Radiological testing program. 1981

RADIOLOGICAL TESTING PROGRAM
CRANDON PROJECT

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REPORT TO

EXXON MINERALS COMPANY
RHINELANDER, WISCONSIN

RADIOLOGICAL TESTING PROGRAM
CRANDON PROJECT

PREPARED AND SUBMITTED
BY
HAZLETON ENVIRONMENTAL SCIENCES
PROJECT NO. 8007-100

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PREFACE

The staff members of the Nuclear Sciences Department of Hazleton Environmental Sciences were responsible for the acquisition of data presented in this report, with the exception of uranium and thorium data which were provided by Camp, Dresser, and McKee, Denver, Colorado. Exxon Minerals Company (Exxon) was responsible for collection and compositing of all samples utilizing methodology provided in the technical work plan reviewed by Wisconsin Department of Health and Social Services, Radiation Protection Section; Wisconsin Geological and Natural History Survey, and Wisconsin Department of Natural Resources personnel. Exxon personnel prepared the report sections pertaining to sample collection and compositing. L. G. Huebner, Director Nuclear Sciences Department of Hazleton Environmental Sciences, had overall responsibility for the report preparation with input from Exxon technical staff.

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1.0 Introduction

Exxon Minerals Company (Exxon) is presently conducting studies on the feasibility of developing a mine/mill complex for the mining and processing of ores from a sulfide deposit of zinc and copper located in Forest County, Wisconsin, which is known as the Crandon Project. Because of the public concern over the radiological impact that may be associated with the proposed Crandon Project, Exxon conducted a Radiological Testing Program in 1980-81. The primary objective of the Program was to identify and quantify the level of radioactive elements within the Crandon deposit.

Hazleton Environmental Sciences, Northbrook, Illinois, and Camp, Dresser and McKee, Denver, Colorado, performed the laboratory analyses of the samples. Hazleton was responsible for preparation of the report. The Program, with Wisconsin Department of Health and Social Services; Radiation Protection; Wisconsin Geological and Natural History Survey; and Wisconsin Department of Natural Resources input, was completed in August 1981.

2.0 Summary and Conclusion

Exxon Minerals Company conducted a Radiological Testing Program during 1980-81 to characterize the radioactivity that may be associated with the Crandon Project orebody. Composite samples representative of bedrock to be mined were prepared from massive and stringer ores and waste rock. Also soil composites from areas considered for the mine/mill complex and candidate mine waste disposal areas, plus a local granite outcrop, were analyzed for comparative purposes. The principle parameters measured were gross alpha, gross beta, radium-226, total uranium, total thorium and gamma radiation. Gamma radiation provided data on radioactivity resulting from the decay of naturally occurring uranium-238 and thorium-232.

The data indicate that the local granite outcrop had higher levels of uranium, thorium, and radium than either the Crandon ore and waste rock or Project area soils. With respect to uranium, the average total uranium content of waste rock and massive ore samples was 1.46 and 1.33 ppm, respectively. Stringer ore samples had the lowest average level of uranium (<0.83 ppm) of all sample types, including Project area soils.

The granite outcrop samples had uranium content approximately three times that found in the massive ore and waste rock samples analyzed. Overall, the Crandon orebody has uranium (0.83 to 2.33 ppm) and thorium (2.8 to 8.7 ppm) concentrations similar to values reported for other basaltic and andesitic igneous rocks. In descending order the relative ranking of the sample types, based on radioactivity, was generally: granite outcrop > soil > Crandon ore and waste rock.

A beta-gamma survey also was conducted on 659 meters (2160 feet) of core used for the ore composites in the radiological analyses. Survey results indicated uniform levels of radiation indistinguishable from background levels.

The analyses also showed that the composition and levels of radioactivity in soil, waste rock, ore, and granite outcrop were at the background level in the area. No unusual levels of radioactivity were detected in any of the samples analyzed. Trace amounts of cesium-137 and ruthenium-106 detected in most of the soil samples were attributable to the fallout of radioactive debris from nuclear tests conducted in the atmosphere.

3.0 Program Definition and Methodology

The objective of the Radiological Testing Program was to identify and quantify the radioactivity content of waste rock and ore samples from the Crandon deposit, as well as associated radiation levels.

To meet this objective, composite samples of bedrock and ore, representative of materials to be removed during mining, and soil from the Project area were collected and analyzed. A sample of granitic outcrop from the local area also was obtained for analysis. Soil and granitic outcrop were analyzed to provide data for comparison with the waste rock and ore sample analyses from the Crandon deposit.

The analyses performed on the samples included: gross alpha, gross beta and gamma scanning. The gamma spectroscopic analysis provided data on thorium-228, radium-226, potassium-40, cesium-137 and ruthenium-106. Total uranium, total thorium, and radium-226, determined by the radon-222 emanation method, were also measured.

These parameters were selected to provide data on the two prevalent naturally-occurring radioactive decay series starting with uranium-238 and thorium-232 parent isotopes. Sample types, number of samples analyzed, and parameters measured are summarized in Table 1.

The field and laboratory methodologies that were utilized for the Radiological Testing Program are presented in the following subsections.

TABLE 1

SAMPLE TYPE AND ANALYTICAL PARAMETERS FOR THE RADIOLOGICAL TESTING PROGRAM
CRANDON PROJECT

Sample Type	Number of Samples	Analytical Parameters					
		Gross Alpha	Gross Beta	Gamma Scan[a]	Ra-226	Total Uranium	Total Thorium
Waste Rock[b]							
Mine Shaft	1	X	X	X	X	X	X
Ventilation Raise	1	X	X	X	X	X	X
Hanging Wall Composite	1	X	X	X	X	X	X
Footwall Composite	1	X	X	X	X	X	X
Ore[b]							
Massive Composite	5	X	X	X	X	X	X
Stringer Composite	5	X	X	X	X	X	X
Other							
Granite Outcrop[c]	1	X	X	X	X	X	X
Surficial Soil	5	X	X	X	X	X	X

[a] Provides data on Ra-226, Th-228, K-40, and any detectable man-made fission products which emit gamma radiation, e.g., Cs-137 and Ru-106.
[b] Composite = representative of material to be removed during mining.
[c] Taken from outcrop near Jennings, Wisconsin, approximately 11 kilometers (6.8 miles) west-northwest of the Crandon deposit.

3.1 Sampling and Compositing

3.1.1 Soil

Soil samples for this testing program were collected by personnel from Exxon Minerals Company in April and May 1981. Three grab samples were collected from each of the following three areas within the Project site: candidate waste disposal site 40, candidate waste disposal site 41, and the proposed mine/mill complex. The sampling locations within each of the above three areas, as noted by the reference borings, are shown in Figure 1. A detailed description of each sampling location, including azimuth and distance relative to each reference boring, is presented in Table 2. Sampling locations were selected in areas of previously surveyed soil borings in accordance with the following criteria: (1) minimal vegetation cover, (2) undisturbed soil, and (3) outside the zone of anticipated future mine-related development. Each location was identified relative to an existing bore hole using a Brunton compass and a measuring tape.

At each sampling location two soil cores were taken and combined to form one grab sample. The samples were collected with a pipe sampler from the surface to a depth of 25 centimeters (10 inches) and placed in labeled plastic bags. This sampling depth was selected because most terrestrial gamma radiation is contributed from this upper soil layer.

In the laboratory, samples were placed in a hot air oven at 32.2°C (90°F) until dry. After drying, each grab sample was sieved through a No. 4 mesh Tyler series screen to remove stones (>4.75 mm in size) and organic matter, e.g., plant roots. Soil clumps were reduced by mortar and pestal and recombined with the sample. Three grab samples from each

