**RMC Technical Services**

3356 Commercial Avenue • Northbrook, IL 60062 • 312-291-1030 • TWX 710-670-1989 • CABLE: RMCPHIL

January 20, 1983

Mr. D. M. Montgomery
101 Marietta Street
Suite 3100
Atlanta, GA 30303

Dear Mr. Montgomery,

At the request of Mr. W. T. Crow, USNRC, we have sent a copy of the Draft Report on the Radiological Survey of the Nuclear Fuel Services, Inc. Erwin Plant Burial Site for your review. Please provide any comments, suggestions or recommendations concerning the report to this office by February 7, 1983.

Sincerely,

Lee Booth

Leroy F. Booth, C.H.P.
Manager, Midwest Regional Office

kgc
Enclosure

cc: W. T. Crow, USNRC

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RMC
Corporate Office
3508 Market Street
Philadelphia, PA 19104
215 243-2950

# RADIOLOGICAL SURVEY OF THE NUCLEAR FUEL SERVICES, INC. ERWIN PLANT BURIAL SITE

DRAFT REPORT

Prepared By:

L. F. Booth D. W. Groff

P. L. Nyerges S. I. Peck

F. L. Bronson

Radiation Management Corporation

Prepared For:

U. S. Nuclear Regulatory Commission

Division of Fuel Cycle and Material Safety

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## ABSTRACT

This report presents the results of a radiological survey of the burial site on the Nuclear Fuel Services (NFS), Inc. Erwin Plant grounds. This site contains approximately 30 burial pits, into which has been placed a variety of disposable waste, contaminated with low levels of thorium and uranium, with enrichments ranging from depleted to 97%. Measurements were made to determine if these materials are migrating from the burial pits into the environment, and if so, at what levels. Survey results indicate that contamination is not moving from the pits, and that previous burials of radioactive waste on the site have had little or no adverse effect on the environment or population.

# I. INTRODUCTION

In the spring and summer of 1982, Radiation Management Corporation (RMC), under contract to the U. S. Nuclear Regulatory Commission (NRC) performed a radiological evaluation of the NFS plant burial site in Erwin, Tennessee. An initial site visit occurred in April, 1982, and the detailed radiological evaluation was performed in the summer of 1982.

The purpose of this survey was to clearly define the radiological conditions at the burial site and to determine if radioactive material is moving from the burial pits into the surrounding environment.

The methods used to evaluate this site included the following:

1) Measurement of external exposure rates at one meter above the ground surface and beta-gamma count rates at one cm. above the ground surface;

2) Measurement of radionuclide concentrations in surface soil;

3) Measurement of radonuclide concentrations in

subsurface deposits.

4) Measurement of gross alpha and beta activity in surface and subsurface water samples; and

5) Measurement of airborne radioactivity, including radon flux emanation rates.

These measurements were performed on-site using a mobile laboratory designed by RMC. A small number of samples were returned to the RMC radiological laboratories in Philadelphia for analysis for nuclides which could not be detected in the field, and for quality assurance checks on the field measurements. A set of reference background measurements were made in the Erwin area near the NFS site.

## II. SITE CHARACTERISTICS

The NFS plant site is located in Unicoi County in northeast Tennessee, approximately 0.5 mile southwest of the city limits of Erwin. The site property is bounded to the northwest by the Clinchfield Railroad right-of-way, to the northeast by Martin Creek, and to the southeast by Carolina Avenue (Fig. 1). The site is surrounded primarily by undeveloped forest land, although there are some scattered private residences as near as 0.2 mile from the center of the site, to the southeast.

Of the total 57.8 acre plant site area, all production facility buildings and three waste retention ponds are on 21.2 acres enclosed by a security fence. Additional acreage is enclosed by an outer barbed wire fence, restricting public access to the burial pit near Martin Creek. Routine security measures now in effect to control site access include surveillance of the fenced areas and badging and escorting plant site visitors.

The plant site facilities include numerous warehouse and processing buildings. Current operations include: 1) uranium recovery from scrap material and sub-specification highly-enriched uranium material, 2) highly enriched uranium fuel fabrication from uranium

hexafluoride, 3) low-enriched uranium scrap recovery, and 4) uranium hexafluoride cylinder washing. Operations performed in the past, but which are now discontinued, included plutonium fuel element fabrication, uranium-233 recovery from scrap materials, and the production of thorium dioxide powder, thorium metal, uranium tetraflouride and uranium metal.

Various measures have been taken during the lifetime of the site to control and dispose of wastes generated in the recovery and production processes. Gaseous effluents are treated with filter systems and scrubber systems throughout the facility. Liquid waste retention is currently achieved with underground collection tanks, where wastes can be sampled before release or reprocessing. Prior to the use of the underground tanks three unlined settling ponds were used to treat the liquid wastes. Discharge from these ponds reached Banner Spring Branch, flowing through the site and into Martin Creek (and eventually into the Nolichucky River). These retention ponds are currently maintained by replacing water lost through evaporation or seepage to prevent dried sediment from becoming airborne.

Radioactive solid wastes not packaged and shipped for disposal at a licensed commercial site were placed in burial pits near the northeast edge of the site property.

Approximately 30 individual pits of various sizes have been used from 1966 to the present (Fig. 2). The burial pits are located outside the security fence but inside the outer barbed wire fence. A detailed inventory of materials disposed of in each pit has been maintained, and has been provided to RMC by NFS personnel (Table 1). Small pits contain uranium and/or thorium contaminated wastes packaged in plastic-lined buckets or plastic bottles. Larger pits contain mainly uncontaminated shipping containers, "clean" incinerator ash, and unpackaged low-enriched uranium-contaminated laboratory waste. No plutonium wastes were buried on site. Pits are believed to be no deeper than 20 feet, with approximately five feet of surface fill covering the buried material. Individual pits are marked with cement cornerposts and identification plates. Only non-contaminated items are being buried at present.

## III. RADIOLOGICAL SURVEY METHODS

The detailed radiological survey of the NFS burial pit area was begun in April and completed in July, 1982. During that period, measurements of external radiation levels and of contaminants in soil, water and air, in and near the burial pits, were performed.

Since the burial pits are fairly well defined, in both location and content, limited sampling was done in the pit area itself. The primary purpose of this sampling was to verify location and content of a few selected pits. The remaining measurements were performed to determine if material is migrating from the pits, and if so, how much and where.

Survey methods were designed with the intent of being able to determine whether positive findings, if any, were due to burial or other activities. Because the NFS Erwin site is an active processing facility, any positive indications of material present at significant distances from the burial site must be evaluated in light of past and present effluent releases due to normal plant operations. NFS maintains a radiological monitoring program to evaluate such effluent releases, including the sampling of air, surface water, sediment, soil and vegetation on and off site.

## A. Measurement of External Radiation Levels

The survey area was divided and marked with a ten meter by ten meter grid network. Initially, external exposure rates measurements were taken at one meter above the surface at each grid point (every ten meters at the intersection of two perpendicular grid lines), by using a sensitive tissue equivalent ionization chamber (Shonka Chamber) at a few selected locations. Simultaneously, measurements were made with a (more portable) sodium iodide (NaI) scintillation detector. The NaI count rate was correlated with the Shonka chamber exposure rate measurements and a conversion factor established. The NaI detector was then used to perform the majority of the exposure rate measurements. These instruments are described in Appendix 1.

At each grid point an end window G-M tube was used for surface measurements. Open and closed window readings were made at 1 cm and the ratio of the two used to indicate the presence or absence of surface contamination.

## B) Measurement of Surface Radioactivity

Based on external measurements, surface soil samples were collected from locations where surface deposits were indicated, as well as locations where drainage characteris-

tics indicated the possibility that radioactive materials may have been transported from their original burial locations. The samples were dried and sealed in 500 ml aluminum cans for counting on the intrinsic germanium (IG) gamma ray spectroscopy system described in Appendix 1.

C) Measurement of Subsurface Radioactivity

Since it is know that most, or all, of the waste activity consists of buried uranium and thorium, measurements of subsurface activity by logging auger holes was the primary evaluation technique at NFS. A series of holes through and bordering the burial site were drilled and lined with four-inch PVC casing. Qualitative and quantitative *in situ* measurements of each auger hole were performed using the RMC custom designed instrinsic germanium (IG) well logging system (Appendix 1). This system has been calibrated with an NBS supplied Eu-152 source in a counting geometry approximating a uniform distribution of activity in soil extending to an "infinite" distance. In addition, split spoon core samples were taken from four holes and analyzed on the mobile laboratory gamma spectroscopy system, as a comparison with the *in situ* measurements. Selected core samples and surface soil samples were also sent to the RMC analytical laboratory for additional studies, including uranium isotopic determinations.

D) Measurement of Radioactivity in Water

Whenever possible, water samples were taken from bore holes. Five permanent water monitoring wells were drilled to provide access to ground water flow through the burial site. These wells were located at points which intercept the ground water flow through the pit areas, and therefore will monitor movement of material from the pits, via ground water.

Water samples were filtered to remove suspended particulates, then 100 ml aliquots were evaporated onto planchetts and counted for gross activities. Any samples with greater than EPA drinking water standards were sealed in Marinelli beakers and counted using the gamma spectroscopic analysis system.

E) Measurement of Airborne Radioactivity

Measurements were made in order to determine to what extent, if any, the buried material is a source of airborne radioactivity. Since it was believed that all burials were covered by about five feet of soil, the likelihood of surface contamination leading to particulate airborne activity is small. However, a few high volume particulate "grab" air samples were collected to verify the absence of elevated

particulate activity.

Because it was known that the long lived uranium daughter Ra-226 was not present, emanation of its decay product Rn-222 was not expected to be significantly greater than background levels. However, because thorium was known to be present, Rn-220 emanation was thought to be a possibility. Because of this possibility, radon flux measurements were made. The measurement technique used was collection in a charcoal cannister and subsequent analysis for Rn-220 daughters using the laboratory gamma spectroscopy system (see Appendix 1).

## IV. RADIOLOGICAL SURVEY RESULTS

### A) External Radiation Levels

Slightly elevated external radiation levels have been measured in the burial pits area, as shown in Fig. 4 and Table 2. However, nearly all the elevated readings are found immediately west of the actual burial pits, primarily along an unpaved road which has been used as a vehicle route for transporting waste to the pits. Beta gamma counts at 1 cm indicated the presence of surface contamination in this area, which was subsequently verified by soil sample analyses (Section B).

The only elevated readings above the pits themselves occurred near the west end of pit 69-12, which was known to contain both uranium and thorium. Surface measurements and soil borings showed contamination in this pit extending to the surface. No other elevated levels were detected, even above pits known to contain much larger quantities of thorium than in pit 69-12.

Although elevated external radiation levels were detected, these levels were quite low. The highest level was 71 uR/hr, and only about 800 sq m exceeded 20 uR/hr. No surface contamination, as measured by open window vs closed

window beta-gamma readings, was detected in areas other than those where elevated gamma levels at one meter existed.

B) Surface Soil Analyses

A total of 16 surface soil samples were collected from the burial pits site. Of these, 11 were taken from areas where survey results indicated the presence of surface contamination, and the remainder from other locations on or near the site. The locations of the surface soil samples are shown in Fig. 5 and the analytical results in Table 3.

All surface soil samples taken from areas of elevated external radiation levels showed both uranium and thorium contamination. In each case the uranium concentrations were much higher than the thorium daughter activities, by as much as a factor of 1000. The ratios of U-238 to U-235 indicate the surface contamination to be low enriched or depleted uranium. Concentrations up to 9000 pCi/g U-238 and 100 pCi/g U-235 were measured in surface soils, and 17,000 pCi/g U-238 was measured in a single "rock" sample found on the surface. All K-40 and Ra-226 daughter concentrations were indistinguishable from normal background levels. In areas where there were no elevated external radiation levels, there was no detectable surface contamination (i.e. uranium contamination). contamination.

All thorium concentrations have been inferred from daughter measurements. However, if the thorium which was buried only 12 to 15 years ago was freshly processed (free of daughters), insufficient time will have elapsed to allow for complete ingrowth of daughters. Thus, because of possible disequilibrium, thorium concentrations could be 25% higher than reported daughter (Ac-228) activities.

C. Subsurface Soil Analyses

Subsurface contamination was assessed by extensive logging of bore holes drilled through and around the burial pits, using the intrinsic germanium (IG) detector for in situ measurements. Each hole was logged with this detector, and the resulting gamma spectra analyzed for contaminants in soil. A total of 16 holes were drilled on site, 11 of which were lined with 4 inch PVC casing for logging. The remaining 5 were lined with 2 inch slotted casing for use as permanent ground water monitoring wells.

Fig. 6 shows the location of all holes drilled on site. Two bore holes (#10 and #15) were drilled directly through pits known to contain contaminated waste, while the remaining 9 were placed around the burial pit site. Two of these, as well as two ground water monitoring wells, were located 100 to 200 meters west of the pits, in the general direction

of ground water flow. These were situated in this manner in an effort to detect possible movement from the retention ponds on site, as well as from the burial pits.

The bore hole logging results are listed in Table 4. Only two showed significant subsurface contamination; not suprisingly the two (10 & 15) drilled through the pits. Bore hole 10, through pit 69-12, showed both uranium (probably depleted) and thorium, while bore hole 15, through one of the pits in the group 70-1 thru 70-5, showed primarily enriched uranium. These logging results are consistant with the recorded burials for these pits (see Table 1). Contamination in bore hole 10 is seen to extend from a depth of about 10 feet to the surface, which was verified by surface sampling at this location. Contamination in bore hole 15 displayed a similar distribution.

All other bore holes displayed only background characteristics, except bore hole 16, which was drilled through the higher radiation area to the west of the pits. Logging of this bore hole showed that the contamination in this area in only on the surface, and that no material is buried beneath this area.

In addition to logging each hole, split spoon core samples were taken from 4 holes and analyzed. Results of the

core analyses by gamma spectroscopy are shown in Table 5. As expected, the cores of the two pits on site (10 and 15) show elevated uranium and/or thorium activities, while the cores from holes not through pits (6 and 8) are essentially background.

Several core samples were also analyzed at the RMC Analytical Laboratories in Philadelphia and compared with on-site measurements. Results are presented in Table 6. Comparison of core sample analyses vs in situ logging results showed some inconsistancies. This is probably due to the fact that contamination in pits (and in core samples) is expected to exist as discrete sources, while the in situ measurements assume a uniform infinite distribution. Nevertheless, the measurements show qualitative agreement.

D) Analyses of Radioactivity in Water

A total of 18 water samples were collected, 13 from the ground water monitoring wells, 2 from Martin Creek, 2 from the Nolichucky River and one from standing water on site. The location of the water samples is shown in Fig. 7.

From each sample, a 100 ml aliquot was filtered and evaporated on a planchett, then counted 100 minutes for gross alpha and gross beta activity. Results are shown in

Table 7. None of the samples had gross alpha alpha activity exceeding the target criteria (MPC for U-235 for release to an unrestricted area, 30,000 pCi/l), nor did any exceed the EPA interim primary drinking water standard (15 pCi/l gross alpha). The highest concentration measured from gross alpha was 3.3 pCi/l for a sample from bore hole 9.

