purposes may cause radiation exposures above the background level to be received by workers in the industry, and to a lesser extent, by

** The half-life is the time required for half of the atoms of a radioactive substance to disintegrate ("decay" or transform).*

members of the general public. Scientifically based guidelines have been developed to place an upper limit on these additional exposures. Limits established for exposures to the general public are much lower than the limits established for workers in the nuclear industry.

RADIATION LEVELS ON THE SCA PROPERTY H

The survey identified elevated levels of direct radiation and contamination of the soil above the normal background levels. The major radionuclides noted in these soils are Ra-226, U-238, and Cs-137. Increased levels of radioactivity resulting from contaminated residues on this property can cause increased radiation exposures to persons. The exposure potentially comes from two primary sources or pathways: direct radiation emitted by the radionuclides in the residue or soil and inhalation of suspended airborne particulates and radon gas and its daughter products.* Additional exposures may also be received through ingestion of contaminated food or water. In Table D-3 the exposure levels associated with this property are summarized and compared with the guidelines and background radiation levels.

External Radiation Exposure Levels

As Tables D-1 and D-2 indicate, several members of the naturally occurring decay series emit gamma radiation as does Cs-137. (Gamma rays are penetrating radiation like x-rays.) Contaminated areas can, therefore, be sources of external gamma radiation exposure.

The National Council on Radiation Protection and Measurements has recommended a maximum annual whole-body exposure of 500,000 microroentgens** per year to an individual exposed in the general population. This is equivalent to a continuous level of approximately 57 microroentgens per hour. The maximum exposure level noted on this property was

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Radon-222 is a gas that results from the decay of radium-226, a member of the naturally occurring uranium series (see Table D-1).

** *The Roentgen is the unit of exposure to X- or gamma radiation. A microroentgen is one-millionth of a Roentgen.*

365 microroentgens per hour. This level was noted only at contact with several small areas of contaminated surface soil. The average exposure rate of 9 microroentgens per hour at about 3 feet above the surface is a better estimate of the average exposure an individual might receive. For comparison, the average background level in the Lewiston area is about 8 microroentgens per hour, and continuous exposure at this level would produce an annual exposure of about 69,800 microroentgens. Also, a typical chest x-ray (according to data from the Department of Health and Human Services) might yield an exposure of about 27,000 microroentgens.

The soil is contaminated with radium, uranium, cesium, and strontium which emit beta and gamma radiations. Nuclear Regulatory Commission (NRC) guidelines for decommissioning former nuclear facilities require that the dose rate (from beta and gamma radiation) measured at a distance of one centimeter above surface does not exceed 1.0 millirad* per hour maximum and 0.2 millirad per hour average. The maximum dose rate measured at this site was 5.58 millirad per hour and the average was 0.043 millirad per hour. Although the maximum level exceeds the NRC guideline, the primary concern of this guideline is exposure of skin surfaces. The thickness of ordinary shoe soles is adequate to protect the skin of feet from beta radiation. In most cases, exposures are negligible at a distance of 1 ft. away from the surface and areas of body skin are adequately protected from these exposures if they remain away from these surfaces. Beta radiation from surface residues are therefore not a significant factor in evaluating the potential health effects at this site.

Exposure From Inhalation of Airborne Radioactive Particulates

A very small amount of the radioactive contamination on this property may become airborne by resuspension of particulates from the surface layer of soil. The actual fraction of material that becomes resuspended is dependent on a number of factors including surface conditions (i.e. damp, dry, covered by ground vegetation, etc.), particle sizes, activities on the site which disturb the surface soil, and micrometeorological conditions (e.g. surface wind speed and direction). Determining average conditions of

* *The rad is the unit of beta-gamma dose. A millirad is one-thousandth of a rad.*

airborne radionuclides requires air sampling over an extended time period and was beyond the scope of the ORAU survey. However, an estimate of the potential airborne concentrations can be made based on the average concentration of radioactive material in the surface soil and using standard computation procedures of the Nuclear Regulatory Commission.