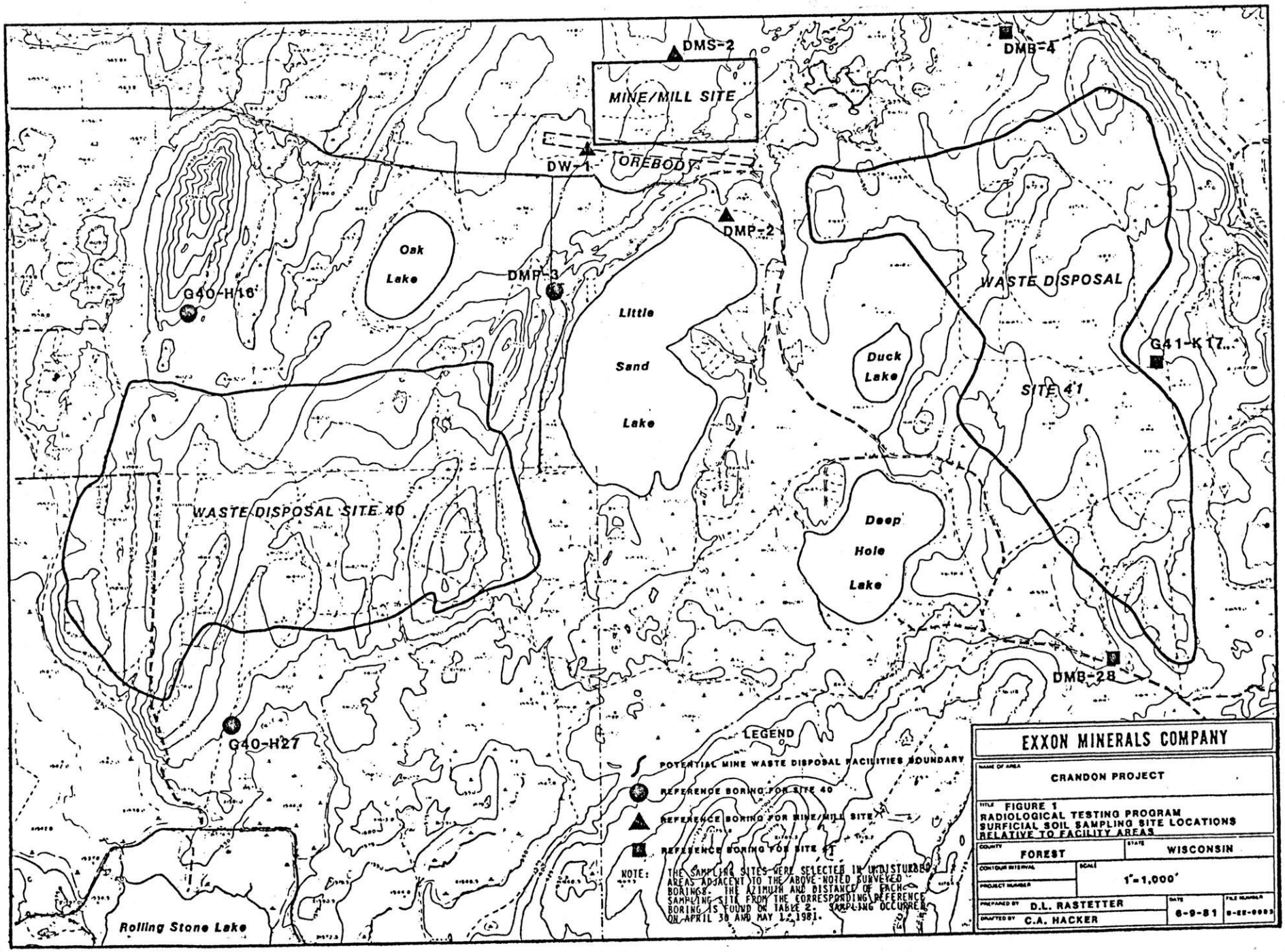

Figure 1. Radiological Testing Program surficial soil sampling site locations relative to facility areas.

TABLE 2

SURFICIAL SOIL SAMPLING LOCATIONS
FOR THE RADIOLOGICAL TESTING PROGRAM
CRANDON PROJECT

Sampling Area	Reference Boring Data			Azimuth[a] and Distance (Meters) From Reference Boring to Sampling Site	
	Bore Hole Number	Coordinates[b] (Feet)			
		North	East		
Mine/Mill	DMS-2	117,927	2,277,890	7°	25
	DW-1	116,321	2,276,261	120°	39
	DMP-2	115,135	2,278,685	23°	34
Site 40	DMP-3	113,665	2,275,625	295°	14
	G40-H16	113,260	2,269,110	270°	16
	G40-H27	105,930	2,269,650	160°	11
Site 41	DMB-4	118,405	2,283,785	210°	10
	DMB-28	106,840	2,285,425	345°	13
	G41-K17	112,155	2,286,325	315°	10

[a] Relative to Magnetic North.
[b] Based on Wisconsin State Coordinate System (North Zone).

of the three individual sampling areas were combined to yield three soil composites, one for each area, e.g., candidate waste disposal site 40. The grab samples were composited for each sampling area by processing them five times through a one-eighth split Jones riffle splitter. Immediately after blending, 1 kilogram (2.2 pounds) subsamples were obtained from the three soil composites for radiological analysis.

3.1.2 Bedrock

3.1.2.1 Ore

Six composite ore samples were obtained from the Crandon deposit for radiological analysis. Composite samples were obtained for both massive and stringer ore above and below the planned 350 meter development level (Figure 2). Also, composite samples of massive and stringer ore were obtained from a representative portion of the total ore body, above and below the 350 meter level. The 350 meter level was selected as the division because initial mine development will occur at or above this level. Also, the deposit is approximately divided on a horizontal plane into equal halves on a mass and volume basis at the 350 meter level. These compositing procedures were verified by Wisconsin Department of Natural Resources and Geological and Natural History Survey personnel on April 7, 1981.

The samples were composited on an ore interval weighted basis. Ore for each of the six composite samples was derived from 5-foot interval composites taken from the mineralized zone of the orebody. The composites were prepared from diamond drill hole cores extracted from the deposit. An east-west longitudinal cross-section of the Crandon deposit showing the diamond drill holes sampled for the ore composites is shown.

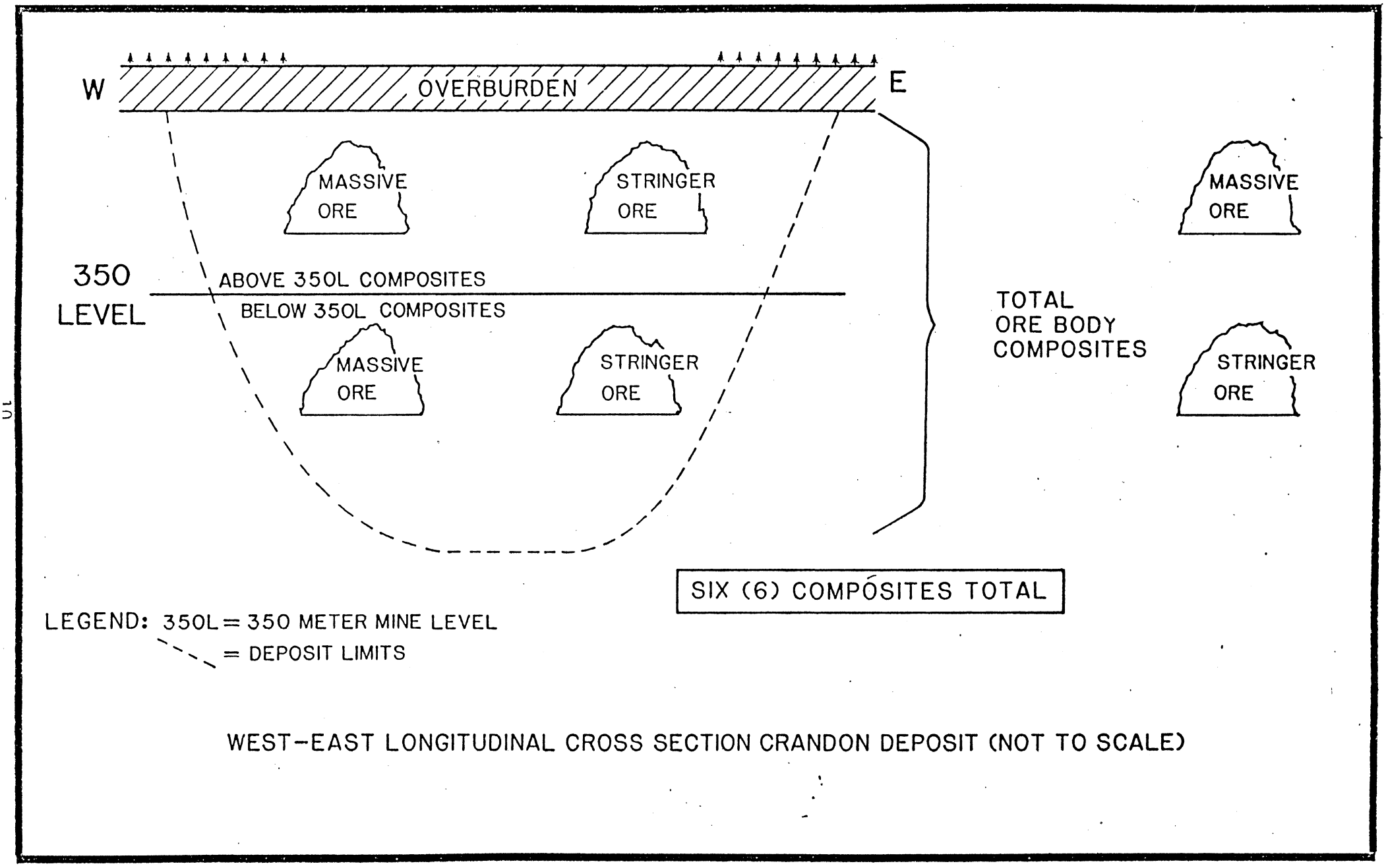

Figure 2. Graphic representation for preparation of six composite samples of massive and stringer ore for the Radiological Testing Program.

in Figure 3. The holes selected for sampling were chosen based on mine development plans and geological characteristics of the deposit so that composite samples representative of future mining zones were obtained.

The 5-foot interval composites, previously prepared by geologists from Exxon Minerals Company for ore reserve studies, were obtained from one-half diamond drill hole core splits taken along the entire length of each 5-foot interval intercepting mineralized bedrock. The core splits were crushed, pulverized, and blended (riffled) using standard procedures to produce representative sample pulps of particle size <80 mesh (<180 μm).

Appendix A contains more detailed information on the ore compositing procedure, the diamond drill holes selected for composite sampling, and the 5-foot interval composites included in the ore composite samples for radiological analysis.

3.1.2.2 Waste Rock

Four composite samples of waste rock from the Crandon deposit were obtained during 1980 for radiological analysis. These samples were representative of waste rock that will be excavated and disposed during development of the Crandon deposit. Waste rock from the hanging wall and footwall will be the two types of spoil from the Crandon deposit.