Gross beta activities were also very low, with the highest level being 16 pCi/l, for the same sample from bore hole 9 as that discussed above. Due to the low gross activities of the water samples collected during this study, no isotopic analyses were performed.

E) Measurement of Airborne Radioactivity

Since the uranium which was buried in the pits had been enriched (or depleted), no long lived daughters (e. g. Ra-226) were present. Therefore, the uranium could not be a source of radon emanations. However, some thorium, including natural, has been buried and could be a source of Rn-220, especially form surface contamination. In addition, resuspension of surface materials could be a source of airborne radioactivity.

Both gaseous and particulate radioactivity were sampled and analyzed during this study. The sampling program was

designed to detect and measure radon-220 and daughters. Two methods were used: high volume particulate samples for radon daughters, and charcoal cannister collectors for radon gas.

The results of the high volume air samples are shown in Table 8. Gross beta and alpha activities are generally low, except for sample 2, which showed slightly higher activity near the area of surface contamination.

A total of eight radon flux accumulations were made by sealing a charcoal cannister onto the ground surface, then collecting and counting the charcoal for Rn-220 daughter activity on the gamma spectroscopy system. Results are shown in Table 9, and indicate that the surface contamination is a source of Rn-220. Emanation rates ranging from 26 to 13,000 pCi/m2.s were detected during the brief measurement periond were 22 activities were near or at background levels.

## V. CONCLUSIONS

The results of this survey confirm that uranium and thorium wastes have been disposed of in burial pits on the NFS site. These disposals are well documented and were performed in accordance with all applicable regulations. At this time only uncontaminated waste is being buried on site.

Slightly elevated external radiation levels have been measured in the burial pits area, although all levels are less than 100 uR/hr. Nearly all the readings above 20 uR/hr (target criteria as shown in Table 10) are found in an area immediately west of the actual burial pits. These readings were found to correspond to surface contamination in this area. Since this surface contamination is located primarily along an unimproved access road it has been postulated that it is a result of spillage from vehicles transporting waste to burial pits. Whatever the source, it is not possible that this surface contamination's from the burial pits, since the soil beneath this area and between this area and the pits is not contaminated.

Only two small areas of elevated radiation levels and surface contamination were found in the pit area. The spot near the edge of pit 69-12 shows contamination extending from the surface to a depth of 11 feet, indicating inade-

quate cover for the pit at this location. The other spot, near the edge of pit 66-1, appears to be only surface contamination. All surface contamination contained both uranium and thorium daughters, which produces the external radiation levels. In areas where external levels were not elevated, no contamination (i.e. uranium contamination only) was found.

Measurement of subsurface deposits (in situ) confirm recorded burial data. Logging of pit 69-12 (bore hole 10) revealed the presence of both uranium and thorium, while bore hole 15, through pit 70-5, showed primarily enriched uranium. Both findings are consistant with burial records. Results of loggings of all bore holes beyond the pits were negative, implying little or no migration of contaminants through the soil.

Results of all ground water sampling were also negative, confirming that material is probably not moving from the pits via ground water. Negative findings in samples from wells furthermost from the pits (wells 12 and 14 in Fig. 5) also indicate minimal effect of retention pond seepage on ground water at this time. However, these results are from a few samples only, over a limited time span.

While the waste buried in pits is not a source of airborne contamination, surface material located near the pits is a source of Rn-220 and daughters. Although sampling results indicate airborne concentrations are not high, and significant exposures are not likely, the source could be eliminated by removing a small surface area.

The overall conclusion is that the waste material buried in the pits is not moving from the pits, nor does it have a significant effect on the environment or population. In addition, it appears that movement of contamination from the waste retention ponds into the areas examined in the study, is not significant.

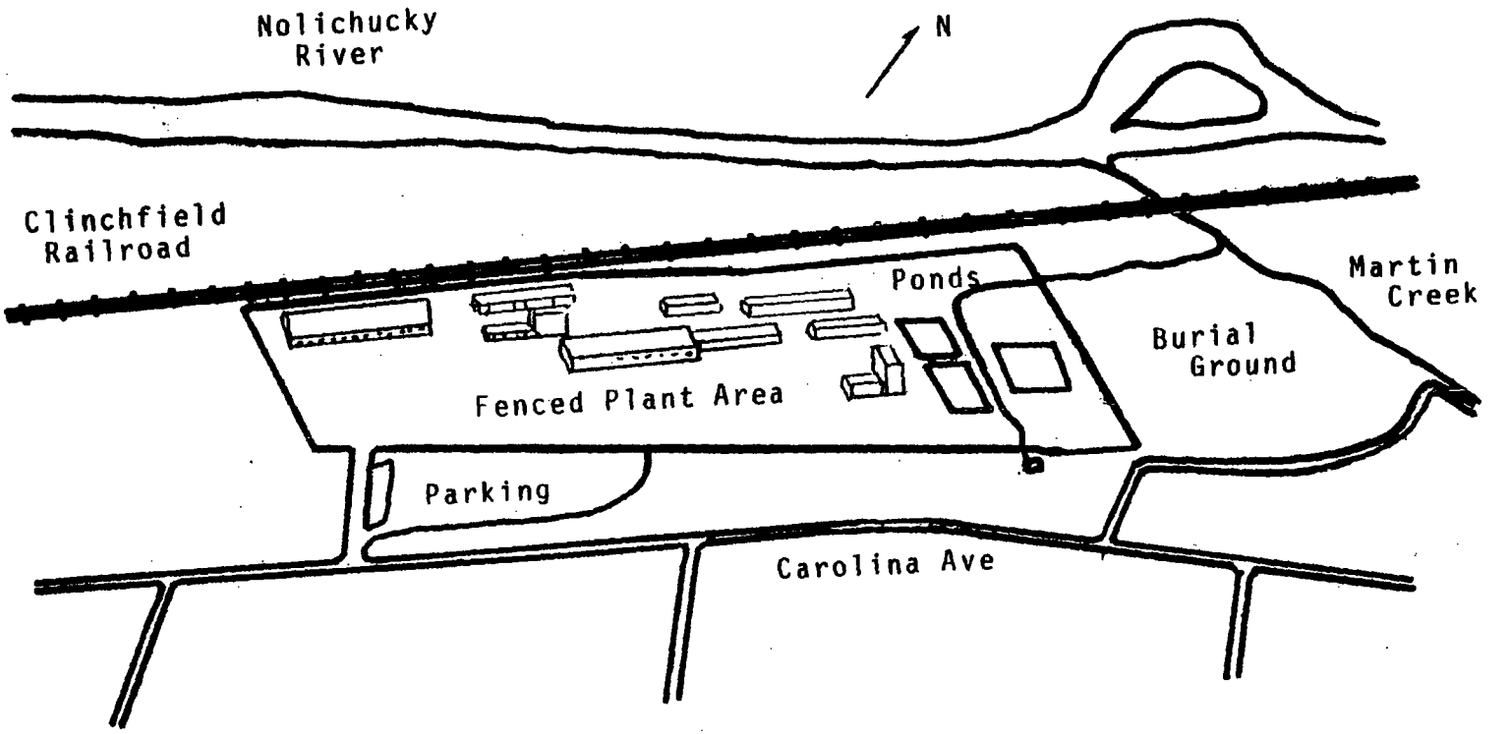


Fig. 1. Nuclear Fuel Services, Inc., Erwin Plant.

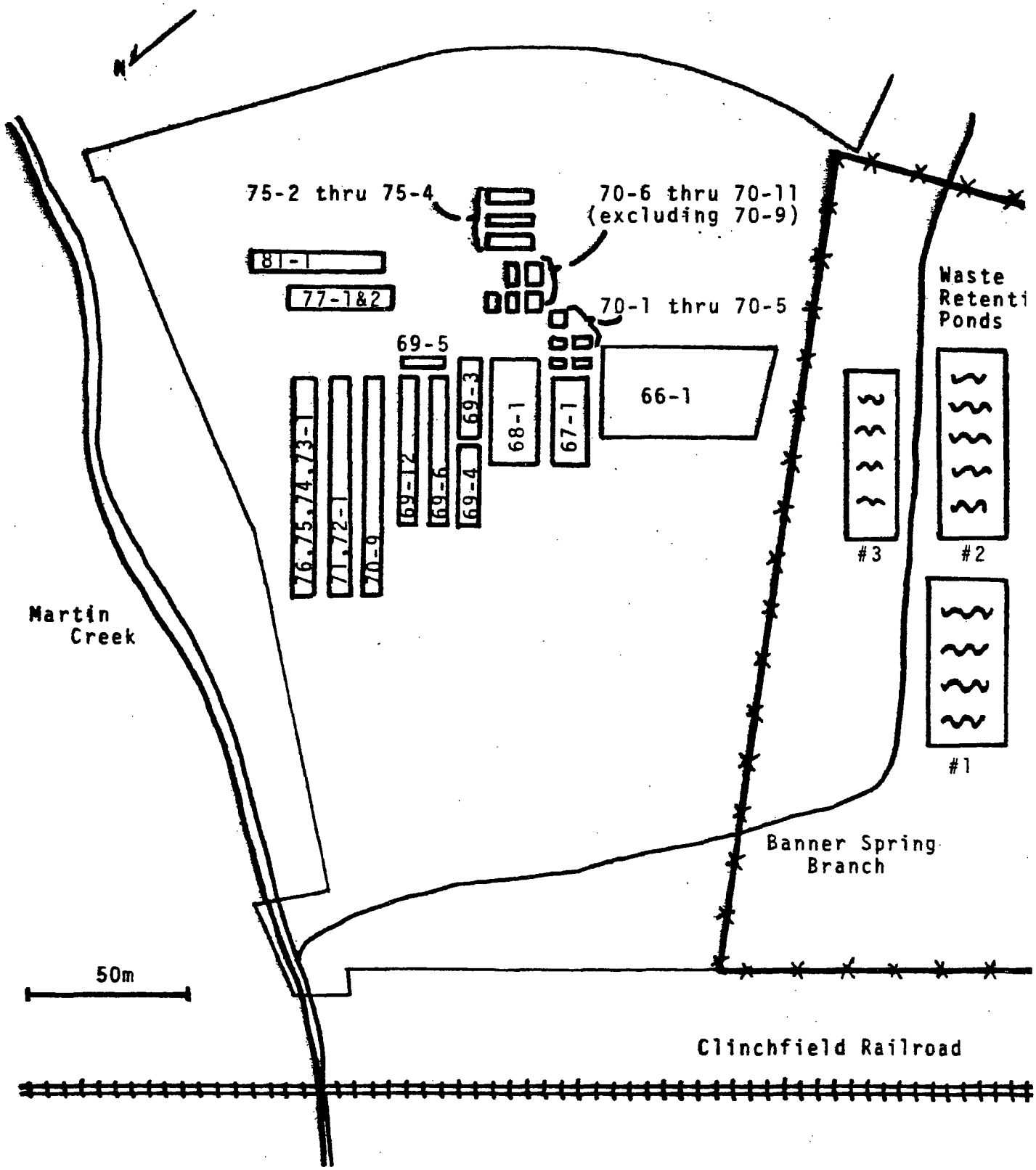


Fig. 2. NFS burial pit designations.

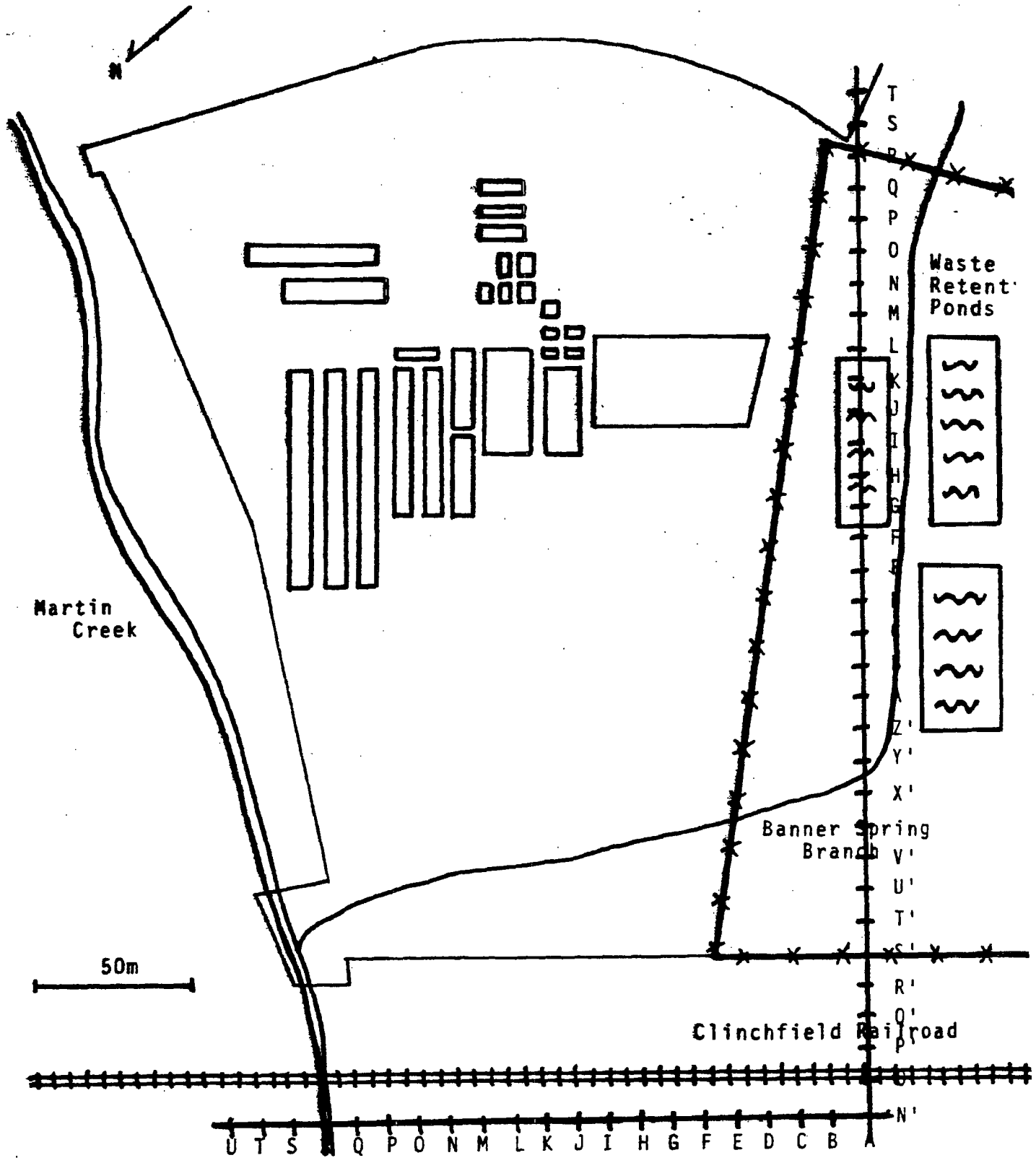


Fig. 3. NFS burial pits site grid locations.