Areas of significantly higher surface contamination levels are isolated and small (usually less than 6 inches in diameter). The average surface soil concentration for property H′ is therefore best approximated by the samples collected at the grid line intersections. Radium-226 is the major radionuclide of concern on this site and the average concentration in surface soil is 3.0 picocuries* per gram or about 2.3 picocuries per gram above the level normally present in surface soils in the Lewiston area. The resulting concentration of resuspended Ra-226, based on a resuspension factor of 5×10^{-9} per meter, would be about 3×10^{-16} microcuries per cubic centimeter of air. For comparison, the Nuclear Regulatory Commission′s guideline level for continuous exposure of the general public is 2×10^{-12} microcuries per cubic centimeter. The estimated concentration of airborne Ra-226 is almost a factor of 7000 less than the guidance level and would therefore not result in a significant increase in radiation exposure to individuals on this property.

<u>Exposure from Inhalation of Radon in Air</u>

The deposits of radium-bearing residues in soil may be indirect sources of radiation exposure on site. As shown in Table D-2, Ra-226 changes to Rn-222 as a result of radioactive decay. Radon-222 is an inert gas which can emanate from the ground and, with its daughter products, result in lung exposures. Radon levels in the vicinity of NFSS are continuously monitored by Department of Energy contractors. Sampling near property H′ indicated average radon concentrations of approximately 0.27 picocuries per liter of air during 1979 and 1980. The guideline for continuous exposure of the general public is 3 picocuries per liter. For comparison the average area background level during the same time period was 0.23 picocuries per liter.

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* *The curie is the unit indicating the quantity of a radioactive substance. A picocurie is one-millionth-millionth of a curie.*

Other Exposure Considerations

Loose radioactive contamination can result in exposure through ingestion (eating or drinking) of contaminated foodstuffs. This site is not used for raising crops and average radionuclide concentrations in the ground water at this site are within the EPA drinking water limits. These pathways would not, therefore, result in significant exposures.

ESTIMATES OF HEALTH EFFECTS

The primary health effect associated with radiation exposure is an increased risk of cancer. In general, the risk is assumed to increase as the total dose of radiation increases. Total dose is dependent not only on exposure rate and concentration levels on the property, but also on the nature and duration of the exposure. In addition, a given individual's increased risk is dependent upon many factors including the individual's age at onset of exposure, variability in latency period (time between exposure and physical evidence of disease), the individual's personal habits and state of health, previous or concurrent exposure to other hazardous agents, and the individual's family medical history. Because of these variables, large uncertainties would exist in any estimates of the number of increased cancers in a relatively small exposed population such as might be the situation on this site. Estimates of the increased risks have been calculated and are given in Table D-4. Assumptions made in performing these calculations are:

1. The levels reported in Table D-3 are representative of the conditions and will not change during the year or from year to year.

2. Average exposure levels in Table D-3 are representative of the averages to which an individual working on the property might be exposed.

3. An individual would spend a working lifetime, i.e. 40 hours per week, 50 weeks per year, for 45 years (age 20 to 65) on the site.

4. Background exposure rates to individuals while not on the property will be 8 microroentgens per hour from external gamma radiation.

The risk estimates are based on the 1980 National Academy of Sciences report, "The Effects on Populations of Exposure to Low Levels of Ionizing Radiation," and the 1977 report by the United States Scientific Committee on Effects of Atomic Radiation. The lifetime risk estimate used to calculate the values in Table D-4 is 100 cancer deaths per million persons exposed per rem of radiation exposure. It is believed by many radiation biologists that with low dose rates such as those encountered at this property, the actual risks of cancer are much less than 100 per million persons per rem, zero not being excluded.

Since the estimated Ra-226 air concentrations are a very small fraction of the guidance level and the Rn-222 air concentrations are essentially background, exposures and risk from the inhalation pathway would be negligible and were therefore not evaluated further. Exposures and risk from the pathways of ingestion of crops grown on contaminated soils and water containing radionuclides from the soil are also considered negligible, based on the low-levels and the present and intended use of this property. Exposures and risk are therefore limited to one pathway -- direct exposure to gamma radiation.