A single waste rock composite sample from the hanging wall was obtained for both the proposed main shaft and a ventilation raise of the Crandon mine. Cores from individual diamond drill holes intersecting the entire vertical depth of these two mine facilities were sampled to obtain the composites. Their relative location in the Crandon deposit is shown

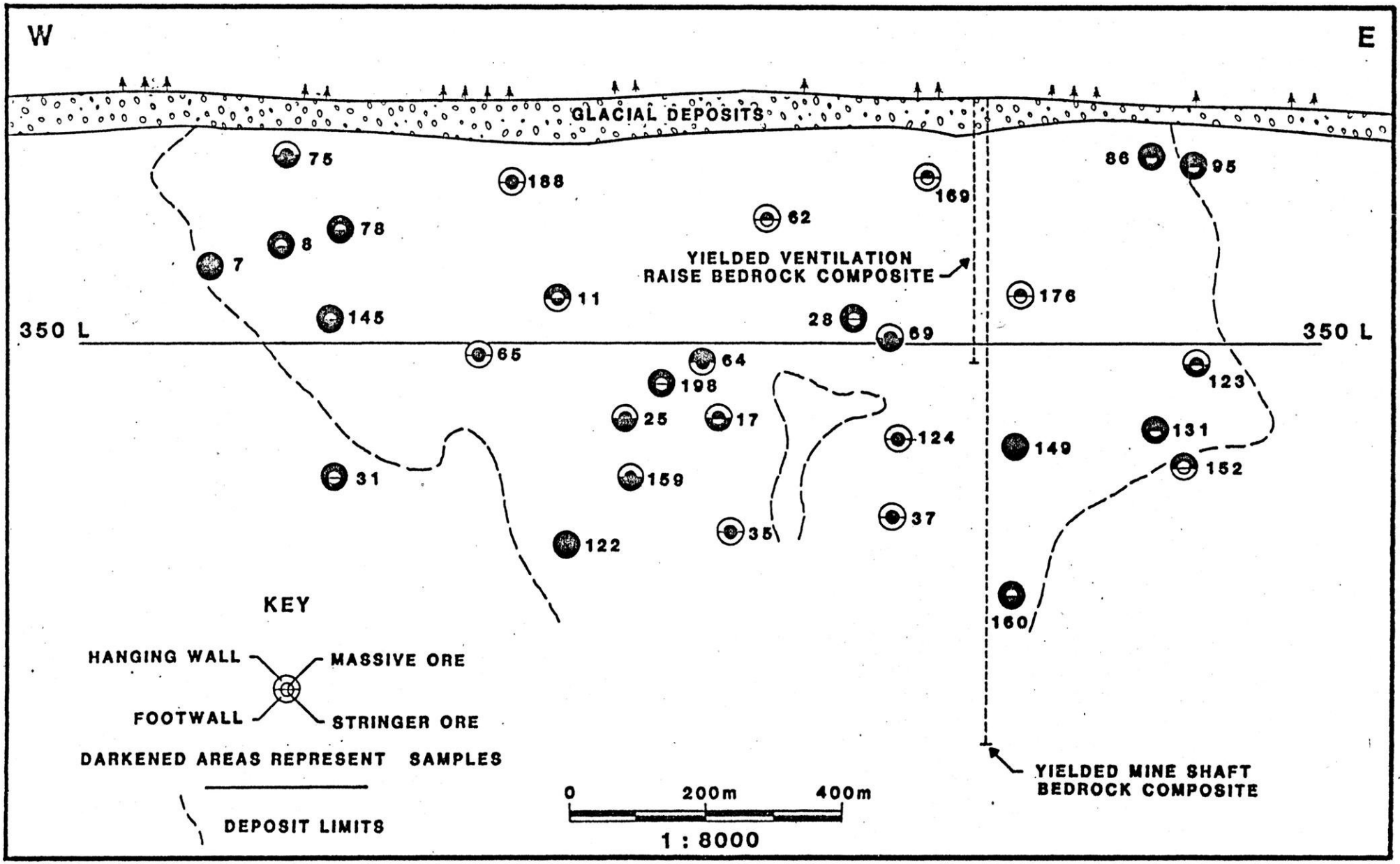

Figure 3. Radiological Testing Program diamond drill holes used to produce mine waste rock and ore composites.

by dashed vertical lines in Figure 3. These diamond drill cores were sampled by a mass split technique which involved taking 5 centimeters (2 inches) of half split core at 0.61 meter (2 feet) intervals. The core samples were then crushed, pulverized, and blended using standard procedures to yield representative sample pulps of particle size <80 mesh (<180 μm) for analysis.

A composite sample of waste rock from both the hanging wall and footwall also was obtained. The core samples for these waste rock composites was taken from diamond drill holes representative of the entire orebody. Material from sixteen holes in the hanging wall and 19 holes in the footwall was sampled for the composites; the location and spatial distribution of these holes on an east-west longitudinal cross-section are shown in Figure 3. Five-foot interval composites, prepared exactly like those for ore (subsection 3.1.2.1), were sampled to obtain the waste rock composites. One level teaspoon (U.S. Standard) from each 5-foot interval composite of core from the selected holes intersecting waste rock was utilized in the respective composites.

After the compositing procedure was completed, the four composite samples were blended to ensure homogeneity and placed in labeled containers. The samples then were shipped to the laboratory for radiological analysis.

3.1.2.3. Granite Outcrop

A granite outcrop, located approximately 11 kilometers (6.8 miles) west-northwest from the Crandon deposit near Jennings, Wisconsin, was sampled during 1980 to obtain comparative radiological data.

Approximately 15 kilograms (33 pounds) were removed by hammering the face of the outcrop. The entire sample then was crushed, and a split equal to one-eighth of the sample mass (Jones riffle splitter) was further reduced to a particle size of <80 mesh (<180 μm) for analysis.

3.2 Radiation Survey

Before the ore samples were composited, most of the 5-foot interval composites were surveyed for beta-gamma radiations to provide data regarding potential dilution of higher activity samples. The measurements were made on April 7 through 9, 1981, using a Ludlum Model 12 count rate meter with a Ludlum Model 44-7 end window Geiger-Mueller (G.M.) detector. Approximately 93 percent of the 709 meters (2325 feet) of diamond drill hole core which contributed to the composites was surveyed. All beta-gamma survey data are presented in Appendix C.

3.3 Laboratory Analysis

3.3.1 Soil

The samples were air dried and reduced using a pulverizer and transferred to 0.5 gallon plastic containers. The containers were tumbled for 0.5 hour to blend the samples. A portion of each sample was transferred to a 450 ml Marinelli beaker for gamma spectroscopic analysis and the remainder transferred to air tight containers for future use.

The following methods were used during the testing program with minor modifications to meet specific requirements of each laboratory. For each parameter analyzed in the laboratory, a description is presented below for the method utilized, one or more references for the method, and the instrumentation utilized in performing the analyses. A more detailed discussion of methods is presented in Appendix B.

Gross Alpha and Gross Beta

A pulverized and blended 100 milligram sample was slurred and distributed evenly on a stainless steel planchet and dried under an infrared lamp. A few drops of lucite-acetone solution was added and the sample was dried again under the lamp. The sample then was counted for gross alpha and beta activities with low background proportional counters. See Appendix B-2, page B-6 for calculation details.

References: USDHEW (1967); Harley (1972); APHA (1975); USEPA (1976, 1979).

Instruments: Beckman Model Widebeta II - Hazleton Environmental Sciences (HES).
Canberra Low Background Alpha-Beta Counter - Camp, Dresser, McKee (CDM)

Radium-226

A pulverized and blended 0.5 gram sample was decomposed with nitric acid and pyrosulfate fusion. Radium, actinium, and thorium were separated from other constituents on lead sulfate, then radium was separated by coprecipitation with barium sulfate. The precipitate was dissolved in sodium diethylenetriamine pentacetate (DTPA), transferred to a bubbler, deemanated, and aged for 2 to 4 weeks to allow for the in growth of radon-222. The solution was again deemanated into an evacuated scintillation cell, and the alpha activity of radon-222 was counted. See Appendix B-5, page B-24 for calculation details.

References: USDHEW (1967); Harley (1972); Percival and Martin (1974); APHA (1975); Misagi (1975); USEPA (1976, 1979, 1980).

Instruments: Random Model No. 918-4 and 1200 - HES
Ludlum Portable Sealer Rate Meter Model 2200 with Ludlum Radon Flask Counter, Model 182 - CDM

Gamma Spectrometry

An aliquot of pulverized and blended sample was put into a standard geometry container and gamma scanned on a Ge(Li) detector. The spectrum was computer scanned from 40 to 2048 KeV and the radioisotopes of interest were identified and quantified. For isotopes below the detection limit, the lower limit of detection (LLD) is provided.

References: USDHEW (1967); Harley (1972, 1975); USEPA (1979).

Instruments: Ortec Model No. 6240, System 42 - HES
Hewlett-Packard Model No. 5406B - HES
4096 Channel MCA ("The Nucleus", Oak Ridge, Tennessee) using a Ge(Li) Detector - CDM

Total Uranium

A 0.5 gram sample was digested with nitric, sulfuric, perchloric, and hydrofluoric acid and evaporated until dry. The residue was dissolved in dilute nitric acid and extracted with ethyl acetate. An aliquot of the organic layer was pipetted onto a NaF-LiF pellet and fused using a Geoco fusion burner. The pellet was exposed to ultraviolet light and the fluorescence measured using a fluorometer. Calculation information is presented in the reference cited below. The results are presented in pCi/g and ppm.

Reference: Harley (1975).

Instrument: G-M Fluorometer (Jarrel-Ash Model 26-000) - CDM

Total Thorium

The sample was digested in nitric, sulfuric, and hydrofluoric acid. The digested sample (0.25 to 2.0 grams) was evaporated and diluted with nitric acid. The thorium was separated by passing the solution through an ion exchange column. After washing, the thorium was eluted from the column with hydrochloric acid and transferred to a stainless steel planchet for alpha counting. Calculation information is presented in the reference cited below. The results are presented in pCi/g and ppm.

Reference: Latimer et.al., (1940).

Instrument: Internal Proportional Counter/Scaler, PCC-IIT/DS-2 - CDM

3.3.2 Bedrock

Pulverized bedrock samples were tumbled for 0.5 hour for blending.

Portions of the samples were packed in plastic containers and shipped to CDM for analyses. The remainder of the samples was retained for analysis by HES.

The analytical methods used to analyze the bedrock samples were the same as those used to analyze soil samples (Subsection 3.3.1).

4.0 Results and Discussion

The Crandon massive sulfide deposit was formed through the interaction of prehistoric hot springs and volcanoes. It is theorized that, as massive sulfide deposits are formed, the processes involved tend to limit their radioactive element content. Metallic ions released from hot springs on the prehistoric ocean floor probably precipitated as sulfides in depressions near the springs (Henley and Thornley 1979). Current information on the source of metals for massive sulfide deposits suggests that they were leached from basaltic rocks beneath the forming deposit. As presented in Table 3, analyses of basalts from the ocean floor indicate that these rocks have minimal amounts of uranium and thorium. During formation, the Crandon deposit was altered by volcanic activity during and after its formation. Consequently, it is located in basaltic and andesitic igneous rocks.