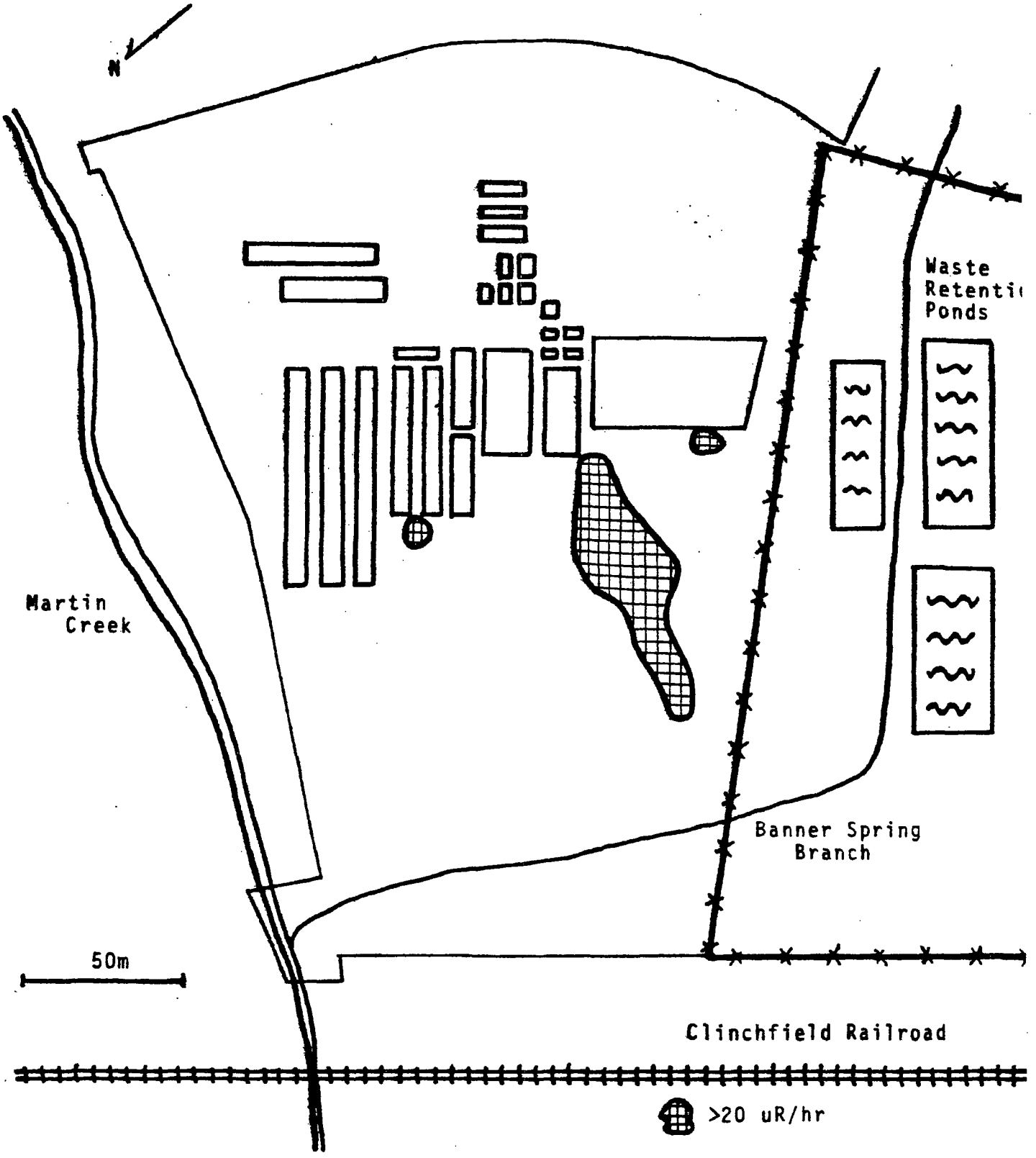


Fig. 4. External exposure rates, NFS burial pits site.

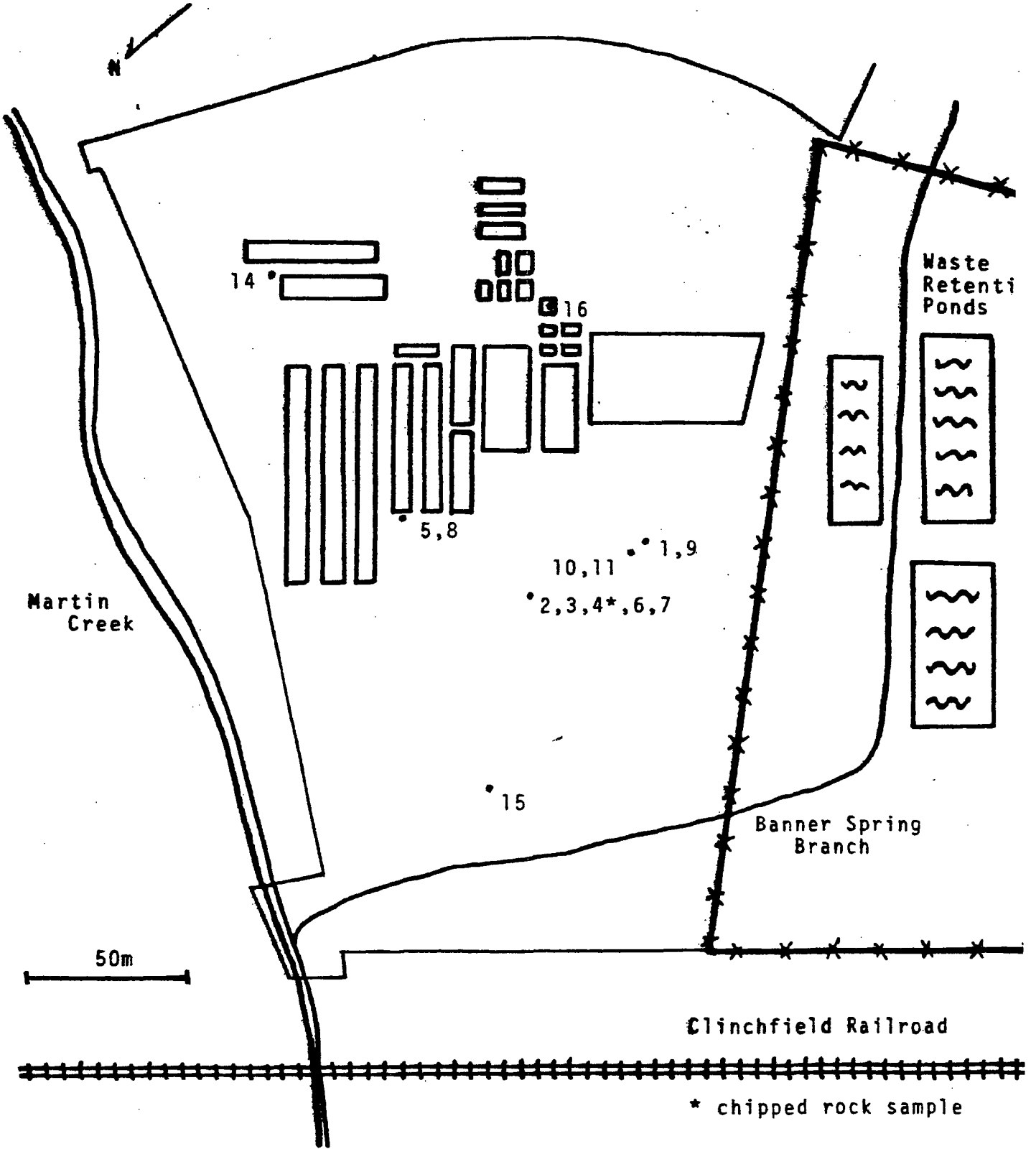


Fig. 5. Location of surface soil samples, NFS burial pits site.

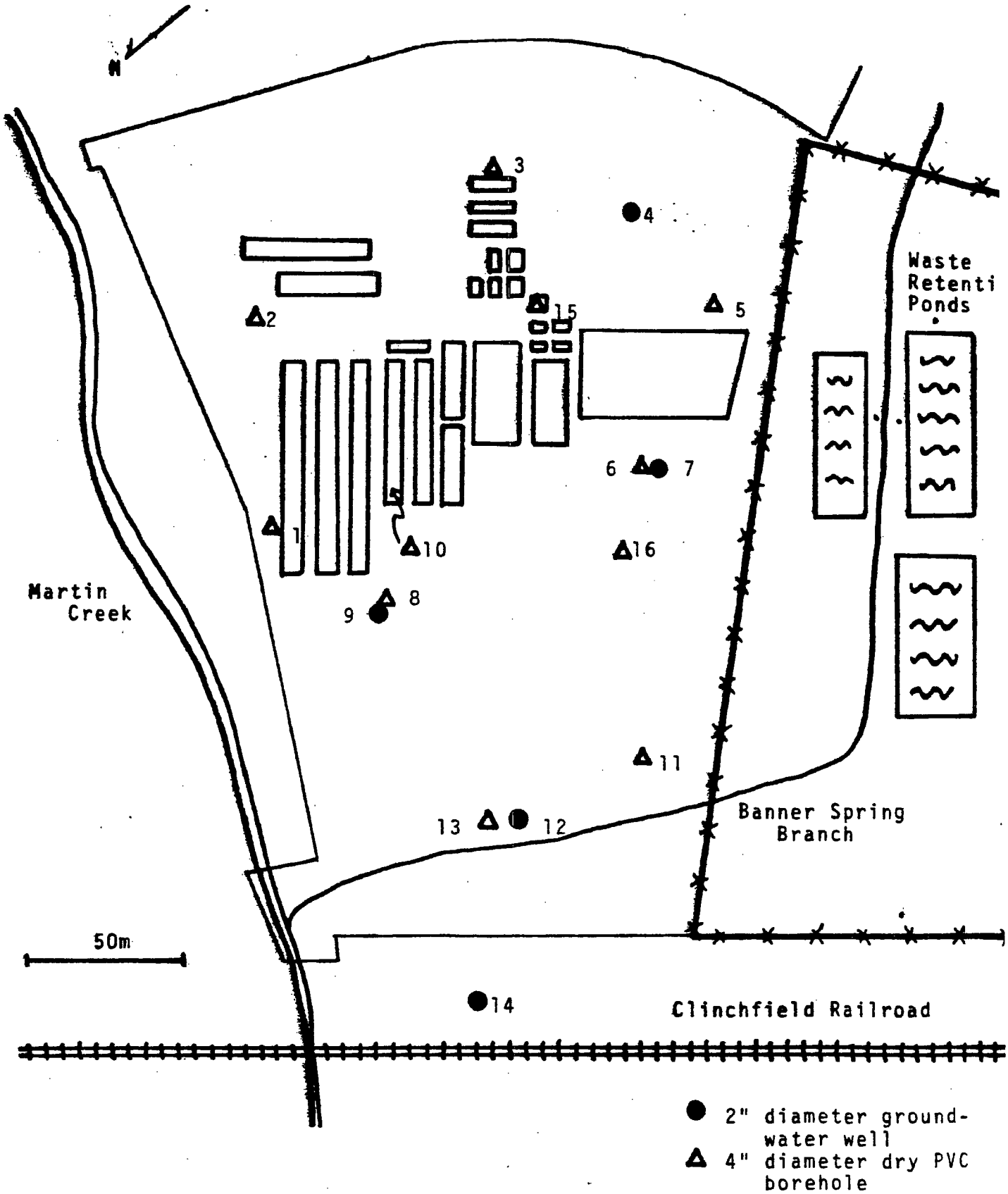


Fig. 6. Location of bore holes used for logging subsurface contamination and water monitoring wells. NFS burial pits site

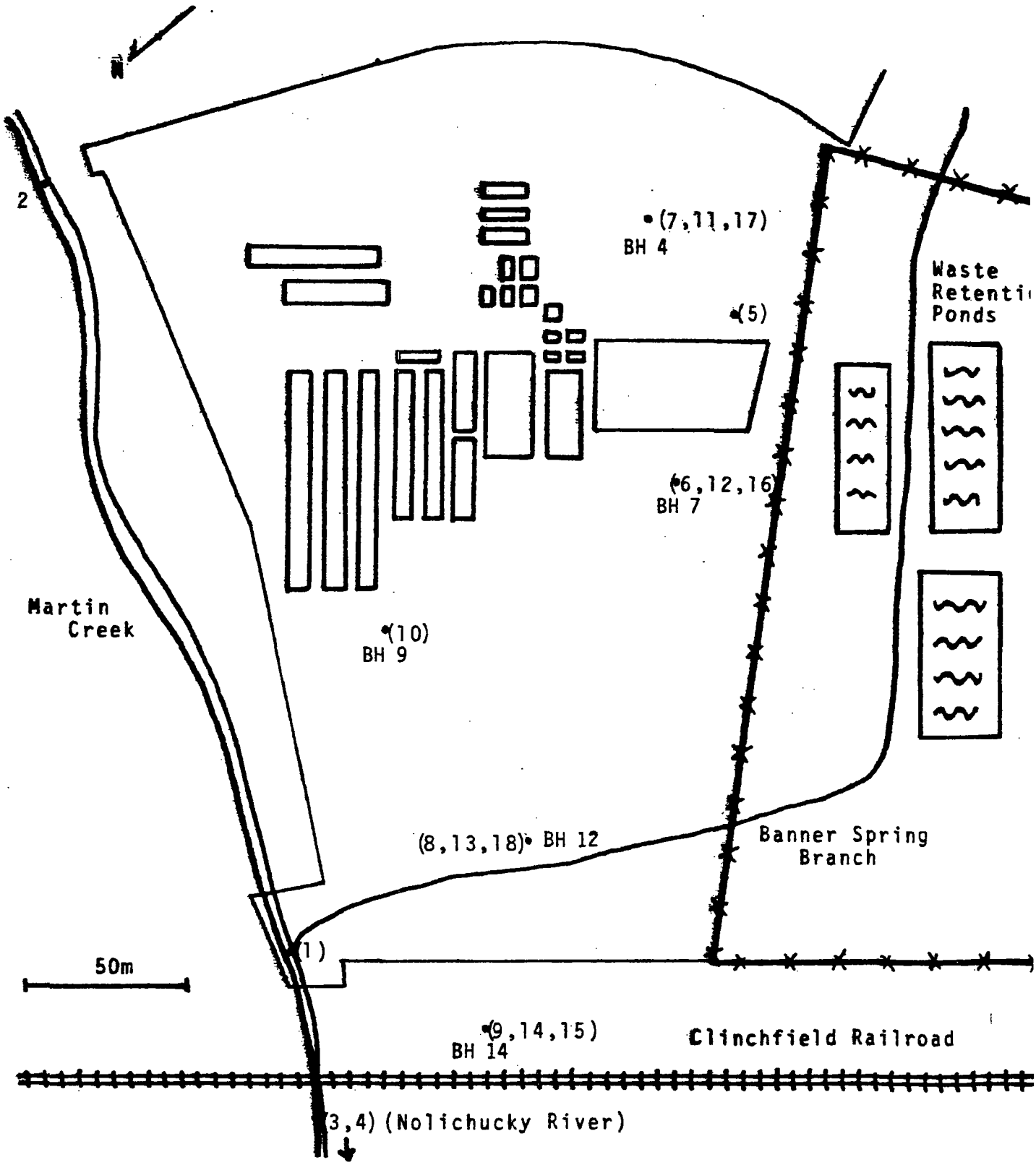


Fig. 7. Location of water samples. Sample numbers listed in Table 7 are shown in parentheses.