The estimated increased risk due to cancer from exposure to the average radiation level on property H′, for a working lifetime is 0.009 per 1000 deaths. This can be compared with the average lifetime risks of cancer in Niagara County of 218 per 1000 deaths based on 1977 crude death rate statistics for this same year. The average lifetime risks of cancer in the State of New York and the United States are 216 per 1000 deaths and 203 per 1000 deaths respectively. An individual working under the assumed conditions will therefore be subject to an increased risk of dying from cancer of 0.0009 percent or an increase in total risk from 21.8 to 21.8009 percent when compared to the average risk in Niagara County. This may also be expressed as a percent increase in overall risk of getting a fatal cancer of 0.004 percent - a negligible increase.

SUMMARY

In summary, portions of off-site property H' at the Niagara Falls Storage Site, belonging to SCA Chemical Services, Inc., are contaminated with low-level residues containing naturally occurring radionuclides and Cs-137 and Sr-90. The level of Ra-226 contamination in the surface soil in some areas of the property exceeds the present criterion for release of this property for unrestricted use. Although this contamination is capable of producing slight radiation exposures to persons on this property, under current conditions of property use these exposures are well within the scientifically-based guidelines and risks to such persons are negligible.

TABLE D-1

URANIUM DECAY SERIES

Parent	Half-Life	Major Decay Products	Daughter
Uranium-238	4.5 billion years	alpha	Thorium-234
Thorium-234	24 days	beta, gamma	Protactinium-234
Protactinium-234	1.2 minutes	beta, gamma	Uranium-234
Uranium-234	250,000 years	alpha	Thorium-230
Thorium-230	80,000 years	alpha	Radium-226
Radium-226	1,600 years	alpha	Radon-222
Radon-222	3.8 days	alpha	Polonium-218
Polonium-218	3 minutes	alpha	Lead-214
Lead-214	27 minutes	beta, gamma	Bismuth-214
Bismuth-214	20 minutes	beta, gamma	Polonium-214
Polonium-214	.0002 seconds	alpha	Lead-210
Lead-210	22 years	beta	Bismuth-210
Bismuth-210	5 days	beta	Polonium-210
Polonium-210	140 days	alpha	Lead-206
Lead-206	stable	none	none

TABLE D-2

ACTINIUM DECAY SERIES

Parent	Half-Life	Decay Products	Daughter
Uranium-235	710 million years	alpha	Thorium-231
Thorium-231	25.5 hours	beta	Protactinium-231
Protactinium-231	32,000 years	alpha	Actinium-227
Actinium-227	21.6 years	beta, gamma	Thorium-227
Thorium-227	18.2 days	alpha	Radium-223
Radium-223	11.4 days	alpha	Radon-219
Radon-219	4.0 seconds	alpha	Polonium-215
Polonium-215	.0018 seconds	alpha	Lead-211
Lead-211	36.1 minutes	beta, gamma	Bismuth-211
Bismuth-211	2.15 minutes	alpha	Thallium-207
Thallium-207	4.79 minutes	beta	Lead-207