During igneous rock formation, uranium and thorium, rejected by early crystallizing minerals because of their large ionic charge and size (Mason 1966), are preferentially partitioned into magma (molten rock). It is usually late in the crystallization history of a magma, when silica content is enriched, that uranium and thorium are accepted into accessory minerals. Generally, accessory minerals containing uranium and thorium comprise <1 percent (by volume) of igneous rocks. Accessory minerals of the type commonly found in igneous rocks and their elemental composition are listed in Table 4. Apatite has been the only uranium bearing accessory mineral identified in the Crandon deposit. The apatite was detected in three of 600 thin sections of diamond drill core inspected.

TABLE 3

URANIUM (U) AND THORIUM (Th) CONTENT IN IGNEOUS ROCKS

Source (type)	ppm* U	ppm* Th
New Zealand, Comendite (rhyolite)	6.0	20.2
New Zealand, Taupo (rhyolite)	2.53	11.3
Mid Atlantic Ridge (basalt)	0.16	0.15
East Pacific Ocean (basalt)	0.09	0.21
Karoo Province, South Africa (diabase)(N=8)	0.2 - 0.37	1.3 - 1.5
Antarctica (diabase)	1.70	4.20
	1.6	5.4
	0.41	1.56
Tasmania (diabase)	0.9	3.3
New Jersey (diabase)	0.35	1.8
Tasmania (tholeiitic basalt)	1.9	0.78
Hawaii (tholeiitic basalt)	0.2	0.7
New Zealand, Taupo (basalt)	0.37	1.53
(andesite)	1.22	5.23
(dacite)	1.93	7.88
(rhyolite)	2.64	11.5
(rhyolite, welded ash)	2.48	11.4
(rhyolite, pumice)	2.23	10.2
Japan tholeiitic (basalt)	0.15	0.26
(andesite)	0.38	0.38
high Al_2O_3 (basalt)	0.38	1.04
(andesite)	0.59	1.69
(dacite)	1.46	4.11
alkali (olivine basalt)	0.68	3.34
Montana, Boulder batholith (granodiorite)	3.4	11
(granodiorite)	1.5	7.3
(quartz monzonite)	4	16.2
(alaskite)	9.2	35.3
shale	3.7	12
sandstone	0.45	1.7
carbonate	2.2	1.7

* ppm = mg/kg

References: Turekian and Wedepohl (1961); Carmichael et al. (1974).

TABLE 4

URANIUM AND THORIUM BEARING ACCESSORY MINERALS COMMONLY FOUND IN IGNEOUS ROCKS

Allanite	(Ca, Fe, U, Th) Al_2O OH (Si_2O_7) (SiO_4)
Apatite*	$(Ca, U)_5$ $(PO_4)_3$ (OH, F, Cl)
Monazite	(Ce, La, Y, Th) PO_4
Sphene	(Ca, U, Th) TiO SiO_4
Zircon	(Zr, U, Th) SiO_4

*Identified in three thin sections of Crandon deposit diamond drill core.

Reference: Deer et al. (1966).

Siliceous rocks, such as rhyolites and alaskites, which crystallize late in magma solidifications, are higher in uranium and thorium content. There is no indication that these rock types are present in the Crandon deposit. This discussion on hot spring and volcano activity and uranium and thorium geochemistry during igneous rock formation provides supporting information that would lead one to predict very low levels of radioactivity in massive sulfide deposits.

Project data suggested insignificant radioactivity within the Crandon deposit and adjacent bedrock (Exxon Minerals Company 1978). Quantitative analysis, by inductively coupled argon plasma (ICP) emission spectroscopy, of Crandon massive and stringer ore composites performed during 1977-1978 revealed uranium and thorium concentrations less than detection limits (Table 5). Of the seven stringer and seven massive ore samples analyzed (Figure 4), uranium was always below the 2 ppm detection limit for the ICP. Thorium content only exceeded the 5 ppm detection limit in three massive ore composite samples from drill holes and ranged from 7 to 10 ppm. These results indicated that ore from the Crandon deposit is within the normal range of uranium and thorium content, 0.1-10 ppm and 0.5-10 ppm, respectively, for quartz and feldspar, both common igneous minerals (Rogers and Adams 1969a, b). The Crandon ore is also within the normal range of uranium content, 0.5-10 ppm, reported for intermediate rocks such as andesites, dacites, rhyodacites, diorites, quartz diorites, and granodiorites (Rogers and Adams 1969b). Additionally, during September 1980, the Wisconsin Geological and Natural History Survey detected no major gamma activity above background in the Crandon upper ore zone (Figure 4).

TABLE 5

URANIUM (U) AND THORIUM (Th) CONTENT[a]
IN COMPOSITE ORE SAMPLES FROM THE
CRANDON DEPOSIT, 1977-1978
CRANDON PROJECT

DIAMOND DRILL HOLE COMPOSITE SAMPLE[c]	ppm[b] U	ppm[b] Th
Massive Ore		
3	< 2	8
5 (high grade)	< 2	7
5 (low grade)	< 2	< 5
18	< 2	< 5
23	< 2	< 5
28	< 2	< 5
122	< 2	10
Stringer Ore		
3	< 2	< 5
5	< 2	< 5
8	< 2	< 5
12	< 2	< 5
16	< 2	< 5
18	< 2	< 5
122	< 2	< 5

[a] Analyses performed using inductively coupled argon plasma emission spectroscopy (ICP) on single hole composites (Exxon Minerals Company 1978).
[b] ppm = mg/kg.
[c] Diamond drill hole locations shown in Figure 4.

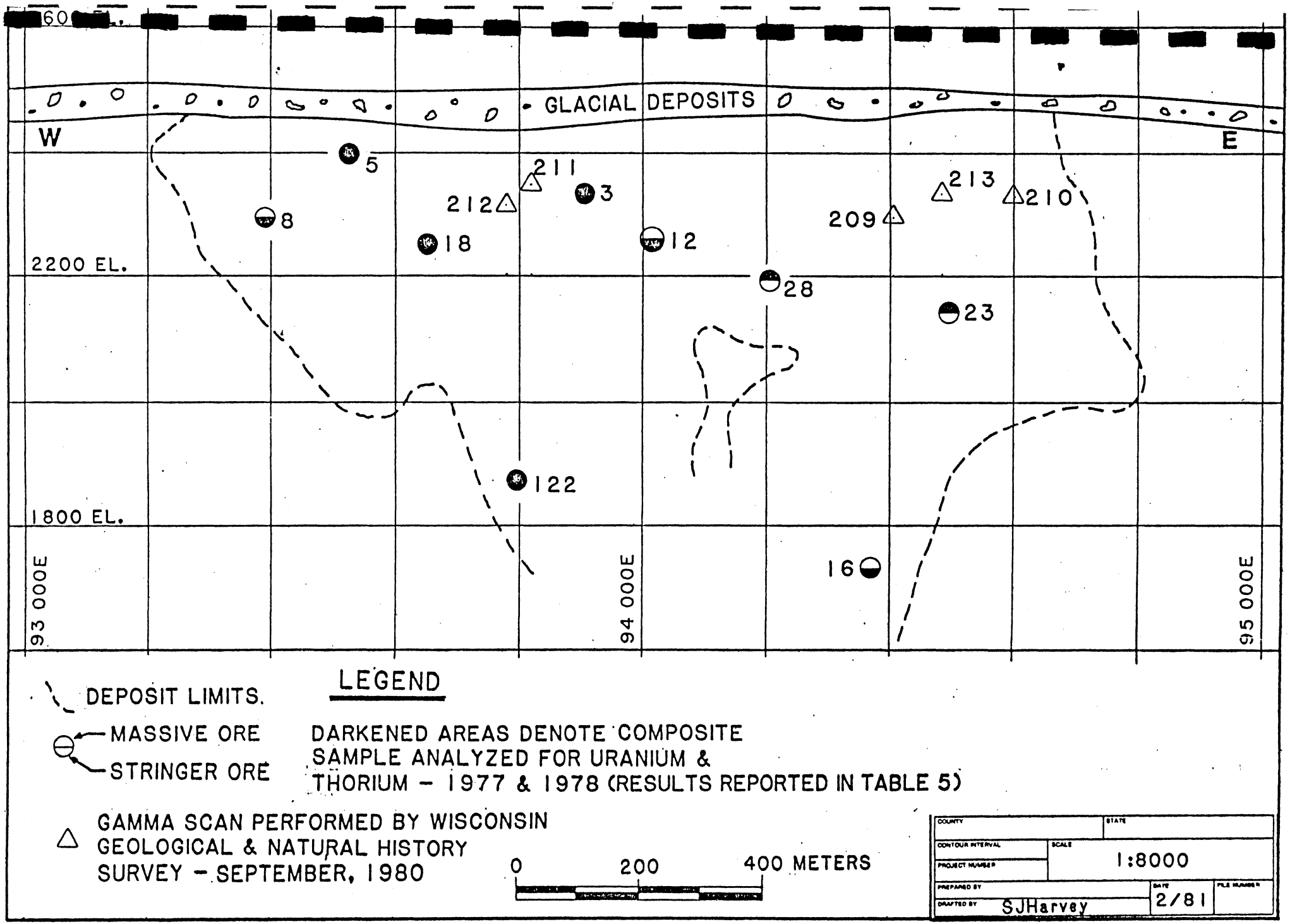

Figure 4. Coring locations and survey points for Crandon orebody radiological measurements obtained during 1977, 1978, and 1980.

Presented in the following subsections are the results and discussion of radiological analyses of Crandon Project site area soils, ore, waste rock and granite outcrop from a nearby area. A radiation survey of the core sample pulps is also discussed below.