Table 1

NFS burial pit contents

| Pit No. | Closure Date | Quanity | Nuclides | Mass | Description |
|---|---|---|---|---|---|
| 66-1 | Dec. 1966 | 65.4 mCi | U-93% enriched<br>Dep U<br>Thorium | 96 g<br>86.2 Kg<br>126.0 Kg | Mostly non-combustable trash |
| 67-1 | Nov. 1967 | 68.4 mCi | U-93% enriched<br>Dep U<br>Thorium | 357 g<br>33 g<br>131 Kg | Combustables |
| 68-1 | No date | 35.4 mCi | Dep U<br>Thorium | 117.6 Kg<br>63.1 Kg | |
| 69-1 | | (0) | | | |
| 69-2 | | (0) | | | |
| 69-3 | July | 30.0 mCi | Thorium<br>Enriched U | 271.2 Kg<br>0.5 g | Trash |
| 69-4 | June | 98.0 mCi | Thorium<br>U-235 | 400 Kg<br>0.5 g | 10,000 cu ft of trash & 12 drums |
| 69-5 | July | 0.04 mCi | U-235 | 1 g | Contaminated trailer |
| 69-6 | Oct. | 2.5 mCi | Dep U<br>U-235<br>U-233<br>Pu-239<br>Thorium | 2.3 g<br>53.4 g<br>< 1 g<br>1 ug<br>600 g | |
| 69-12 | Dec. 1969 | 0.2 mCi | U-238<br>U-235<br>Thorium | 129 g<br>3 g<br>160 g | |
| 70-1 | June 1970 | 38.1 mCi | U-97% enriched | 491 g | |

Table 1, cont.

| Pit No. | Closure Date | Quanity | Nuclides | Mass | Description |
|---|---|---|---|---|---|
| 70-2 | March 1970 | 2.7 mCi | U-97% enriched | 34.7 g | |
| 70-3 | March 1970 | 48.7 mCi | U-97% enriched | 628 g | |
| 70-4 | March 1970 | 50 mCi | U-70% enriched | 2201 g | Bottles & 5 gal cans |
| 70-5 | March 1970 | 49.1 mCi | U-88% enriched | 629 g | |
| | | | U-20% enriched | 3195 g | |
| | | | U-20% enriched | 600 g | |
| | | | U-20% enriched | 600 g | |
| | | | U-52% enriched | 42 g | |
| 70-6 | April 1970 | 48.6 mCi | U-70% enriched | 333 g | |
| | | | U-52% enriched | 2249 g | |
| | | | U-2.5% enriched | 2640 g | |
| 70-7 | April 1970 | 53.31 mCi | U-93% enriched | 108.6 g | |
| | | | U-76.38% enriched | 704 g | |
| | | | U-52% enriched | 1551 g | |
| | | | U-20% enriched | 50 g | |
| | | | U-16% enriched | 56 g | |
| 70-8 | April 1970 | 49.28 mCi | U-238 | 15557 g | |
| | | | U-235 | 1289 g | |
| 70-9 | April 1970 | 2.6E3 mCi | Dep U | 11 g | |
| 70-10 | May 1970 | | U-97% enriched | 1.2.44 g | |
| | | | 93% Press cake | 867 g | |
| 70-11 | May 1970 | 87 mCi | 93%-U enriched | 1046.8 g | |
| 71,72-1 | Aug. 1973 | .288 mCi | 97%-U enriched | .003 g | |
| | | 2.76 mCi | Dep U | 11.35 Kg | |

Table 1, cont.

| Pit No. | Closure Date | Quanity | Nuclides | Mass | Description |
|---|---|---|---|---|---|
| 73,74-1 | May 1977 | 1.747 uCi | U-235<br>U-235-5%<br>U-235-93% | 22.831 mgm<br>4 mgm<br>106 mgm | |
| 75-2 | May 1975 | 6.5 uCi | Enriched U | 4.87 g | |
| 75-3 | May 1975 | 9.2 uCi | Enriched U | 6.88 g | |
| 75-4 | May 1975 | 3 uCi | Enriched U | 2.29 g | |
| 76,75,74,73-1 | 1977 | 6.2 uCi | U-93% enriched<br>U-5% enriched<br>U-93% enriched | 22.831 mgm<br>4 mgm<br>101 mgm | |

Table 2

Gamma radiation levels and beta-gamma counts rates at grid locations

| Grid Location | NaI Count Rate (c/min) | Exposure Rate (uR/hr) | Beta-Gamma Count Rate w/window (c/min) | Beta-Gamma Count Rate w/o window (c/min) |
|---|---|---|---|---|
| D00L | 700 | 10 | 60 | 10 |
| E00H | 1100 | 14 | 100 | 160 |
| E00I | 100 | 14 | 120 | 170 |
| E00J | 900 | 12 | 190 | 140 |
| E00K | 700 | 10 | 120 | 90 |
| E00L | 700 | 10 | 140 | 120 |
| F00A | 700 | 10 | --- | --- |
| F00B | 800 | 11 | --- | --- |
| F00C | 900 | 12 | --- | --- |
| F00D | 900 | 12 | 80 | 110 |
| F00E | 1100 | 14 | 120 | 90 |
| F00F | 1100 | 14 | 130 | 150 |
| F00G | 900 | 12 | 100 | 100 |
| F00H | 1000 | 13 | 130 | 110 |
| F00I | 6000 | 54 | 560 | 620 |
| F00J | 1200 | 14 | 180 | 210 |
| F00K | 700 | 10 | 150 | 180 |
| F00L | 800 | 11 | 210 | 180 |
| F00M | 700 | 10 | 90 | 140 |
| G00A | 2000 | 21 | 150 | 160 |
| G00B | 4300 | 40 | 250 | 320 |
| G00C | 1500 | 17 | 80 | 120 |
| G00D | 1600 | 18 | 150 | 130 |
| G00E | 2900 | 28 | 250 | 210 |
| G00F | 1500 | 17 | 140 | 150 |
| G00G | 1000 | 13 | 90 | 140 |
| G00H | 1100 | 14 | 130 | 110 |
| G00I | 1100 | 14 | 120 | 110 |
| G00J | 900 | 12 | 80 | 90 |
| G00K | 800 | 11 | 80 | 110 |
| G00L | 700 | 10 | 140 | 120 |
| G00M | 700 | 10 | 70 | 90 |
| H00A | 1100 | 14 | 50 | 100 |
| H00B | 1100 | 14 | 120 | 130 |
| H00C | 2500 | 25 | 140 | 280 |
| H00D | 4200 | 39 | 170 | 220 |
| H00E | 2500 | 25 | 100 | 100 |
| H00F | 4400 | 41 | 370 | 310 |
| H00G | 1400 | 16 | 80 | 50 |
| H00H | 1400 | 16 | 80 | 100 |
| H00I | 900 | 12 | 80 | 70 |
| H00J | 700 | 10 | 70 | 70 |
| H00K | 1000 | 13 | 60 | 70 |
| H00L | 1000 | 13 | 70 | 80 |

Table 2, cont.

| Grid Location | NaI Count Rate (c/min) | Exposure Rate (uR/hr) | Beta-Gamma Count Rate w/window (c/min) | Beta-Gamma Count Rate w/o window (c/min) |
|---|---|---|---|---|
| H00M | 800 | 11 | 60 | 80 |
| H00N | 800 | 11 | 40 | 40 |
| H00O | 700 | 10 | 30 | 30 |
| H00P | 700 | 10 | 50 | 50 |
| H00Q | 600 | 9 | 30 | 30 |
| H00R | 600 | 9 | 50 | 60 |
| I00A | 900 | 12 | 60 | 90 |
| I00B | 1000 | 13 | 100 | 80 |
| I00C | 1100 | 14 | 150 | 100 |
| I00D | 1500 | 17 | 70 | 120 |
| I00E | 2300 | 24 | 190 | 270 |
| I00F | 3500 | 33 | 220 | 180 |
| I00G | 3800 | 36 | 220 | 260 |
| I00H | 3000 | 29 | 150 | 180 |
| I00I | 1700 | 18 | 100 | 110 |
| I00J | 1300 | 15 | 130 | 90 |
| I00K | 1100 | 14 | 80 | 100 |
| I00L | 900 | 12 | 80 | 90 |
| I00M | 800 | 11 | 80 | 80 |
| I00N | 600 | 9 | 40 | 60 |
| I00O | 700 | 10 | 60 | 60 |
| I00P | 600 | 9 | 40 | 40 |
| I00Q | 700 | 10 | 60 | 50 |
| I00R | 700 | 10 | 40 | 50 |
| J00D | 1300 | 15 | 110 | 100 |
| J00E | 900 | 12 | 80 | 80 |
| J00F | 1000 | 13 | 80 | 60 |
| J00G | 1100 | 14 | 80 | 90 |
| J00H | 1400 | 16 | 60 | 60 |
| J00I | 1500 | 17 | 80 | 60 |
| J00J | 1400 | 16 | 130 | 120 |
| J00K | 1100 | 14 | 100 | 70 |
| J00L | 800 | 11 | 60 | 80 |
| J00M | 700 | 10 | 60 | 50 |
| J00N | 800 | 11 | 90 | 50 |
| J00O | 700 | 10 | 80 | 50 |
| J00P | 700 | 10 | 50 | 50 |
| J00Q | 800 | 11 | 60 | 70 |
| J00R | 800 | 11 | 50 | 40 |
| K00D | 1300 | 15 | 70 | 100 |
| K00E | 800 | 11 | 70 | 90 |
| K00F | 1000 | 13 | 70 | 50 |
| K00G | 2000 | 21 | 90 | 100 |
| K00H | 1100 | 14 | 90 | 90 |
| K00I | 900 | 12 | 100 | 60 |

Table 2, cont.

| Grid Location | NaI Count Rate (c/min) | Exposure Rate (uR/hr) | Beta-Gamma Count Rate w/window (c/min) | Beta-Gamma Count Rate w/o window (c/min) |
|---|---|---|---|---|
| K00J | 1000 | 13 | 90 | 70 |
| K00K | 800 | 11 | 60 | 60 |
| K00L | 1000 | 13 | 70 | 70 |
| K00M | 1000 | 13 | 70 | 50 |
| K00N | 800 | 11 | 50 | 50 |
| K00O | 800 | 11 | 60 | 60 |
| K00P | 700 | 10 | 60 | 70 |
| K00Q | 600 | 9 | 70 | 60 |
| K00R | 700 | 10 | 60 | 40 |
| L00D | 1200 | 14 | 110 | 80 |
| L00E | 1000 | 13 | 100 | 130 |
| L00F | 900 | 12 | 60 | 100 |
| L00G | 600 | 9 | 100 | 70 |
| L00H | 900 | 12 | 70 | 70 |
| L00I | 800 | 11 | 100 | 70 |
| L00J | 700 | 16 | 60 | 70 |
| L00K | 1200 | 14 | 90 | 90 |
| L00L | 900 | 12 | 70 | 60 |
| L00M | 800 | 11 | 90 | 70 |
| L00N | 900 | 12 | 60 | 80 |
| L00O | 900 | 12 | 60 | 80 |
| L00P | 700 | 10 | 60 | 50 |
| L00Q | 700 | 10 | 70 | 100 |
| L00R | 800 | 11 | 80 | 60 |
| M00E | 600 | 9 | 110 | 80 |
| M00F | 600 | 9 | 80 | 90 |
| M00G | 600 | 9 | 100 | 60 |
| M00H | 600 | 9 | 70 | 50 |
| M00I | 600 | 9 | 110 | 120 |
| M00J | 800 | 11 | 90 | 130 |
| M00K | 800 | 11 | 80 | 100 |
| M00L | 1000 | 13 | 120 | 100 |
| M00M | 1000 | 13 | 110 | 120 |
| N00E | 1200 | 14 | 120 | 150 |
| N00F | 700 | 10 | 130 | 120 |
| N00G | 700 | 10 | 110 | 100 |
| N00H | 600 | 9 | 130 | 130 |
| N00I | 700 | 10 | 140 | 180 |
| N00K | 900 | 12 | 90 | 80 |
| N00L | 900 | 12 | 90 | 80 |
| N00M | 1000 | 13 | 100 | 160 |
| O00E | 1500 | 17 | 190 | 140 |
| O00F | 8000 | 71 | 700 | 600 |
| O00G | 700 | 10 | 150 | 190 |
| O00H | 800 | 11 | 120 | 170 |

Table 2, cont.

| Grid Location | NaI Count Rate (c/min) | Exposure Rate (uR/hr) | Beta-Gamma Count Rate w/window (c/min) | Beta-Gamma Count Rate w/o window (c/min) |
|---|---|---|---|---|
| O00I | 700 | 10 | 130 | 170 |
| O00J | 800 | 11 | 140 | 130 |
| O00K | 600 | 9 | 100 | 70 |
| O00L | 900 | 12 | 160 | 180 |
| P00E | 800 | 11 | 110 | 160 |
| P00F | 800 | 11 | 130 | 90 |
| P00G | 700 | 10 | 70 | 120 |
| P00H | 600 | 9 | 110 | 70 |
| P00I | 700 | 10 | 60 | 90 |
| P00J | 700 | 10 | 90 | 70 |
| P00K | 800 | 11 | 160 | 140 |
| P00L | 900 | 12 | --- | --- |
| Q00E | 800 | 11 | 130 | 160 |
| Q00F | 700 | 10 | 140 | 180 |
| Q00G | 800 | 11 | 170 | 190 |
| Q00H | 800 | 11 | 170 | 130 |
| Q00I | 800 | 11 | 160 | 180 |
| Q00J | 700 | 10 | 180 | 180 |
| Q00K | 800 | 11 | 160 | 170 |
| Q00L | 1200 | 14 | --- | --- |
| R00E | 700 | 10 | 130 | 130 |
| R00F | 800 | 11 | 106 | 110 |
| R00G | 800 | 11 | 110 | 120 |
| R00H | 800 | 11 | 120 | 100 |
| R00I | 800 | 11 | 130 | 180 |
| R00J | 800 | 11 | 130 | 120 |
| R00K | 800 | 11 | 120 | 160 |
| R00L | 800 | 11 | --- | --- |
| S00E | 800 | 11 | --- | --- |
| S00F | 900 | 12 | 140 | 120 |
| S00G | 900 | 12 | 110 | 160 |
| S00H | 700 | 10 | 150 | 160 |
| S00I | 800 | 11 | 100 | 160 |
| S00J | 800 | 11 | 120 | 130 |
| S00K | 900 | 12 | 120 | 100 |
| S00L | 700 | 10 | --- | --- |