TABLE D-3

SUMMARY OF EXPOSURE LEVELS ON PROPERTY H'
LEWISTON, NEW YORK

Exposure Source	Levels on Site: Average	Levels on Site: Maximum	Background Levels	Guidelines for General Public	Guidelines for Radiation Workers
Gamma Radiation from Cesium-137 and uranium and actinium decay	9 μR/h[a]	365 μR/h	8 μR/h	0.5 rem[b] per year for individual, equivalent to 250 μR/h above natural background for 40 h/wk and 50 wk/yr or 60 μR/h continuous exposure.	5 rems per year
Radionuclides (Radium-226) in air	3×10^{-16} μCi/cc[c]	---	unknown	2×10^{-12} μCi/cc for continuous (168 h/wk) exposure	5×10^{-11} μCi/cc for 40 h/wk exposure
Radon in air	0.27 pCi/l[c] (1979 & 1980 avg.)	---	0.23 pCi/l 1979 & 1980 avg.	3 pCi/l	30 pCi/l for 40 h/wk exposure
Radionuclides (gross alpha concentration) in Ground Water	12 pCi/l[d]	799 pCi/l	Appr. 0.8 pCi/l	15 pCi/l, EPA Standard for Public Drinking Water Systems	400 pCi/l
Radionuclides in Soil:[a]					
Radium-226	3.0 pCi/g	1750 pCi/g	Appr. 0.7 pCi/g	EPA Mill Tailings (Criteria is 5 pCi/g above background averaged over 100 m² of surface soil.)	none
Cesium-137	0.7 pCi/g	33 pCi/g	Appr. 0.5 pCi/g	80 pCi/g above background (Criteria developed by Los Alamos Sci. Lab. for cleanup at sites contaminated by fission product residues.	none

TABLE D-3, cont.

SUMMARY OF EXPOSURE LEVELS ON PROPERTY H'
LEWISTON, NEW YORK

Exposure Source	Levels on Site: Average	Levels on Site: Maximum	Background Levels	Guidelines for General Public	Guidelines for Radiation Workers
Strontium-90	<0.23 pCi/g[f]	9.7 pCi/g	<0.5 pCi/g	100 pCi/g (LSAL Criteria)	None
Uranium-238	<4.5 pCi/g	1480 pCi/g	<3.3 pCi/g	40 pCi/g (LASL Criteria)	None
Thorium-232	0.7 pCi/g	<3.5 pCi/g	0.7 pCi/g	20 pCi/g (LASL Criteria)	None
Uranium-235	<0.3 pCi/g	66 pCi/g	<0.2 pCi/g	1.5 pCi/g (based on NRC criteria of 30 pCi/g of enriched Uranium, U-234/U-235 ratio assumed appr. 20/1)	None

[a] The Roentgen (R) is a unit which was defined for radiation protection purposes for people exposed to penetrating gamma radiation. A microroentgen (μR) is one millionth of a Roentgen.

[b] The rem is the unit of ionizing radiation that produces the same biological damage in man as an absorbed dose of 1 roentgen of high voltage x-ray. A roentgen of gamma exposure to a man is equivalent to one rem.

[c] The microcurie (μCi) and picocurie (pCi) are units which are defined for expressing the amount of radioactivity present in a substance. 1 μCi = 10^{-6} Ci, 1 pCi = 10^{-12} Ci.

[d] The average includes only wells near the property boundary and does not consider the maximum level (at a location of high contamination in the interior of the site) as affecting the off-site ground water levels.

[e] Average is based on samples from grid line intersections, maximum represents concentration measured in samples from "hot spots".

[f] Based on the maximum ratio of Sr-90 to Cs-137 observed in soil from this site - 1/3.

TABLE D-4

SUMMARY OF WORKING LIFETIME RADIATION EXPOSURES AND ESTIMATES OF ASSOCIATED CANCER RISK FOR PROPERTY H´, LEWISTON, NY

Source of Exposure	Working Lifetime Dose Equivalent Corrected for Background	Increased Risk Due to All Cancers
External gamma radiation	0.09 rem	0.009 per 1000 [a]
Inhalation of resuspended particulates	negligible	0
Inhalation of radon	negligible	0
Ingestion of food and water contaminated by radioactive materials on-site	negligible	0
TOTAL	0.09 rem	0.009 per 1000 [b]

[a] Using the risk coefficient of 100 cancer deaths/10^6 person rem. This is approximately a mean value from BEIR-III (1980) and UNSCEAR (1977).

[b] The average lifetime risk of death due to cancer in the United States is 203 per 1000 (20.3 percent); in Niagara County the average lifetime risk is 218 per 1000 (21.8 percent).