4.1 Soil

Pulverized and blended soil samples were analyzed for gross alpha, gross beta, total uranium, total thorium, radium-226 (by radon emanation method) activities, and gamma-emitting isotopes. A summary of the soil testing results is presented in Table 6 and supporting data are presented in Appendix D, Tables D-1, D-3, D-4, and D-5.

The gross alpha activity for all samples averaged 9.4±1.6 pCi/g and ranged from 7.1 to 11.6 pCi/g. The gross beta activity of the samples averaged 23.8±1.4 pCi/g and ranged from 22.1 to 24.7 pCi/g. Most of the gross beta activity was due to the naturally occurring potassium-40. The radium-226 activity, as measured by the radon-222 emanation method, averaged 0.77±0.06 pCi/g and ranged from 0.70 to 0.86 pCi/g, this is in agreement with the value obtained by gamma spectroscopy (0.72±0.22 pCi/g; range: 0.26 to 0.88 pCi/g).

Total uranium, as determined by fluorimetry, was detected in five of seven soil samples but was near the lower limit of detection of 0.56 pCi/g (0.83 ppm) in all five samples. Total thorium activity averaged 2.2±0.4 pCi/g (10.1±1.8 ppm) and ranged from 1.7 to 2.7 pCi/g (7.8 to 12.4 ppm).

Gamma-spectroscopic analysis showed the presence of naturally occurring radium-226, thorium-228, and potassium-40 in all samples; cesium-137 in six of seven samples; and ruthenium-106 in four of seven samples.

TABLE 6

LEVELS OF GROSS ALPHA, GROSS BETA, RADIUM-226, TOTAL URANIUM, TOTAL THORIUM, AND GAMMA-EMITTING ISOTOPES IN WASTE ROCK, MASSIVE ORE, STRINGER ORE, GRANITE AND SURFICIAL SOIL SAMPLES FOR THE RADIOLOGICAL TESTING PROGRAM CRANDON PROJECT

	pCi/g dry wt.											
	Gross Alpha	Gross Beta	Ra-226 by Rn-222	Gamma Emitters					Total Uranium		Total Thorium	
				Ra-226	Th-228	K-40	Cs-137	Ru-106	pCi/g dry wt.	ppm	pCi/g dry*	ppm
Waste Rock												
Mean ± s.d.	6.5±1.9	16.2±2.5	0.66±0.20	0.63±0.19	0.66±0.18	17.2±3.7	< 0.04	<LLD	0.99±0.39	1.46±0.55	1.66±0.29	7.61±1.33
Range	(3.2-8.6)	(13.2-19.9)	(0.40-0.96)	(0.34-0.85)	(<0.21-0.83)	(13.1-22.4)			(<0.56-1.58)	(<0.83-2.33)	(1.3-1.9)	(6.0-8.7)
Massive Ore												
Mean ± s.d.	4.7±1.1	4.9±1.7	0.74±0.22	0.45±0.17	0.25±0.07	1.8±0.6	< 0.06	<LLD	0.90±0.31	1.33±0.46	0.85±0.12	3.90±0.55
Range	(3.7-7.2)	(2.5-8.1)	(0.48-1.30)	(0.12-0.79)	(<0.09-0.31)	(<1.0-2.5)			(0.56-1.13	(0.83-1.67	(0.7-1.0)	(3.2-4.6)
Stringer Ore												
Mean ± s.d.	3.2±1.0	6.3±1.5	0.27±0.06	0.22±0.04	< 0.18	3.5±0.4	< 0.06	<LLD	< 0.56	<0.83	0.65±0.05	2.98±0.23
Range	(2.0-3.9)	(<3.7-9.0)	(0.20-0.40)	(<0.11-0.27)		(2.8-3.7)					(0.6-0.7)	(2.8-3.2)
Granite Outcrop	20.7±6.3	43.0±4.5	1.54±0.05	2.01±0.12	3.02±0.18	46.8±1.5	< 0.029	<LLD	2.94	4.34	4.9±0.5	22.5±2.3
Soil												
Mean ± s.d.	9.4±1.6	23.8±1.4	0.77±0.06	(0.72±0.22)	0.84±0.26	20.9±0.7	0.39±0.08	0.68±0.06	0.56±0.00	0.83±0.00	2.2±0.4	10.1±1.8
Range	(7.1-11.6)	(22.1-24.7)	(0.70-0.86)	(0.26-0.88)	(0.28-0.99)	(19.8-21.8)	(<0.22-0.46)	(<0.22-0.74)	(<0.56-0.56)	(<0.83-0.83)	(1.7-2.7)	(7.8-12.4)

*LLD = Lower limit of detection.
NOTE: The error given for the granite outcrop sample results is the probable counting error at the 95 percent confidence level. All others are one standard deviation.

The thorium-228 activity averaged 0.84±0.26 pCi/g and ranged from 0.28 to 0.99 pCi/g. The mean potassium-40 level was 20.9±0.7 pCi/g and ranged from 19.8 to 21.8 pCi/g. The cesium-137 activity averaged 0.39±0.08 pCi/g and ranged from <0.22 to 0.46 pCi/g.

The presence of cesium-137 in top soil is attributable to the fallout from nuclear tests conducted in the atmosphere during the last several decades. Cesium-137 is a man-made isotope with a half life of 30 years.

The presence of the relatively short-lived ruthenium-106 isotope (368 days half-life) in top soil is attributable to the fallout from the nuclear test conducted on October 16, 1980 by the People's Republic of China.

In general, levels of radioactivity found in soil were similar to those found in other areas. For example, four soil samples collected at locations in the vicinity of Kewaunee,Wisconsin in 1980 (Hazleton Environmental Sciences 1981) yielded the following results, in pCi/g:

	Mean	Range
Gross alpha	5.6	3.6 - 8.0
Gross beta	27.9	21.6 - 32.1
Cesium-137	0.62	0.38 - 1.00
Potassium-40	26.4	22.7 - 30.4

The levels of other naturally occurring radioactive elements (e.g., uranium and thorium), in major rock types and soil were within the expected ranges found in other parts of the United States (Table 7). Table 8 lists individual results for gross beta and radium-226 activities in soil. As is evident in Table 8, the respective levels of radioactivity were nearly identical at the candidate waste disposal sites 40 and 41, and at the mine/mill area.

TABLE 7

SUMMARY OF POTASSIUM-40 (K-40), TOTAL THORIUM AND TOTAL URANIUM CONCENTRATIONS IN IGNEOUS ROCKS AND SOILS OF THE UNITED STATES[a]

Rock Type	pCi/g dry wt.	ppm[b]	
	K-40	Total Thorium	Total Uranium
Igneous Rocks			
Basalt (Crustal Average)	7	2.8-3.7	0.6-0.9
Mafic	2-9	1.8,2.8	0.6,0.9
Salic	30-40	15.6,20.2	3.9,4.8
Granite (Crustal Average)	>30	17.4	3
Soils	12	9.2	1.8

[a] Adapted from the National Council on Radiation Protection and Measurements (1975).
[b] These data were calculated using original data for Th-232 and U-238 presented in pCi/g.

TABLE 8

COMPARISON OF GROSS BETA AND RA-226 LEVELS IN INDIVIDUAL SAMPLE COMPOSITES VERSUS OVERALL AVERAGES BY SAMPLE TYPE FOR THE RADIOLOGICAL TESTING PROGRAM
CRANDON PROJECT

Sample Type	pCi/g dry wt. Gross Beta	pCi/g dry wt. Ra-226 (by Rn-222 analysis)
Waste Rock		
Mine Shaft[a]	17.0±3.4	0.87±0.05
Ventilation Raise[a]	19.9±3.2	0.71±0.04
Hanging Wall Composite	17.6±2.9	0.78±0.26
Footwall Composite	14.3±1.2	0.51±0.11
Overall Average[b]	16.2±2.5	0.66±0.20
Ore		
Massive Ore		
Total Orebody Composite	4.8±1.0	0.78±0.22
Above 350 Level Composite	8.1±3.7	0.69±0.06
Below 350 Level Composite	2.5±2.9	0.48±0.03
Overall Average[b]	4.9±1.7	0.74±0.22
Stringer Ore		
Total Orebody Composite	6.8±2.3	0.29±0.10
Above 350 Level Composite	5.2±3.1[a]	0.24±0.01
Below 350 Level Composite	6.3±0.6	0.28±0.01
Overall Average[b]	6.3±1.5	0.27±0.06
Other		
Granite Outcrop[a]	43.0±4.5	1.54±0.05
Soil		
Site 40	22.9±0.7	0.73±0.02
Site 41	24.3±2.0	0.79±0.08
Mine/Mill	23.9±0.1	0.79±0.01
Overall Average[b]	23.8±1.4	0.77±0.06

[a] The error given for these sample results is the probable counting error at the 95 percent confidence level. All others are one standard deviation.

[b] These values represent the overall average of all measurements for a sample type, e.g., massive ore. Overall average values taken from Table 6.

4.2 Bedrock

The results of the radiological analyses of ore and waste rock composite samples from the Crandon deposit and of a granite outcrop located near the Project area are presented and discussed below. An evaluation of the results of the beta-gamma survey on the ore zone cores from the diamond drill holes also is presented.

All the beta-gamma survey measurements were within the range of variation in background measurements, which indicate uniform radiation levels throughout the Crandon deposit. Based on these data and the need for analyzing representative ore and waste rock, composite samples were utilized.

Six composite samples of massive and stringer ore were analyzed. Data on gross beta and Ra-226 levels in these ore composites from above and below 350 meter level indicate little variability in the orebody (Table 8). Also the levels in the two total orebody composite samples were similar to the two composite samples above and the two composite samples below the 350 meter level. The other parameters measured displayed this trend as well (Appendix D, Tables D-2 and D-3). Thus, individual values for stringer and massive ore samples were similar to overall mean values for a given sample category (Table 8). This uniformity is also evident in the radioactivity levels for individual composite waste rock samples and overall mean values. These findings support the results of the beta-gamma survey (Appendix C) and indicate that ore and waste rock from the Crandon deposit have uniform radioactivity throughout the orebody. On the basis of the above findings, the individual composite sample data sets were grouped into major sample categories, e.g., massive

ore, stringer ore, waste rock, and only overall means and ranges were presented. These data are summarized by major category in Table 6.