Table 3

Surface soil sample radionuclide concentration, by gamma analysis
pCi/g +/- % error

| Sample | Location | Mass | U-238 | U-235 | Ac-228 | Pb-212 | Pb-214 | Bi-214 | K-40 |
|---|---|---|---|---|---|---|---|---|---|
| 1 | H00F | 148 | 8.3E1+/-10 | 9.2E0+/-24 | 2.9E1+/-11 | 2.4E1+/-5 | 8.1E-1+/-73 | 4.6E-1+/-110 | 5.7E0+/-75 |
| 2 | K52D | 251 | 5.4E3+/-1 | 5.8E1+/-6 | 5.2E0+/-28 | 3.1E0+/-21 | 3.9E-1+/-170 | 7.3E-1+/-72 | 3.2E0+/-74 |
| 3 | K52D | 248 | 8.7E3+/-1 | 9.1E1+/-5 | 8.4E0+/-23 | 7.9E0+/-14 | 1.1E0+/-94 | -5.9E-1+/-150 | 2.3E0+/-120 |
| 4 | K52D (1) | 44 | 1.7E4+/-1 | 2.0E2+/-7 | 4.8E0+/-87 | 2.0E0+/-100 | 1.8E0+/-140 | 1.0E0+/-240 | 1.1E1+/-98 |
| 5 | 000F (2) | 218 | 2.1E1+/-20 | 2.6E-1+/-360 | 1.4E1+/-14 | 1.2E1+/-6 | 7.6E-1+/-48 | 6.7E-1+/-60 | 2.8E0+/-90 |
| 6 | K52D | 212 | 6.7E3+/-1 | 7.0E1+/-6 | 4.9E0+/-31 | 5.4E0+/-15 | 1.0E0+/-89 | 4.0E-1+/-190 | 3.1E0+/-94 |
| 7 | K52D | 228 | 9.1E3+/-1 | 9.4E1+/-1 | 6.7E0+/-28 | 3.8E0+/-22 | 6.2E-1+/-120 | 7.1E-1+/-110 | 3.5E0+/-90 |
| 8 | 000F (2) | 174 | 2.3E1+/-20 | 1.3E0+/-86 | 1.4E1+/-15 | 1.4E1+/-6 | 4.0E-1+/-98 | 4.5E-1+/-87 | 4.1E0+/-81 |
| 9 | H00F | 157 | 1.1E2+/-9 | 1.2E1+/-21 | 4.5E1+/-9 | 4.7E1+/-3 | 7.7E-1+/-83 | 4.2E-1+/-140 | 9.9E0+/-46 |
| 10 | H38E | 232 | 1.1E2+/-7 | 9.8E0+/-17 | 2.5E1+/-10 | 2.4E1+/-4 | 6.1E-1+/-71 | 5.8E-1+/-67 | 4.5E0+/-60 |
| 11 | H38E | 192 | 1.3E2+/-7 | 1.2E1+/-17 | 2.9E1+/-10 | 2.8E1+/-4 | 6.1E-1+/-85 | 5.6E-1+/-93 | 7.4E-1+/-47 |
| 12 | Offsite | 235 | 4.9E-1+/-370 | -5.7E-2+/-1000 | 8.1E-1+/-82 | 4.6E-1+/-48 | 6.3E-1+/-49 | 5.1E-1+/-55 | 3.9E0+/-62 |
| 13 | Offsite | 135 | 6.8E-1+/-390 | 7.7E-3+/-1460 | 2.2E0+/-57 | 9.2E-1+/-47 | 9.4E-1+/-54 | 6.0E-1+/-76 | 9.1E0+/-52 |
| 14 | S55N | 223 | 4.8E-1+/-330 | -1.2E-1+/-480 | 5.7E-1+/-110 | 4.2E-1+/-54 | 4.5E-1+/-64 | 5.1E-1+/-58 | 4.9E0+/-54 |
| 15 | M00X | 205 | 2.1E0+/-92 | 8.0E-2+/-500 | 8.0E-1+/-89 | 7.1E-1+/-37 | 1.8E-1+/-160 | 2.4E-1+/-110 | 3.8E0+/-70 |
| 16 | 151M (3) | 235 | 9.9E-1+/-160 | -5.3E-3+/-1200 | 6.2E-1+/-95 | 3.0E-1+/-66 | 4.2E-1+/-67 | 2.6E-1+/-95 | 5.7E0+/-47 |

(1) Rock sample
(2) Bore hole #10 location
(3) Bore hole #15 location

Table 4

Bore hole *in situ* gamma analyses
pCi/g +/- % error

Bore hole #1

| Depth | U-238 | U-235 | Pb-214 | Bi-214 | Ac-228 | K-40 |
|---|---|---|---|---|---|---|
| 0 | 1.2E0+/-123 | 1.1E-1+/-650 | 1.7E-1+/-87 | 2.5E-1+/-40 | 4.4E-1+/-45 | 3.9E0+/-19 |
| 2 | 1.7E0+/-114 | 3.0E-1+/-255 | 5.9E-1+/-241 | 1.1E-1+/-85 | 4.5E-1+/-43 | 3.7E0+/-21 |
| 4 | -1.3E0+/-150 | 3.6E-1+/-222 | 5.1E-1+/-34 | 4.9E-1+/-27 | 9.0E-1+/-29 | 8.6E0+/-13 |
| 6 | 1.2E0+/-170 | -1.1E-1+/-732 | 2.7E-1+/-61 | 4.1E-1+/-30 | 9.9E-1+/-26 | 6.8E0+/-15 |

Bore hole #2

| Depth | U-238 | U-235 | Pb-214 | Bi-214 | Ac-228 | K-40 |
|---|---|---|---|---|---|---|
| 0 | 8.8E-1+/-143 | 4.6E-1+/-138 | 3.1E-1+/-47 | 3.7E-1+/-31 | 5.3E-1+/-40 | 4.4E0+/-19 |
| 2 | 6.0E-1+/-235 | -1.8E-2+/-2200 | 1.2E0+/-16 | 8.6E-1+/-18 | 9.0E-1+/-29 | 6.5E0+/-15 |
| 4 | 0.0E-1+/-1000 | 5.9E-2+/-1120 | 9.3E-1+/-19 | 9.5E-1+/-15 | 7.5E-1+/-29 | 4.1E0+/-21 |
| 6 | 6.0E-1+/-211 | 8.8E-2+/-745 | 1.1E0+/-17 | 8.2E-1+/-16 | 6.2E-1+/-32 | 3.7E0+/-21 |
| 8 | 3.6E-1+/-343 | 2.5E-2+/-266 | 4.7E-1+/-36 | 4.9E-1+/-25 | 6.9E-1+/-30 | 5.4E0+/-17 |
| 10 | 6.0E-1+/-203 | 1.1E-1+/-588 | 4.2E-1+/-37 | 4.3E-1+/-26 | 6.1E-1+/-36 | 5.2E0+/-17 |
| 12 | -2.0E-1+/-675 | -1.6E-1+/-423 | 4.6E-1+/-35 | 5.0E-1+/-23 | 5.4E-1+/-43 | 8.1E0+/-13 |
| 14 | 1.5E0+/-95 | 3.6E-1+/-200 | 4.8E-1+/-33 | 5.1E-1+/-25 | 7.4E-1+/-32 | 7.5E0+/-14 |
| 16 | 3.2E-1+/-462 | 4.4E-1+/-165 | 6.0E-1+/-30 | 6.6E-1+/-21 | 7.5E-1+/-35 | 9.7E0+/-12 |

Bore hole #3

| Depth | U-238 | U-235 | Pb-214 | Bi-214 | Ac-228 | K-40 |
|---|---|---|---|---|---|---|
| 0 | 1.3E0+/-154 | 1.1E0+/-74 | 9.4E-2+/-150 | 9.9E-2+/-91 | 2.9E-1+/-61 | 2.1E0+/-31 |
| 2 | 3.8E-1+/-305 | -1.5E-1+/-412 | 2.8E-1+/-55 | 2.0E-1+/-52 | 6.8E-1+/-31 | 3.5E0+/-22 |
| 4 | 2.5E-1+/-493 | 4.0E-1+/-161 | 4.0E-1+/-41 | 2.2E-1+/-54 | 5.3E-1+/-40 | 5.2E0+/-17 |
| 6 | 8.0E-2+/-1540 | -5.7E-1+/-116 | 3.5E-1+/-47 | 2.9E-1+/-40 | 3.8E-1+/-58 | 5.2E0+/-18 |
| 8 | -5.6E-1+/-270 | 1.5E-1+/-471 | 2.7E-1+/-63 | 4.1E-1+/-32 | 2.9E-1+/-79 | 7.9E0+/-14 |

Table 4, cont.

Bore hole #5

| Depth | U-238 | U-235 | Pb-214 | Bi-214 | Ac-228 | K-40 |
|---|---|---|---|---|---|---|
| 0 | 1.1E0+/-133 | 8.8E-2+/-699 | 1.4E-1+/-98 | 1.0E-1+/-92 | 4.0E-1+/-44 | 2.9E0+/-245 |
| 2 | 5.5E-1+/-210 | 3.5E-2+/-1770 | 3.0E-1+/-51 | 3.0E-1+/-34 | 5.6E-1+/-36 | 3.0E0+/-24 |
| 4 | 2.4E-1+/-514 | 2.5E-1+/-249 | 4.3E-1+/-37 | 5.2E-1+/-24 | 7.9E-1+/-29 | 5.8E0+/-16 |
| 6 | 2.0E-2+/-791 | 1.6E-1+/-436 | 8.5E-1+/-23 | 5.6E-1+/-26 | 7.1E-1+/-37 | 1.2E1+/-11 |

Bore hole #6

| Depth | U-238 | U-235 | Pb-214 | Bi-214 | Ac-228 | K-40 |
|---|---|---|---|---|---|---|
| 0 | 1.4E0+/-126 | 3.2E-1+/-267 | 2.1E-1+/-79 | 1.6E-1+/-73 | 1.6E0+/-20 | 3.8E0+/-20 |
| 1 | 2.9E-1+/-564 | 3.9E-1+/-211 | 4.4E-1+/-43 | 5.7E-1+/-25 | 1.8E0+/-18 | 6.1E0+/-16 |
| 3 | 9.0E-2+/-1480 | 1.9E-1+/-335 | 4.3E-1+/-38 | 5.1E-1+/-26 | 1.0E0+/-25 | 5.9E0+/-16 |
| 5 | 1.4E-1+/-728 | -5.0E-1+/-120 | 3.8E-2+/-365 | 2.1E-1+/-47 | 2.6E-1+/-68 | 2.5E0+/-27 |
| 7 | 7.0E-2+/-1750 | 5.1E-1+/-128 | 2.2E-1+/-68 | 4.2E-1+/-29 | 9.3E-1+/-25 | 4.6E0+/-19 |
| 9 | 1.1E0+/-87 | 3.4E-1+/-225 | 5.5E-1+/-32 | 5.6E-1+/-24 | 1.2E0+/-23 | 7.8E0+/-14 |

Bore hole #8

| Depth | U-238 | U-235 | Pb-214 | Bi-214 | Ac-228 | K-40 |
|---|---|---|---|---|---|---|
| 2 | 5.2E-1+/-267 | 1.7E-1+/-389 | 5.6E-1+/-29 | 2.5E-1+/-48 | 1.2E0+/-22 | 7.5E0+/-14 |
| 4 | 1.1E-1+/-1070 | 3.5E-2+/-1720 | 2.7E-1+/-56 | 2.9E-1+/-39 | 3.7E-1+/-48 | 4.2E0+/-19 |
| 6 | 1.4E0+/-95 | 1.8E-2+/-3770 | 5.1E-1+/-32 | 4.8E-1+/-26 | 7.2E-1+/-30 | 7.3E0+/-14 |
| 8 | 7.1E-1+/-206 | 1.8E-2+/-3970 | 2.5E-1+/-64 | 2.7E-1+/-43 | 8.7E-1+/-28 | 1.2E1+/-11 |
| 10 | 2.5E-1+/-591 | 3.6E-1+/-199 | 4.5E-1+/-39 | 2.4E-1+/-50 | 8.8E-1+/-29 | 1.7E1+/-9 |
| 14 | 9.7E-1+/-182 | 9.4E-2+/-806 | 6.9E-1+/-27 | 4.4E-1+/-30 | 4.4E-1+/-55 | 1.5E1+/-10 |

Table 4, cont.

Bore hole #10

| Depth | U-238 | U-235 | Pb-214 | Bi-214 | Ac-228 | K-40 |
|---|---|---|---|---|---|---|
| 0 | 3.9E1+/-15 | 6.1E-1+/-486 | 1.2E-1+/-542 | 9.3E-1+/-49 | 7.1E1+/-3 | 2.6E0+/-78 |
| 1 | 4.2E1+/-22 | 2.2E0+/-196 | 6.6E-1+/-160 | 9.3E-1+/-75 | 1.0E2+/-2 | 1.1E1+/-26 |
| 2 | 1.1E2+/-9 | -2.7E0+/-145 | 2.1E-1+/-354 | 2.8E-1+/-202 | 8.7E1+/-3 | 1.6E0+/-116 |
| 3 | 1.6E2+/-4 | 3.1E0+/-84 | 1.9E-1+/-297 | 2.6E-2+/-1400 | 3.1E1+/-5 | 4.4E0+/-370 |
| 4 | 8.5E0+/-43 | 1.0E0+/-163 | 1.1E-1+/-324 | 1.1E-1+/-252 | 2.1E1+/-5 | 2.7E0+/-39 |
| 5 | 5.6E0+/-68 | 8.4E-1+/-165 | 1.9E-1+/-157 | 7.1E-1+/-36 | 2.4E1+/-6 | 4.1E0+/-26 |
| 6 | 2.5E1+/-20 | 9.0E-1+/-224 | 1.2E-2+/-3410 | 6.9E-2+/-434 | 4.6E1+/-3 | 3.5E0+/-37 |
| 7 | 1.9E1+/-27 | 6.2E-1+/-328 | 3.6E-1+/-123 | 9.6E-2+/-311 | 4.5E1+/-3 | 6.4E0+/-21 |
| 8 | 9.4E0+/-39 | 1.8E0+/-92 | 3.9E-1+/-87 | 6.1E-1+/-42 | 3.2E1+/-4 | 8.4E0+/-15 |
| 9 | 1.5E1+/-35 | 3.6E0+/-65 | 8.0E-1+/-66 | 6.8E-1+/-45 | 6.0E1+/-3 | 8.5E0+/-18 |
| 11 | 6.6E0+/-64 | 4.3E-1+/-457 | 5.1E-1+/-89 | 2.6E-1+/-107 | 3.5E1+/-4 | 1.4E1+/-11 |
| 13 | 3.6E-1+/-449 | 5.8E-3+/-1400 | 5.3E-1+/-40 | 4.7E-1+/-31 | 2.0E0+/-18 | 1.2E1+/-11 |
| 15 | 7.9E-1+/-223 | 5.9E-3+/-1500 | 6.4E-1+/-32 | 2.8E-1+/-50 | 2.7E0+/-15 | 1.3E1+/-11 |
| 17 | 1.3E0+/-127 | 3.2E-1+/-256 | 9.5E-1+/-33 | 2.8E-1+/-50 | 2.5E0+/-15 | 1.4E1+/-10 |

Bore hole #11

| Depth | U-238 | U-235 | Pb-214 | Bi-214 | Ac-228 | K-40 |
|---|---|---|---|---|---|---|
| 0 | 3.4E0+/-58 | 1.7E-1+/-448 | 2.5E-1+/-70 | 7.3E-2+/-138 | 1.2E0+/-22 | 3.3E0+/-22 |
| 2 | 1.1E-1+/-1190 | 3.2E-1+/-200 | 2.0E-1+/-77 | 3.3E-1+/-33 | 5.9E-1+/-36 | 3.9E0+/-20 |
| 4 | 3.0E-2+/-3810 | 1.6E-1+/-367 | 1.6E-1+/-90 | 1.7E-1+/-56 | 4.1E-1+/-45 | 3.5E0+/-22 |
| 6 | 1.2E0+/-108 | 7.6E-2+/-854 | 1.9E-1+/-80 | 1.5E-1+/-64 | 4.0E-1+/-49 | 6.5E0+/-15 |
| 8 | 9.8E-1+/-123 | 7.6E-1+/-82 | 2.1E-1+/-69 | 5.0E-2+/-188 | 1.6E-1+/-99 | 6.1E0+/-15 |
| 10 | 7.2E-1+/-186 | 5.3E-2+/-1280 | 1.1E-1+/-137 | 2.5E-1+/-43 | 6.9E-1+/-32 | 1.6E1+/-9 |
| 12 | 8.0E-1+/-181 | 3.3E-1+/-224 | 4.7E-1+/-35 | 4.9E-1+/-26 | 8.9E-1+/-31 | 2.1E1+/-8 |
| 14 | 1.2E0+/-133 | -5.0E-1+/-152 | 3.7E-1+/-51 | 3.3E-1+/-35 | 6.0E-1+/-40 | 2.0E1+/-8 |
| 16 | -3.6E-1+/-466 | -4.8E-1+/-156 | 2.8E-1+/-61 | 3.3E-1+/-38 | 3.5E-1+/-68 | 2.1E1+/-8 |

Table 4, cont.