Radioactivity levels in massive and stringer ores and the waste rock were similar, but were lower than those in the granite outcrop. For example, the granite outcrop gross beta activity of 43.0±4.5 pCi/g exceeded the average values for waste rock, massive ore, and stringer ore of 26.8, 38.1, and 36.7 pCi/g, respectively (Table 6). A similar trend was evident for gross alpha activity with the massive and stringer ores averaging 4.7±1.1 and 3.2±1.0 pCi/g, respectively, and the granite outcrop 20.7±6.3 pCi/g. Thus, the granite outcrop had gross alpha activity approximately 4 times higher than that in massive ore and 6 times higher than that for stringer ore.

Average levels of radium-226, determined by the Rn-222 emanation method, in the Crandon deposit also were lower than those in the granite outcrop. The radium-226 level in stringer ore averaged 0.27±0.06 pCi/g, the lowest average for any of the sample bedrock types. Waste rock and massive ore displayed slightly higher average values of 0.66±0.20 and 0.74±0.22 pCi/g, respectively, and the highest value 1.54±0.05 pCi/g was in the granite outcrop. Average levels of Ra-226 and Th-228 obtained from gamma spectroscopic analysis were also highest in the granite outcrop and lowest in stringer ore with exception of K-40 where massive ore had the lowest activity.

Average uranium and thorium levels in the waste rock and ore samples from the Crandon deposit and the granite outcrop followed the trend noted above. Calculated mean total uranium levels were 0.90±0.31 pCi/g (1.33±0.46 ppm) and <0.56 pCi/g (<0.83 ppm) for massive and stringer

ores, respectively, whereas the highest level was recorded in the granite outcrop 2.94 pCi/g (4.34 ppm). Mean total thorium levels ranged from 0.65 to 1.66 pCi/g (2.98 to 7.61 ppm) in the composite samples from the Crandon deposit versus 4.9±0.5 pCi/g (22.5±2.3 ppm) for the granite outcrop.

In general, radioactivity levels were lowest in the Crandon massive and stringer ores and highest in the granite outcrop. Potassium-40, total uranium, and total thorium concentrations in the ore and waste rock samples were similar to those reported for basaltic and mafic igneous rocks in other portions of the United States (Table 7). Values reported by Rogers (1964) for uranium and thorium in granite samples from Minnesota were similar to those measured in the granite outcrop. He reported values of 3.2 and 20 ppm for uranium and thorium, respectively. Overall, radioactivity levels in the Crandon deposit were very low and were comparable to the values for unmineralized igneous rocks (e.g., granite) reported in the literature.

5.0 Quality Assurance/Quality Control

Hazleton Environmental Sciences' Nuclear Department has a fully developed and operational Quality Assurance Program along with a Quality Control Program for Radiological Environmental Measurements.

The Hazleton Quality Assurance Program is based on the Nuclear Regulatory Commission's "Quality Assurance Criteria for Nuclear Power Plants" (10CFR50, Appendix B) and is applicable to environmental work performed for all industries. The Quality Assurance Program defines the organization, procedures, and actions taken by management to assure that results of studies and analyses are acceptable to both, clients and regulatory agencies. The specific objectives of the Program are described below.

To assure that technical personnel who collect, analyze, and report environmental data are adequately trained to perform their required functions.

To provide adequate confidence that methods, techniques, and procedures used to collect, analyze, and report environmental data will result in scientifically sound data so that study objectives can be met.

To provide assurance that methods, techniques, and procedures used to collect, analyze, and report environmental data are documented and approved.

To assure that departments, groups, and individuals who collect, analyze, and report environmental data comply with contractual specifications and quality assurance/control requirements in the performance of their work.

To insure that the required documentation of quality assurance/control performance is generated in the proper sequence at the time of the performance of the work, and that such records are adequate and complete.

To assure that prompt corrective action measures are implemented by management to correct conditions of unacceptable quality.

To provide a final permanent quality assurance documentation file which is identifiable and traceable to each item.

The quality assurance/control elements which are included in the Quality Assurance Program are briefly described below.

DESIGN CONTROL provides for the preparation, approval, periodic review of, and change control to project-specific Study Plans. Study Plans describe the activities and tasks to be accomplished and outline the basic framework for performing the work.

PROCUREMENT DOCUMENT CONTROL provides for the preparation, review, and approval of procurement documents used to purchase items or services for environmental studies.

INSTRUCTIONS, PROCEDURES, POLICIES, AND DRAWINGS provide for activities affecting quality to be prescribed by and accomplished according to written work instructions.

DOCUMENT CONTROL provides for the preparation, review, approval, distribution, and revision of work instructions and provides for the identification of all pertinent documents used for each project or program.

CONTROL OF PURCHASED MATERIAL, EQUIPMENT, AND SERVICES provides for the selection of procurement sources and the acceptance methods used for control of purchased items and services.

IDENTIFICATION AND CONTROL OF MATERIAL, PARTS, AND COMPONENTS provides requirements for the identification and control of samples, data, reports, calculations, and purchased items and services for environmental studies.

CONTROL OF SPECIAL PROCESSES provides that field studies, laboratory analyses, equipment calibration, data reduction and analyses, etc. are accomplished under controlled conditions by trained pesonnel using approved work instructions and equipment.

QUALITY VERIFICATION provides for the preparation of quality verification plans, the assignment of technical reviewers, the review of the reports, and the control of calculations for each project to insure that Study Plan and quality assurance/control tasks have been performed according to specified requirements.

TEST CONTROL provides that test programs be developed and implemented to demonstrate that an instrument or system will perform satisfactorily in service.

CONTROL OF MEASURING AND TEST EQUIPMENT provides that inspection, measurement, and test equipment be controlled, calibrated, and adjusted at specific periods to maintain accuracy within prescribed limits.

HANDLING, STORAGE, SHIPPING, AND PRESERVATIONS provide the requirements for the handling, storage, shipping, and preservation of samples, data, and records.

INSPECTION, TEST, AND OPERATING STATUS provide for the reporting of the status of field programs with respect to field data acquisition and equipment operating condition and maintenance requirements.

NONCONFORMING ITEMS provide a means for reporting project nonconformances.

QUALITY ASSURANCE RECORDS provide records which furnish evidence of the validity of work are identified, controlled, processed into a quality assurance record file, stored, and dispositioned according to requirements.

QUALITY ASSURANCE AUDITS provide for a comprehensive system of planned and periodic audits to be conducted by trained auditors to verify compliance with Quality Assurance Program and project requirements.

To insure the validity of data, Hazleton's Nuclear Sciences Department maintains a quality control (QC) program which employs quality control checks, with documentation, of the analytical phase of its environmental monitoring studies. The program is defined in a Nuclear Sciences QC Program Manual, and procedures are presented in a Nuclear Sciences QC Procedures Manual. These manuals are not included in this document but are available for inspection at Hazleton's Northbrook, Illinois offices.

Hazleton's Nuclear Sciences QC Program includes laboratory procedures designed to prevent cross contamination and to ensure accuracy and precision of analyses. The quality control checks include blind samples, duplicate samples, and spiked samples as necessary to verify that laboratory analyses activities are being maintained at a high level of accuracy.

The Quality Control Program is in compliance with USNRC Regulatory Guide 4.15 and includes appropriate control charts with specified acceptance levels for instrument source checks, background, and efficency for the counting equipment.

As a cross-check on the performance of Hazleton's Nuclear Department, blind duplicate samples were analyzed by Camp, Dresser and McKee's Nuclear Laboratory. CDM's laboratory has a Quality Assurance and Quality Control Program comparable to the Hazleton QA/QC Program outlined above.

Chain of custody records were maintained by Exxon for all composite samples prepared, and samples were sent for radiological analyses identified only by a code number. This allowed Exxon to provide the analytical laboratories blind duplicate samples as an accuracy and precision check on the analytical results.

Appendix D, Table D-1 presents a description of the sample used to insure an analytical data base of high quality with of blind duplicate samples and a cross-check laboratory.

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APPENDIX A

Ore Compositing Procedure

Appendix A

Ore Compositing Procedure

The process used to composite ore samples is discussed below through the use of an example. The example of the compositing procedure is illustrated in Figure A-1 and is representative of a core from a typical diamond drill hole that intersects massive and stringer ore below the 350 meter level. From each of the three 5-foot interval composites in massive ore, one level tablespoon (U.S. Standard) (one tablespoon is equivalent to three teaspoons as shown in Figure A-1) was placed in the massive subcomposite (points a to b). A similiar procedure was followed for stringer ore (points e to f) except only two intervals were sampled. Two ore interval weighted subcomposites, one per ore type, were obtained from these steps. These two subcomposites were then riffle blended. After blending, one-third, by volume, of the massive subcomposite was contributed to the below 350 meter level massive composite (points b to c) and one-third to the total orebody massive composite (points b to d). The remaining one-third of the massive subcomposite was stored. The same procedure was followed for the subcomposite of stringer ore (points f to g and f to h). These steps were repeated for massive and stringer ore above the 350 meter level in order to complete the ore compositing procedure.

The above process was repeated for each selected diamond drill hole intersecting the Crandon deposit above and below the 350 meter level until the final ore composites shown in Figure 2 (presented in the text, subsection 3.1.2.1) were prepared for radiological analysis. The diamond

drill holes that were sampled and the number of 5-foot interval composites sampled by ore type for the orebody composites are presented in Table A-1. Balanced and representative composites were obtained from this sampling procedure. As indicated in Table A-1, the same number of diamond drill holes contributed to the above and below 350 meter level composites, and approximately the same number of 5-foot interval composites and subsequent diamond drill hole subcomposites contributed to the final six ore composites shown in Figure 2.