Bore hole #13

| Depth | U-238 | U-235 | Pb-214 | Bi-214 | Ac-228 | K-40 |
|---|---|---|---|---|---|---|
| 0 | 1.0E0+/-149 | 2.2E-1+/-337 | 5.0E-2+/-320 | 3.0E-2+/-349 | 1.3E0+/-22 | 3.2E0+/-22 |
| 2 | 4.2E-1+/-309 | 2.4E-1+/-264 | 3.2E-1+/-48 | 1.6E-1+/-68 | 6.4E-1+/-36 | 6.7E0+/-14 |
| 4 | 6.3E-1+/-202 | 1.5E0+/-43 | 3.1E-1+/-51 | 2.5E-1+/-43 | 4.5E-1+/-52 | 6.5E0+/-15 |
| 6 | 7.0E-2+/-1990 | 1.6E-1+/-398 | 2.6E-1+/-64 | 2.1E-1+/-54 | 5.7E-1+/-41 | 8.4E0+/-13 |
| 8 | 1.0E-2+/-1340 | 4.7E-1+/-149 | 3.8E-1+/-47 | 2.9E-1+/-41 | 6.8E-1+/-40 | 8.9E0+/-13 |
| 10 | 1.9E-1+/-711 | 3.03-1+/-233 | 4.0E-1+/-44 | 1.6E-1+/-76 | 6.8E-1+/-37 | 1.2E1+/-10 |

Bore hole #15

| Depth | U-238 | U-235 | Pb-214 | Bi-214 | Ac-228 | K-40 |
|---|---|---|---|---|---|---|
| 0 | 1.5E1+/-28 | 4.0E1+/-6 | 3.1E-2+/-856 | 1.8E-2+/-96 | 1.3E1+/-6 | 3.9E0+/-25 |
| 2 | 8.5E0+/-30 | 1.4E1+/-9 | 2.4E-1+/-79 | 3.6E-1+/-50 | 5.0E0+/-11 | 5.8E0+/-19 |
| 4 | 3.5E0+/-84 | 9.2E0+/-19 | 2.0E-1+/-113 | 1.1E-1+/-153 | 4.8E0+/-11 | 7.3E0+/-16 |
| 5 | 9.8E0+/-49 | 2.2E1+/-13 | 1.8E-1+/-195 | 1.1E-1+/-227 | 1.6E1+/-6 | 6.4E0+/-20 |
| 6 | 8.1E0+/-54 | 2.0E1+/-12 | 1.1E-1+/-266 | 9.6E-2+/-178 | 6.6E0+/-10 | 5.4E0+/-20 |
| 7 | 5.5E0+/-47 | 1.3E1+/-11 | 1.1E-1+/-169 | 1.4E-1+/-87 | 2.0E0+/-19 | 3.6E0+/-24 |
| 8 | 3.9E0+/-58 | 7.1E0+/-15 | 2.4E-1+/-73 | 3.1E-1+/-43 | 1.2E0+/-25 | 4.3E0+/-21 |
| 9 | 8.9E0+/-25 | 5.6E-1+/-171 | 1.1E-1+/-177 | 1.2E-1+/-124 | 3.4E0+/-31 | 8.6E0+/-15 |
| 10 | 1.7E0+/-99 | 2.7E0+/-34 | 4.5E-1+/-42 | 5.9E-1+/-24 | 1.4E0+/-23 | 7.6E0+/-14 |
| 12 | 4.8E-1+/-263 | 4.23-1+/-157 | 3.9E-1+/-48 | 2.4E-1+/-52 | 7.3E-1+/-40 | 1.3E1+/-11 |

Bore hole #16

| Depth | U-238 | U-235 | Pb-214 | Bi-214 | Ac-228 | K-40 |
|---|---|---|---|---|---|---|
| 0 | 3.8E1+/-16 | 1.8E0+/-139 | 6.1E-1+/-97 | 2.9E-1+/-134 | 7.5E0+/-26 | 5.2E0+/-35 |
| 1 | 6.5E0+/-47 | 1.9E-1+/-585 | 3.1E-3+/-873 | 2.1E-2+/-81 | 5.7E0+/-10 | 5.4E0+/-21 |
| 2 | 1.1E0+/-133 | -2.6E-1+/-275 | 2.0E-1+/-87 | 9.6E-2+/-144 | 2.4E0+/-15 | 5.0E0+/-18 |
| 3 | 1.0E-2+/-1340 | 7.1E-2+/-954 | 3.4E-1+/-51 | 3.4E-1+/-38 | 1.3E0+/-22 | 4.3E0+/-20 |
| 5 | 3.6E0+/-52 | 2.6E-1+/-175 | 1.7E-1+/-99 | 1.3E-2+/-976 | 1.4E0+/-25 | 3.8E0+/-21 |

Table 5

Soil core sample radionuclide concentrations, by gamma analysis
pCi/g +/-% error

Bore hole 6

| Depth (ft) | U-238 | U-235 | Pb-214 | Bi-214 | Pb-212 | Ac-228 | K-40 |
|---|---|---|---|---|---|---|---|
| 0 | 6.1E0+/-30 | 1.2E0+/-68 | 1.8E-1+/-159 | 3.4E-1+/-92 | 1.6E0+/-22 | 2.1E0+/-46 | 4.3E0+/-76 |
| 1 | 5.9E-1+/-317 | 4.9E-2+/-1440 | 5.4E+/-55 | 7.6E-1+/-44 | 3.6E-1+/-68 | 6.2E-1+/-102 | 4.0E0+/-69 |
| 2 | 6.8E-1+/-138 | 4.6E-1+/-114 | 2.3E-1+/-91 | 1.5E-1+/-157 | 3.1E-1+/-60 | 5.8E-1+/-98 | 4.8E0+/-48 |
| 3 | 3.6E-1+/-390 | 6.2E-2+/-889 | 1.6E-1+/-112 | 1.4E-1+/-163 | 7.8E-2+/-247 | 7.2E-2+/-565 | 2.2E0+/-91 |
| 4 | 1.9E-1+/-458 | 3.1E-1+/-173 | 2.0E-1+/-113 | 2.5E-1+/-90 | 3.8E-1+/-52 | 4.0E-1+/-132 | 2.4E0+/-91 |
| 5 | 3.7E-1+/-250 | 2.6E-1+/-211 | 4.6E-1+/-47 | 2.5E-1+/-91 | -2.1E-2+/-2552 | 6.7E-1+/-77 | 3.4E0+/-134 |
| 6 | 1.1E0+/-103 | 5.8E-1+/-331 | 5.5E-1+/-64 | 2.0E-1+/-165 | 2.0E-2+/-944 | 2.2E-1+/-271 | 2.3E0+/-128 |
| 7 | 3.5E-1+/-266 | 5.7E-1+/-94 | 2.3E-1+/-96 | 3.2E-1+/-70 | 2.1E-1+/-81 | 2.2E-1+/-227 | 5.8E0+/-44 |
| 8 | 9.9E-1+/-115 | 1.1E-1+/-559 | 3.1E-1+/-87 | 3.9E-1+/-70 | 4.4E-1+/-50 | 5.5E-1+/-109 | 3.5E0+/-69 |
| 9 | 9.9E-1+/-167 | 2.1E-1+/-276 | 3.8E-1+/-83 | 6.5E-1+/-44 | 5.9E-1+/-40 | 4.4E-1+/-140 | 6.7E0+/-44 |
| 10 | 4.1E-1+/-295 | 1.0E-1+/-450 | 3.9E-1+/-75 | 3.1E-1+/-93 | 3.2E-1+/-74 | 6.3E-1+/-95 | 1.2E1+/-32 |
| 11 | 9.6E-1+/-132 | 4.1E-1+/-171 | 3.5E-1+/-66 | 2.9E-1+/-82 | 4.2E-1+/-49 | 7.0E-1+/-78 | 1.0E1+/-33 |

Bore hole 8

| Depth (ft) | U-238 | U-235 | Pb-214 | Bi-214 | Pb-212 | Ac-228 | K-40 |
|---|---|---|---|---|---|---|---|
| 0 | 1.7E0+/-103 | 1.4E-1+/-709 | 7.9E-1+/-49 | 5.2E-1+/-74 | 1.1E-1+/-259 | 6.3E-1+/-126 | 2.9E0+/-115 |
| 2 | 6.6E-1+/-144 | 5.2E-1+/-104 | 3.9E-1+/-64 | 3.0E-1+/-82 | 2.1E-1+/-93 | 2.1E-1+/-250 | 1.3E0+/-154 |
| 3 | 5.7E-2+/-2099 | 9.0E-1+/-559 | 1.6E-1+/-111 | 1.4E-1+/-136 | 1.3E-1+/-126 | 5.6E-1+/-93 | 1.2E0+/-148 |
| 4 | 4.8E0+/-49 | 1.2E0+/-64 | 1.6E-1+/-171 | 2.6E-1+/-125 | 8.2E-2+/-257 | 7.3E-1+/-87 | 2.0E0+/-127 |
| 5 | 1.0E1+/-40 | 2.0E0+/-65 | 2.1E-1+/-206 | 1.7E-1+/-260 | 1.7E-1+/-219 | -1.1E-1+/-871 | 1.1E1+/-50 |
| 6 | 1.8E-1+/-1180 | 1.0E-1+/-450 | 7.7E-1+/-47 | 2.2E-1+/-150 | 3.4E-1+/-80 | 1.5E-1+/-424 | 3.1E0+/-97 |
| 7 | 4.0E-1+/-439 | 1.9E-1+/-352 | 3.3E-1+/-85 | 1.5E-1+/-164 | 2.6E-1+/-85 | 1.1E0+/-63 | 5.3E0+/-55 |
| 8 | 4.3E-1+/-327 | 4.7E-1+/-96 | 2.7E-1+/-86 | 3.4E-1+/-73 | 6.1E-1+/-34 | 8.1E-1+/-60 | 1.0E1+/-29 |
| 10 | 1.2E0+/-71 | 1.3E-1+/-340 | 3.9E-1+/-58 | 3.3E-1+/-72 | 3.9E-1+/-50 | 6.6E-1+/-85 | 1.2E1+/-27 |
| 12 | 3.9E-1+/-337 | 2.8E-1+/-160 | 2.5E-1+/-85 | 3.7E-1+/-57 | 4.4E-1+/-44 | 6.1E-1+/-87 | 1.0E1+/-28 |
| 14 | 1.0E0+/-140 | 3.1E-1+/-289 | 6.6E-1+/-56 | 5.1E-1+/-75 | 2.3E-1+/-118 | 5.3E-1+/-169 | 1.4E1+/-34 |
| 16 | 2.0E-1+/-154 | 1.7E-1+/-769 | 7.6E-1+/-71 | 2.5E-1+/-205 | 1.3E-1+/-289 | 5.8E-1+/-165 | 1.7E1+/-39 |

Table 5, cont.

Bore hole 10

| Depth (ft) | U-238 | U-235 | Pb-214 | Bi-214 | Pb-212 | Ac-228 | K-40 |
|---|---|---|---|---|---|---|---|
| 0 | 6.5E1+/-9 | 5.6E0+/-42 | 5.0E-1+/-146 | 2.2E0+/-43 | 9.8E1+/-2 | 1.2E2+/-4 | 1.2E1+/-36 |
| 1 | 1.2E3+/-2 | 3.6E1+/-3 | 3.7E0+/-136 | 3.2E0+/-154 | 2.4E3+/-1 | 1.6E3+/-2 | 1.6E1+/-8 |
| 2 | 3.1E1+/-13 | 1.1E0+/-78 | 4.8E-1+/-52 | 6.4E-1+/-53 | 3.2E0+/-12 | 3.4E0+/-31 | 6.3E-1+/-258 |
| 3 | 1.7E1+/-12 | 6.4E-1+/-280 | 3.9E-1+/-70 | 2.6E-1+/-98 | 6.2E-1+/-37 | 5.9E-1+/-105 | 1.7E0+/-125 |
| 4 | 2.7E1+/-10 | 1.3E0+/-60 | 1.7E-1+/-134 | 4.9E-1+/-52 | 1.2E0+/-21 | 3.9E-1+/-132 | 4.3E0+/-60 |
| 5 | 1.7E1+/-17 | 3.7E-1+/-183 | 1.7E-1+/-139 | 3.0E-1+/-80 | 3.0E0+/-11 | 3.1E0+/-29 | 2.8E0+/-75 |
| 6 | 1.4E1+/-20 | 7.4E-1+/-94 | 9.0E-2+/-262 | 1.3E-1+/-135 | 2.0E0+/-12 | 3.3E0+/-28 | 2.2E0+/-87 |
| 7 | 4.3E0+/-59 | 6.2E-1+/-107 | 4.0E-1+/-60 | 4.3E-1+/-61 | 3.1E-1+/-65 | 6.2E-1+/-94 | 6.6E0+/-45 |