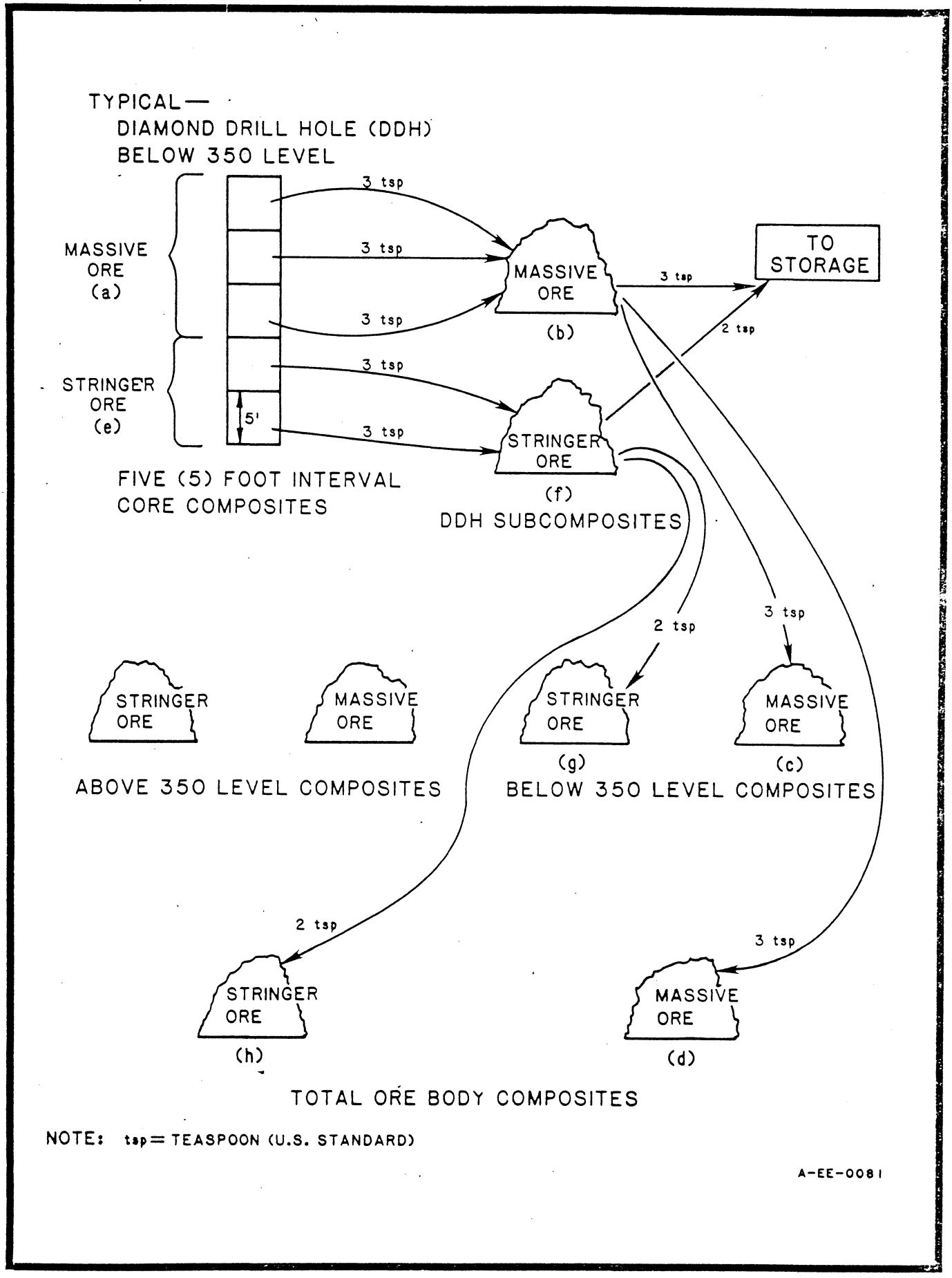

Figure A-1. Example of compositing procedure for Crandon ore radiological testing.

TABLE A-1

DIAMOND DRILL HOLES (DDH) AND CORRESPONDING FIVE FOOT INTERVAL (FFI) COMPOSITES CONTRIBUTING TO THE OREBODY COMPOSITES FOR THE RADIOLOGICAL TESTING PROGRAM CRANDON PROJECT

Summary Information	Below 350 Level[a] Number Of FFI Composites			Above 350 Level[a] Number of FFI Composites		
	DDH Number	Stringer Ore	Massive Ore	DDH Number	Stringer Ore	Massive Ore
	17	--	9	7	2	2
	25	6	2	8	22	--
	31[b]	--	--	11	19	--
	35[c]	10	4	62	--	4
	37[c]	17	2	69	3	19
	64	17	8	75	29	1
	65	6	7	78	11	--
	122	16	5	86	--	15
	123	--	8	95	--	3
	124	9	16	145	4	--
	131	--	9	169	--	39
	149	14	4	176	--	8
	152[b]	--	--	188	37	10
	159	9	36			
	160	23	--			
	198[b]	--	--			

TABLE A-1 (continued)

Summary Information	DDH Number	Below 350 Level[a] Number of FFI Composites: Stringer Ore	Below 350 Level[a] Number of FFI Composites: Massive Ore	DDH Number	Above 350 Level[a] Number of FFI Composites: Stringer Ore	Above 350 Level[a] Number of FFI Composites: Massive Ore
Number of DDH Contributing to "350 L Ore Composites"	13	--	--	13	--	--
Number of DDH Subcomposites Contributing to "350 L Ore Composites"	--	10	12	--	8	9
Number of FFI Composites Contributing to the "Total Orebody Composites"		STRINGER TOTAL = 254	MASSIVE TOTAL = 211			

[a] Diamond drill hole intercepts Crandon deposit mineralization either above or below the planned 350 meter level of mine development.

[b] Sampled only for waste rock.

[c] Individual FFI composites not analyzed during the beta-gamma radiation survey conducted April 7-9, 1981; these diamond drill holes were added to the program on April 13, 1981.

APPENDIX B

Analytical Methods

APPENDIX B

ANALYTICAL METHODS

B-1

SAMPLE PREPARATION

Appendix B-1.1

B-1.1 Soil

Principle of Method

The sample is air dried, pulverized, blended, and stored in an air tight container for analyses.

Procedure

1. Air dry the entire sample. Remove roots and stones larger than 1/4 inch in diameter. Pulverize the sample and sieve through a No. 20 mesh screen.

2. To blend, transfer the sample to 0.5 gallon plastic container, seal tightly, and tumble on an electric tumbler for half an hour.

3. For gamma-spectroscopic analysis, seal 450 cc of the pulverized and blended sample in a 500 ml Marinelli beaker. Record the weight.

4. Seal the remaining sample (up to 1 kg) in a plastic container and save for other analyses or for possible future rechecking.

Appendix B-1.2

B-1.2 Bedrock

Sample preparation procedure for bedrock samples is discussed in Appendix A.

B-2

GROSS ALPHA AND GROSS BETA ACTIVITY DETERMINATION

Appendix B-2

B-2 Gross Alpha and Gross Beta Activity in Soil and Bedrock Samples

Principle of Method

Pulverized and homogenized sample is slurred on a 2 inch ringed planchet, spread uniformly, dryed, and counted in a low background proportional counter.

Procedure

1. Weigh out on a planchet approximately 100 mg of pulverized and homogenized sample for gross alpha assay and approximately 200 mg for gross beta assay.

   NOTE: For gross alpha and gross beta assay in the same sample use 100 mg of sample.

2. Add a few drops of water and spread uniformly over the area of the planchet. Dry under the lamp.

3. Add 2-3 drops of lucite solution in acetone and dry again under the lamp.

4. Count the gross alpha and gross beta activity in low background proportional counter.

5. Calculate the activity in pCi/g using computer program ALFBET.

Calculations:

Gross alpha (beta) activity:

$$(pCi/g) = \frac{A}{B \times C \times D \times 2.22} \pm \frac{2\sqrt{E_{sb}^2 + E_b^2}}{B \times C \times D \times 2.22}$$

Where:

- A = net alpha (beta) count (cpm)
- B = efficiency for counting alpha (beta) activity (cpm/dpm)
- C = weight of sample (grams)
- D = correction factor for self-absorption in the sample
- E_{sb} = counting error of sample plus background
- E_b = counting error of background

Reference:

Radioassay Procedures for Environmental Samples, U.S. Department of Health, Education and Welfare. Environmental Health Series, January 1967.

B-3

GAMMA SPECTROSCOPIC ANALYSIS BY GE(LI) DETECTOR

Appendix B-3

B-3 Gamma Spectroscopic Analyses by Ge(Li) Detector

Principle of Method

The pulverized and blended sample is transferred to a suitable container and counted on the Ge(Li) detector. The spectrum is computer scanned from 100 KeV to 2,000 KeV and the detected radionuclides are identified and quantified.

Procedure

1. Transfer (if not yet transferred) the portion of pulverized and blended sample set aside for gamma scanning into a 450 ml Marinelli beaker.

2. Record the weight.

3. Place the container inside the shield on a Ge(Li) detector.

4. Count the gamma activity in a gamma spectrometer long enough to meet the minimum sensitivity requirements.

5. After counting, identify gamma emitters (if present) by their respective peaks.

6. Store the spectrum on the disc using the computer by running RUN STORE for Ortec system or RUN DXFER for H-P system.

7. After storing, calculate gamma activities using computer Program GAMMA 1 or GAMMA 2.

8. Transfer the sample back to the original container for further analyses.

B-4

RADIUM-226 IN SOIL AND BEDROCK SAMPLES

Appendix B-4

B-4 Radium-226 in Soil and Bedrock Samples

Principle of Method

The sample is decomposed with nitric acid and pyrosulfate fusion. Radium, actinium, and thorium are separated from other constituents on lead sulfate, then radium is separated on barium sulfate. Ra-226 is determined by Rn-222 emanation method.