Bore hole 15

| Depth (ft) | U-238 | U-235 | Pb-214 | Bi-214 | Pb-212 | Ac-228 | K-40 |
|---|---|---|---|---|---|---|---|
| 0 | 8.1E-1+/-166 | 1.8E-1+/-246 | 1.9E-1+/-110 | 3.6E-1+/-61 | 3.6E-1+/-50 | 5.3E-1+/-86 | 1.1E1+/-28 |
| 1 | 9.4E-1+/-97 | 4.3E-1+/-111 | 5.4E-1+/-50 | 3.0E-1+/-79 | 5.2E-1+/-40 | 7.3E-1+/-80 | 1.6E0+/-115 |
| 2 | 1.0E0+/-114 | 1.1E0+/-54 | 2.9E-1+/-81 | 2.7E-1+/-94 | 5.4E-1+/-40 | 1.1E0+/-56 | 4.4E0+/-57 |
| 4 | 5.8E1+/-8 | 9.4E0+/-24 | 1.1E0+/-51 | 6.9E-1+/-92 | 5.3E1+/-3 | 6.4E1+/-6 | 1.3E1+/-32 |
| 6 | 9.8E0+/-23 | 1.4E-1+/-11 | 2.4E-1+/-86 | 1.2E-1+/-182 | 3.3E-1+/-62 | 8.1E-1+/-69 | 1.0E0+/-191 |
| 7 | 7.0E-1+/-138 | 3.1E-1+/-187 | 3.4E-1+/-74 | 2.8E-1+/-86 | 2.0E-1+/-97 | 5.5E-2+/-894 | 2.7E0+/-85 |

Table 6

In situ bore hole measurements vs core sample analyses

Bore hole 10
3 foot

| | In situ gamma spectroscopy (pCi/g) | Core sample gamma spectroscopy on site | Core sample gamma spectroscopy RMC labs | Core sample alpha spectroscopy (pCi/g) |
|---|---|---|---|---|
| U-238 | 1.6E2+/-4% | 2.3E1+/-14% | 0.0E0+/-00% | 3.1E1+/-35 |
| U-235 | 3.1E0+/-84% | 1.5E-1+/-454% | | 7.5E-1+/-19% |
| Pb-214 | 1.9E-1+/-297% | 3.9E-1+/-70% | | |
| Bi-214 | 2.6E-2+/-1400% | 2.6E-1+/-98% | | |
| Ac-228 | 3.1E1+/-5% | 5.9E-1+/-105% | | |
| K-40 | 4.4E0+/-370% | 1.7E0+/-125% | | |

Bore hole 15
4 foot

| | | | | |
|---|---|---|---|---|
| U-238 | 3.5E0+/-84% | 9.6E1+/-8% | | 3.8E1+/-10% |
| U-235 | 9.2E0+/-19% | 9.0E0+/-24% | | 7.0E0+/-14% |
| Pb-214 | 2.0E-1+/-113% | 1.1E0+/-51% | | |
| Bi-214 | 1.1E-1+/-153% | 6.9E-1+/-92% | | |
| Ac-228 | 4.8E0+/-11% | 6.4E1+/-6% | | |
| K-40 | 7.4E0+/-16% | 1.3E1+/-32% | | |

Bore hole 15
6 foot

| | | | | |
|---|---|---|---|---|
| U-238 | 8.1E0+/-54% | 1.5E1+/-25% | | 9.1E0+/-12% |
| U-235 | 2.0E1+/-12% | 1.1E0+/-13% | | 2.5E1+/-10% |
| Pb-214 | 1.1E-1+/-266% | 1.1E-1+/-211% | | |
| Bi-214 | 9.6E-2+/-178% | 1.2E-1+/-182% | | |
| Ac-228 | 6.6E0+/-10% | 4.7E-1+/-128% | | |
| K-40 | 5.4E0+/-20% | 1.0E0+/-191% | | |

Table 6, cont.

Bore hole 8
5 foot

| | In situ gamma spectroscopy (pCi/g) | Core sample gamma spectroscopy on site | Core sample gamma spectroscopy RMC labs | Core sample alpha spectroscopy (pCi/g) |
|---|---|---|---|---|
| U-238 | | 1.0E1+/-40% | | |
| U-235 | | 2.2E-1+/-644% | | |
| Pb-214 | | 2.1E-1+/-206% | (1) | (1) |
| Bi-214 | | 1.7E-1+/-260% | | |
| Ac-228 | | 1.1E-1+/-87% | | |
| K-40 | | 8.4E-1+/-346% | | |

Bore hole 10
1 foot

| | | | | |
|---|---|---|---|---|
| U-238 | 4.2E1+/-22% | 4.4E3+/-1% | | |
| U-235 | 2.2E0+/-196% | 5.0E1+/-5% | | |
| Pb-214 | 6.6E-1+/-160% | 2.6E0+/-21% | (1) | (1) |
| Bi-214 | 9.3E-1+/-75% | 6.8E0+/-13% | | |
| Ac-228 | 1.0E2+/-2% | 2.7E3+/-1% | | |
| K-40 | 1.1E1+/-26% | 1.6E1+/-8% | | |

Bore hole 10
4 foot

| | | | | |
|---|---|---|---|---|
| U-238 | 8.5E0+/-43% | 4.3E1+/-10% | | |
| U-235 | 1.0E0+/-113% | 5.8E-1+/-132% | | |
| Pb-214 | 1.1E-1+/-324% | 1.7E-1+/-134% | (1) | (1) |
| Bi-214 | 9.9E-2+/-252% | 4.9E-1+/-52% | | |
| Ac-228 | 2.1E1+/-5% | 3.9E-1+/-132% | | |
| K-40 | 2.7E0+/-39% | 4.3E0+/-60% | | |

(1) Analysis results not cocmplete in time for draft report. Results will be presented in final report.

Table 7

Water sample analyses

| Sample No. | Sample Location | Gross Alpha (pCi/l) | Gross Beta (pCi/l) |
|---|---|---|---|
| 1 | Martin Creek @ Banner Spring | -5.0E-1+/-270% | 3.3E0+/-120% |
| 2 | Martin Creek N of burial area | 8.3E-1+/-200% | 3.5E0+/-110% |
| 3 | Nolichucky River N of NFS site | 6.7E-1+/-250% | 2.7E0+/-150% |
| 4 | Nolichucky River S of NFS site | 2.0E-1+/-470% | 2.7E0+/-150% |
| 5 | Surface water D05L | 1.3E0+/-130% | 5.2E0+/-78% |
| 6 | Bore hole #7 6/3/82 | 5.0E-1+/-320% | 4.5E0+/-90% |
| 7 | Bore hole #4 6/3/82 | 2.0E-1+/-470% | 2.4E0+/-170% |
| 8 | Bore hole #12 6/3/82 | 1.3E0+/-130% | 3.4E0+/-120% |
| 9 | Bore hole #14 6/3/82 | 2.0E0+/-94% | 8.8E0+/-48% |
| 10 | Bore hole #9 6/3/82 | 3.3E0+/-63% | 1.6E1+/-28% |
| 11 | Bore hole #4 6/8/82 | 1.0+/-E0+/-150% | 8.8E0+/-48% |
| 12 | Bore hole #7 6/8/82 | -1.0E0+/-120% | 1.0E1+/-43% |
| 13 | Bore hole #12 6/8/82 | 2.5E0+/-79% | 7.9E0+/-53% |
| 14 | Bore hole #14 6/8/82 | 1.6E0+/-150% | 4.5E0+/-90% |
| 15 | Bore hole #14 6/11/82 | -3.3E-1+/-280% | 7.1E-1+/-210% |
| 16 | Bore hole #7 6/11/82 | -3.3E-1+/-280% | 5.2E-1+/-210% |
| 17 | Bore hole #4 6/11/82 | 1.0+/-E0+/-150% | 2.7E0+/-170% |
| 18 | Bore hole #12 6/11/82 | 5.0E-1+/-240% | 7.2E0+/-66% |

Table 8

Particulate high volume air samples, long lived activity

| Sample No. | Location | Gross Alpha (uCi/cu cm) | Gross Beta (uCi/cu cm) |
|---|---|---|---|
| 1 | J06L | 1.8E-15+/-240% | 1.1E-13+/-18% |
| 2 | 3 m N of BH #16 | 1.1E-13+/-15% | 1.2E-13+/-17% |
| 3 | 5 m E of BH #10 | 1.0E-14+/-61% | 1.0E-13+/-19% |

Table 9

Radon flux measurements

| Location | Rn-220 flux (pCi/m2.s) | Rn-222 flux (pCi/m2.s) |
|---|---|---|
| K52D | 4.2E1+/-100% | 3.5E-1+/-30% |
| H38E | 1.3E4+/-2% | 5.8E-1+/-25% |
| O00F | 4.0E2+/-14% | 2.0E-1+/-46% |
| H00F | 6.9E2+/-11% | 3.0E-1+/-34% |
| K52D | 2.6E1+/-330% | 3.6E-2+/-500% |
| I51M | 2.4E0+/-150% | 4.2E-1+/-24% |
| O00F | 7.5E1+/-100% | 1.1E-1+/-160% |
| Offsite | 2.6E1+/-220% | 1.3E-2+/-960% |

Table 10

Target criteria and measurement LLDs for NFS burial pits site.

Soil Contaminants

| Nuclide | Target Criteria | LLD |
|---|---|---|
| Ra-226 | 5pCi/g | 1pCi/g |
| Total U | 15pCi/g | 3pCi/g |
| U-238 | 30pCi/g | 6pCi/g |
| U-235 | 30pCi/g | 6pCi/g |
| Th-232 * | 5pCi/g | 1pCi/g |
| Th-230 | 15pCi/g | 3pCi/g |

Water and Airborne Contaminants

| Nuclide | Target Criteria | LLD |
|---|---|---|
| All | MPC Unrestricted | 20% MPC |
| Ra-226 (water) | 3E-8 uCi/ml | 6E-9 uCi/ml |

External Radiation

| Nuclide | Target Criteria | LLD |
|---|---|---|
| All | 20 uR/hr | 4 uR/hr |

* Th-232 in equilibrium with daughters

# APPENDIX I

## Radiological Survey Instruments and Methods

A. Portable Survey Instrument

The portable survey instruments used at the NFS burial pits site included two complete sets of Wm. B. Johnson & Associates equipment, which consist of battery operated rate meters, scalers and alpha, beta and gamma probes, and an Eberline PRS-1 ratemeter scaler and detectors. These systems (see Fig. I-1) are totally portable and can be used in the field for both measurements and sample counting.

The alpha probes use a ZnS(Ag) scintillation detector; the beta detector is a thin window (1.4mg/cm2 mica) GM tube, and the gamma detectors are NaI(Tl) crystals. The alpha and beta probes were calibrated with "NBS traceable" sources at the RMC calibration facility in Philadelphia and the gamma scintillator was cross-calibrated with a primary ionization chamber system, described below.

B. Ionization Chamber System

External gamma dose rates were accurately measured with the RMC constructed Tissue Equivalent Ionization Chamber System (Fig. I-2). This system consisted of a 16 liter tissue equivalent, gas filled ionization chamber (Shonka chamber), a Keithley vibrating capacitor electrometer, a printer and battery pack. It is capable of measuring dose rates at background levels to a precision

of a few percent.

Since this system is bulky and somewhat fragile, it is not as suited for extensive field measurements as a smaller, light-weight NaI(Tl) portable survey instrument. Therefore, the NaI(Tl) detector was used for the majority of the field gamma measurements. Since this detector's response is energy dependent, it cannot be used as a "micro R meter" unless it is initially calibrated for such use.

The calibration performed by RMC consisted of accurately measuring the exposure rate at several locations at the NFS burial pits site using the Tissue Equivalent Ionization Chamber, then recording NaI(Tl) measurements at the same location. In this manner a set of NaI(Tl) count-rate versus exposure rates were obtained and a uR/hr calibration factor established, as shown in Fig. I-3.

Due to the energy dependence of the NaI detector, this conversion factor will apply only to the radionuclides and geometries for which the calibrations were made. In the case of the NFS burial pits site, it is known that only naturally occurring nuclides uranium and thorium are likely to be present. Therefore, the conversion factor established at this site, will apply only to naturally occurring radionuclides distributed in soil.

C. Mobile Lab Gamma Analysis System

The mobile lab gamma analysis system (Fig. I-4) consists of a PGT 15% efficient (relative to a 3" x 3" NaI(Tl) crystal) intrinsic germanium (IG) detector, shield and Tennecomp TP-50 laboratory computer data acquisition module. The analysis system was calibrated for all counting geometries with an NBS supplied Eu-152 source.

Each count was analyzed by a computer program for determination of gamma energies and peak areas. All results were printed out immediately following analysis on-site, and data was stored on floppy discs for future analysis, as needed.

Typical LLDs for U-235 and U-238 in soil are 1 and 2 pCi/g, respectively.

D. Auger Hole Logging System

Detailed logging of selected auger holes was performed with the system shown in Fig. I-5. This system consists of a custom designed EG&G Ortec intrinsic germanium detector (10% eff) with a narrow dewar, coupled to a Tracor-Northern 1750 MCA used for data acquisition and initial field evaluations. Data was stored on a tape cassette recorder, then transferred to the lab computer system for final analysis. The entire system, including an NIM mo-

dule power supply with a bias power supply and amplifier, was powered in the field by a portable 5000 watt gasoline-driven generator.

The logging system was calibrated as described in Attachment 1. Field counting times were normally 10 minutes at each location. Typical LLDs for this system for a 10 minute count are 0.1 pCi/g for U-235 1 pCi/g for U-238, 0.2 pCi/g for Pb-212 and 0.1 for pCi/g Pb-214.

E. Alpha-Beta Counting System.

All particulate air samples and evaporated water samples were counted for gross alpha or beta activity on the Gamma Products low background gas flow proportional counter, shown in Fig. I-6. The system is automatic and can be programmed for a variety of counting parameters.

ATTACHMENT 1 TO APPENDIX I

# INTRINSIC GERMANIUM WELL LOG

## DETECTOR CALIBRATION

The intrinsic germanium detector was connected to the pulse height analysis system consisting of the following components:

Ortec Model 459 High Voltage Power Supply

Canberra 2011 Spectroscopy Amplifier

Tracor Northern 1750 MCA

Teletype Model 43 Printer

Gain and voltage supply settings were adjusted to obtain an energy spectrum of 0 to 2000 keV, which corresponds to approximately one keV per channel.

Calibration of the well logging system was performed using the calibration rig shown in Fig. I-7. This rig is constructed as a series of four concentric rings surrounding a six inch PVC casing. Each ring contains thin plastic tubes 1-1/4" diameter by 36" long. A set of "source rods" and "background rods" were prepared and loaded into these tubes in a variety of configurations for the various calibration and test counts.

The geometry of the rig is such that the distance from the center of the casing (or detector) to the center of the innermost ring is 3.75 inches, to the center of the second ring is 5.0 inches, to the center of the third ring is 6.25 inches, and to

the center of the fourth ring is 7.50 inches. All voids between tubes were filled with low background sand. It was determined that the ratio of source volume in each ring to the total ring area was about 0.6. Hence, when source rods were fully loaded into a given ring, the activity counted represented approximately 60% of the total area (volume) the detector viewed, and counts were adjusted accordingly.

Each source tube is a twelve inch high by one inch diameter tube filled with a material containing Eu-152. The source material was prepared by mixing the standard Eu-152 source solution with plaster of paris, at a constant ratio designed to give a uniform specific activity of 440 pCi/gram. Background rods were filled with "clean" plaster of paris. Plaster of paris was chosen because of its ease of handling, ability to uniformly distribute the source throughout the material, and its density, which approximates that of common soil. (Density of soil, 1.7-2.3 g/cubic cm; density of plaster, 1.5 g/cubic cm; density of sand, 1.4 g/cubic cm)

Four different configurations of source and blank tubes were used for the calibration. Source tubes were placed three high in one of the four concentric rings of the rig for each count while the balance of the rig was filled with blanks. These configurations correspond to the source material being a radial distance of 3.75, 5.00, 6.25 and 7.50 inches from the detector.

Each configuration was counted for 900 seconds, and the area under each of the eight major Eu-152 photopeaks determined for each count.

As a calibration check for the low energy U-238 photons, a second set of calibration rods containing Cd-109 (E =88 keV), was prepared and counted in a similar manner.

Calculation of counts per gamma per gram was determined by the following method (for the Eu-152 rods):

NCNTS/GAMMA/GRAM =

[NCNTS]/[(440pCi/g)(3.7E-2d/s/pCi)(900s)(ABUNDANCEgamma/d)]

For each gamma energy, the net counts/gamma/gram vs distance from the center of the detector was listed. These response curves were then plotted for each energy, for distances and activities which extend to zero net counts. This represents an "infinite" distance from the detector. Using these curves, the total counts from the detector to an infinite distance was calculated by integrating the area under the curve using Simpson's rule for approximating integrals. Of prime importance is the integral from 2 inches to infinity, since this is the area the detector will view when placed inside a four-inch PVC casing.

Finally, the integrated net count/gamma/gram, from two inches to infinity, was plotted vs energy, for each of the Eu-152

photons. With this efficiency curve, a specific activity in soil (pCi/gram) can be determined from a bore hole count, assuming the radionuclide can be identified and its gamma abundance determined. The calculation is:

SPECIFIC ACTIVITYpCi/gm(in soil) =

[NETCOUNTS]/[(ABUNDANCEgamma/dis)(2.22 dis/min/pCi)

(MINUTES COUNTED)(EFFICIENCYcounts/gamma/gm)]

This determination will be valid so long as the radioactive material is uniformly distributed to an "infinite" distance in soil, and the detector is in a four-inch PVC (or similar material) casing. Although soil should be at the surface of the casing, the data indicate that small voids will not produce significant errors in activity estimations.

Results of this calibration indicate that an "infinite" thickness in soil for a bore hole logging device is about 10 inches from the center of the detector. Thus, for a four-inch hole, gamma logging will only "see" activity out to about seven or eight inches from the hole. For low energies (e.g. 100 keV), 50 to 60% of the total activity seen is in the interval of two to four inches. For energies above 500 keV, this value is 40 to 50%. While this volume may not seem large, it represents several thousand (2000 to 4000) grams of soil, which is much larger than typical core samples, and is therefore more representative of the actual soil activity.

This calibration indicates that the sensitivity of the IG well logging system is such that the Ra-226 daughter Bi-214, as measured by the 47% abundant 609 keV peak, can be easily detected at one pCi/gram in soil, in a five minute count, with a 95% confidence level and precision of 0.4 pCi/g.

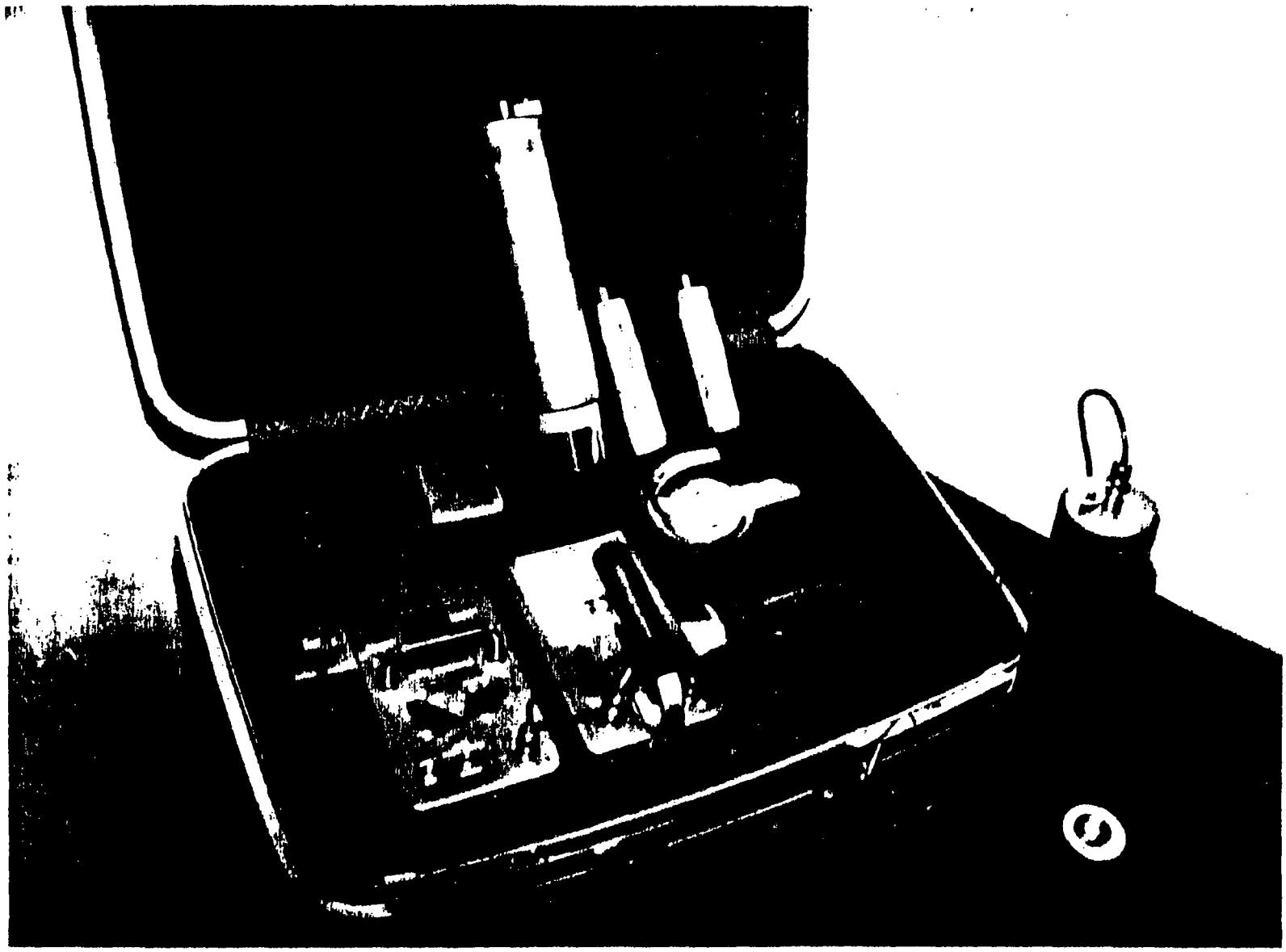

Fig. I-1. Portable survey instrument kit.

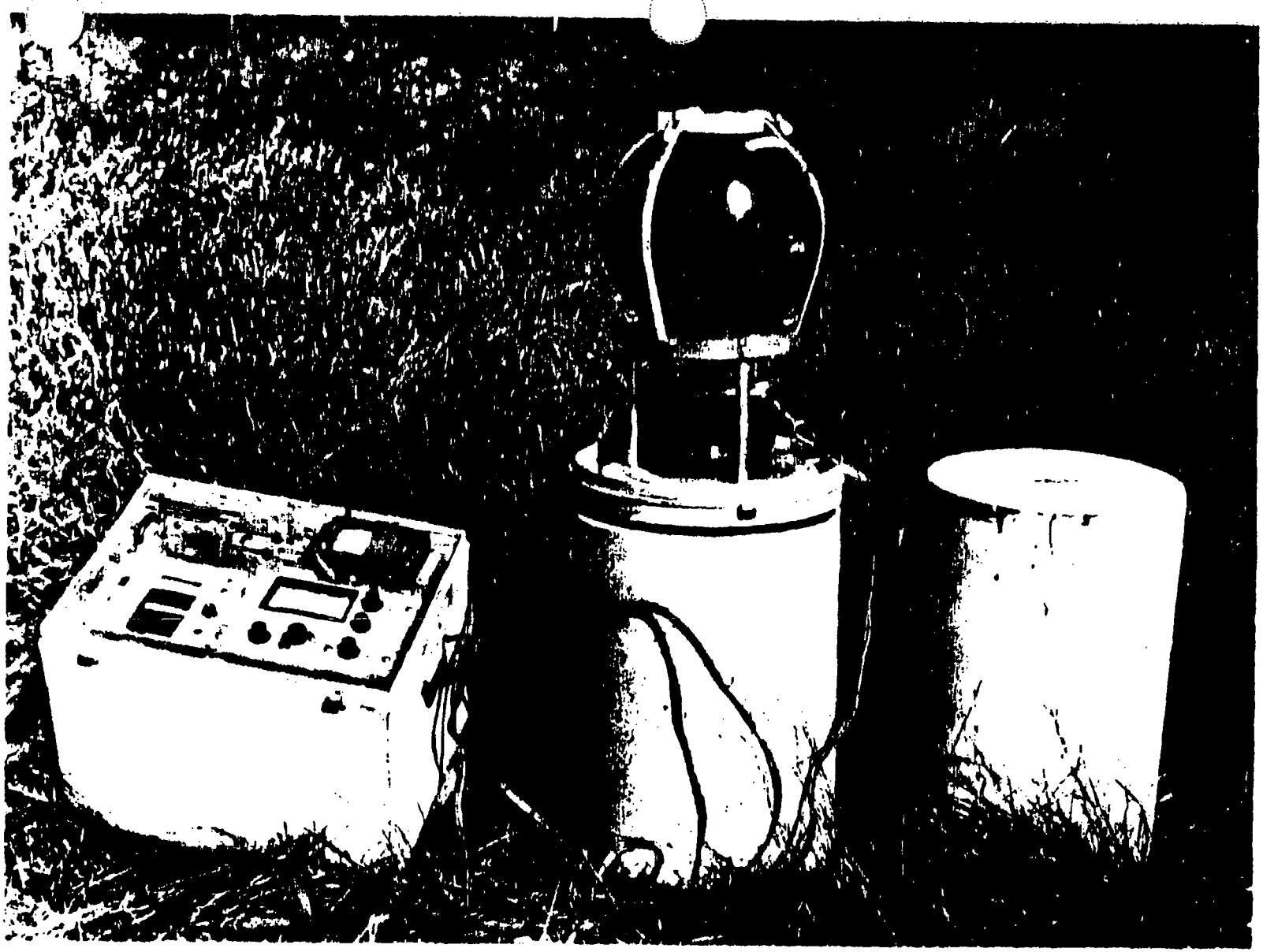

Fig. I-2. High sensitivity tissue equivalent ionization chamber system.

K+E [redacted] X 3
KEUFFEL & ESSER CO. MADE IN U.S.A.
46 7320

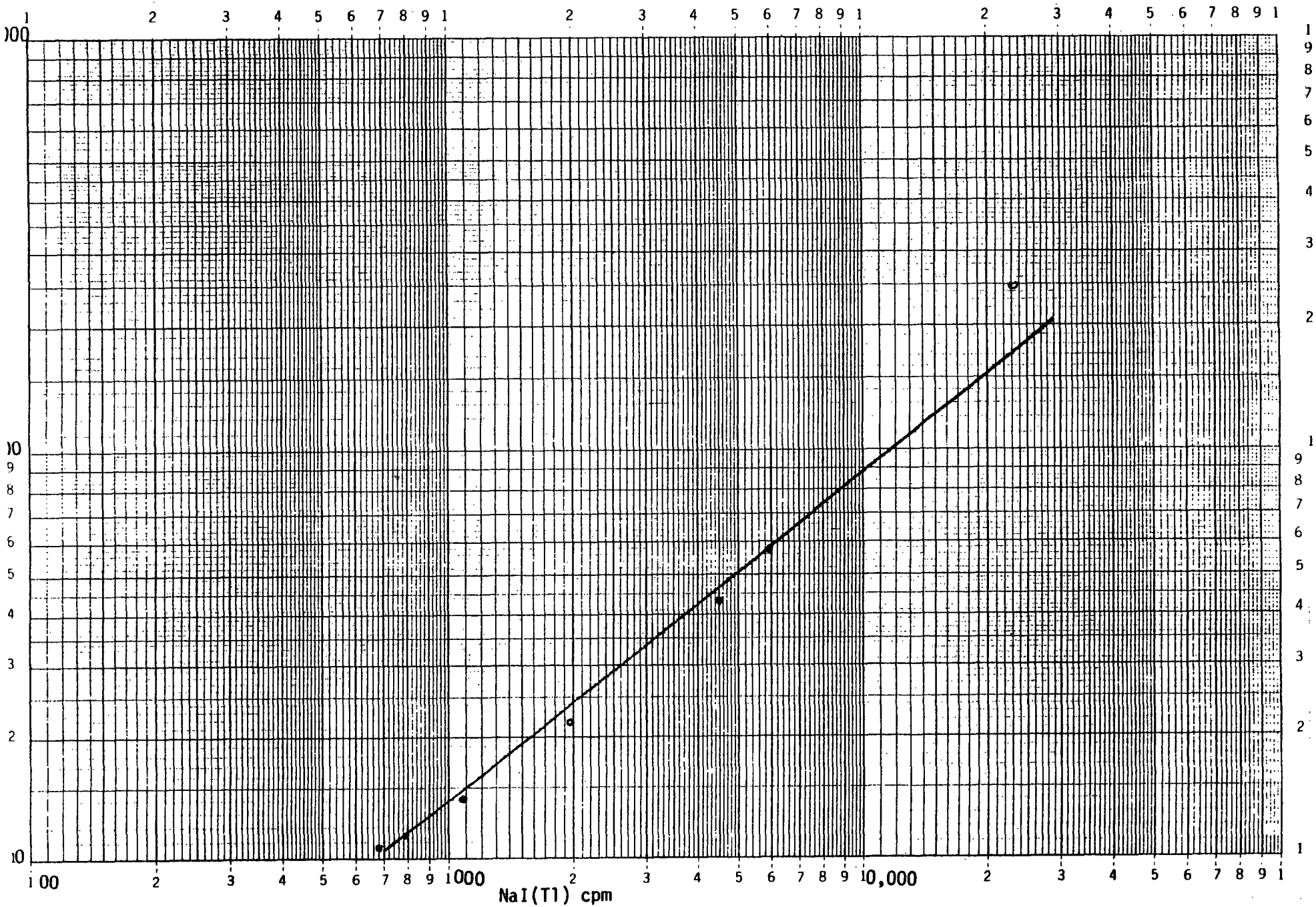


Fig. I.2 Ion Chamber exposure rate vs NaI(Tl) count rate. NES [illegible]