Reagents

Acetic acid, CH_3COOH: 6 N
Actinium wash solution
Ammonium acetate buffer, pH 4.6
Ammonium sulfate, $(HN_4)_2\ SO_4$: 50% w/v in water
Barium chloride dihydrate, $BaCl_2$: 0.45% w/v in water
Ba-133 tracer: appr. 5,000-10,000 dpm/ml
Carrier solutions
    Ba^{+2} as barium nitrate, $Ba(NO_3)_2$: 20 mg B^{+2} per ml
    Ce^{+3} as cerous nitrate, $Ce\ (NO_3)_3.6.H_2O$: 5 mg Ce^{+3} per ml
Diammonium oxalate $(NH_4)_2C_2O_2.H_2O$: 0.2 N, 0.02 N
Diethylenetriaminepentaacetic acid (DTPA): 0.17 M
Di (2-ethyl-hexyl) phosphoric acid, (HDEHP): 15%
Disodium ethylenediamine Tetraacetate (EDTA),
    $Na_2C_{10}H_{14}O_8N_2.2H_2O$: 10% w/v in water
Ethyl alcohol, CH_3CH_2OH, (EtOH)
Hydrochloric acid, HCl: concentrated (12 N), 4N
Hydrofluoric acid, HF; concentrated (1.5 N, 48%)
Hydrogen peroxide, H_2O_2: 30% solution
Lead nitrate, $PC\ (NO_3)_2$: 3.2% solution
Lead sulfate wash solution
Monochloroacetic acid: CH_2ClOOH: 2 N
Nitric acid, HNO_3: concentrated (16 N), 1N, 10%
Perchloric acid, $HClO_4$: concentrated (12 N - 72%)
Potassium fluoride, anhydrous, KF; 12 N (11,6 N -70-72%)
Potassium sulfate, anhydrous, K_2SO_4
Sodium acetate, $NaC_2H_3O_2$: saturated solution
Sodium carbonate, Na_2CO_3: anhydrous, 3 N
Sodium Diethylenetriamine pentacetate (DTPA), 0.17 M
Sodium sulfate, anhydrous, Na_2SO_4: anhydrous, 20% w/v in water
Sulfuric acid, H_2SO_4: concentrated (36N), 2 N
Sulfuric-Hydrochloric acid solution
Tetrasodium salt of EDTA: 30% w/v in water
2-thenoyltrifluoroacetone (TTA): 10% w/v in water
Triethanolamine, $N(CH_2CH_2OH)_3$: 1:1

Apparatus

Desiccator
Drying oven
Filter paper, Whatman No. 42
Gamma scintillation counter
Magnetic stirrer
Muffle furnace
pH Meter
Platinum crucible
Plastic scintillation vials, 22 ml capacity, for counting Ba-133 gamma activity

Separatory funnel: 60 ml capacity
Suction-filtration flask

Appendix B-4.1

B-4.1 Decomposition - Method 1

NOTE 1: Since many chemicals contain trace amount of radium, it is necessary to run a blank when a new batch of chemicals is used.

NOTE 2: This method should be used for samples in the 0.1 to 1.0 g weight range. For larger samples (5 g) Method 2 should be used.

1. Add 2 ml of conc. HNO_3 acid to a 0.1-0.5 g sample in a platinum crucible at one edge of the powder.

   NOTE 3: For 1 g samples, use the same quantities of nitric and hydrofluoric acids but double the quantities of all other reagents including the sulfuric-hydrochloric acid solution.

   NOTE 4: Smell cautiously to see if hydrogen sulfide (H_2S) is being evolved. If sulfides are present, add excess HNO_3 acid and evaporate to near dryness before evaporating with HF acid to avoid adverse effects on the platinum dish.

2. Add 3 ml of 48% HF acid to wet the entire sample thoroughly and evaporate to near dryness, leaving the cake barely moist with acid.

3. Add 1 ml of Ba-133 tracer in 10% HNO_3 acid and reevaporate gently.

4. Sprinkle 3 g of anhydrous potassium fluoride over the residue, mix coarsely with a stirring rod, and fuse on a ring stand over a blast burner until a clear melt is obtained.

5. Cool the melt, add 4 ml of conc. H_2SO_4 acid and heat gently on a hot plate until all hydrogen fluoride, silicon tetrafluoride, and water have been expelled.

6. Heat the crucible over a blast burner until copious fumes of H_2SO_4 acid are evolved, add 2 g of anhydrous sodium sulfate, and continue heating until a clear pyrosulfate fusion is obtained.

   NOTE: Do not heat longer than necessary to minimize dissolution of platinum.

7. Cool the melt with gentle swirling to deposit the cake in a thin uniform layer up the sides of the crucible to facilitate removal of the cake.

8. Loosen the pyrosulfate fusion cake by flexing the sides of the crucible and tapping the bottom on a flat surface.

9. Transfer the cake to a 250 ml beaker and dissolve the cake in 60 ml of H_2SO_4-HCl acid solution and 1 ml of 30% hydrogen peroxide.

10. Proceed to the "Separation on Lead Sulfate" as described in Appendix B-4.3.

Appendix B-4.2

B-4.2 Decomposition - Method 2

NOTE: This method should be used when increased sensitivity in the determination of natural levels of activity in soils, sand, and ashed vegetation is desired.

Procedure

1. Add 10 ml of concentrated HNO_3 to a 5 g sample in a platinum crucible.

   NOTE: Smell cautiously to see if hydrogen sulfide (H_2S) is being evolved. If sulfides are present, add excess HNO_3 acid and evaporate to near dryness before adding HF acid to avoid adverse effects on the platinum dish.

2. Add 10 ml of 48% HF acid to wet the entire sample thoroughly and evaporate to near dryness.

3. Add 1 ml of Ba-133 tracer.

4. Moisten the residue with 2 ml of 4 M HNO_3.

5. Add 30 g of anhydrous potassium fluoride, (KF) mix coarsely with a stirring rod, and fire on a ring stand over a blast burner until a clear melt is obtained.

6. Cool the melt, add 35 ml of concentrated H_2SO_4 acid and heat gently on a hot plate until all hydrogen fluoride, silicone tetrafluoride, and water have been expelled.

7. Heat the crucible over a blast burner until copious fumes of H_2SO_4 acid are evolved, add 20 g of anhydrous sodium sulfate, and continue heating until a clear pyrosulfate fusion is obtained.

   NOTE: Do not heat longer than necessary to minimize dissolution of platinum.

8. Cool the melt with gentle swirling in order to depost a thin, uniform layer up the sides of the crucible to facilitate removal of the cake.

9. Loosen the pyrosulfate fusion cake by flexing the sides of the crucible and tapping the bottom on a flat surface.

10. Transfer the cake to a 1 liter beaker and dissolve it in 500 ml of water, 30 ml of concentrated H_2SO_4 acid, 10 ml of concentrated HCl acid, and 10 ml of 30% hydrogen peroxide (H_2O_2).

11. Add two boiling chips, heat the sample to boiling and continue as described under "Separation on Lead Sulfate", Appendix B-4.4.

Appendix B-4.3

B-4.3 Separation on Lead Sulfate - Method 1

NOTE: This procedure is used for samples in the 0.1 to 1.0 g weight range.

Procedure

1. Boil the solution.

NOTE: Radium, thorium, and actinium are separated on lead sulfate.

2. To the boiling ± solution add 5 ml of 3.2% lead nitrate solution over a 20 sec (±5 sec) interval while stirring or swirling the boiling solution continuously (or use stirrer).

3. Boil the sample for 1 to 2 min.

4. Add second 5 ml portion of lead nitrate solution in the same manner (Step 2).

5. Cover the beaker with a watch glass and boil the sample for 1 min with occasional swirling of the smaller samples.

6. Cool the samples to at least room temperature in a bath of cold running water.

7. Transfer the contents of the beaker, except the stirrer, to a centrifuge tube with lead sulfate wash solution and centrifuge at 2000 rpm for 5 min with this and all subsequent centrifugations.

8. Decant and discard the supernate.

9. Wash the precipitate with 25 ml of the lead sulfate wash solution, centrifuge, and discard supernate.

10. Proceed to the "Radium Separation" as described in Appendix B-4.4.

Appendix B-4.4

B-4.4 Separation on Lead Sulfate - Method II

NOTE: This procedure is used for samples in the 1.0 to 5.0 g weight range.

Procedure

1. Boil the solution.

NOTE: Radium, thorium, and actinium are separated on lead sulfate.

2. To the boiling solution add 5 ml of 3.2% lead nitrate solution over a 20 sec (±5 sec) interval while stirring or swirling the boiling solution continuously (or use stirrer).

3. Boil the sample for 1 to 2 min.

4. Add second 5 ml portion of lead nitrate solution in the same manner (Step 2).

5. Cover the beaker with a watch glass and boil the sample for 1 min with occasional swirling of the smaller samples.

6. Cool the samples to at least room temperature in a bath of cold running water.

7. Filter the entire sample, excluding the boiling chip, through 5.5 cm Whatman 40 paper using suction. Use lead sulfate wash solution to transfer the precipitate to the filter.

8. Fold the filter and place it in a 125 ml Erlenmeyer flask.

9. Wet ash the filter with 5 ml of conc. HNO_3 and 2 ml of 72% perchloric acid.

10. Add 4.5 g of anhydrous potassium sulfate, 2 g of anhydrous sodium sulfate, 4 ml of conc. H_2SO_4 and fuse the sample over a high temperature blast burner. Any turbidity is probably due to siliceous material and may be ignored at this point. The best place to interrupt the procedure when the remaining steps cannot be completed on the same day is after the pyrosulfate fusion.

11. Add a boiling chip, 60 ml of sulfuric-hydrochloric acid solution, 2 ml of 30% hydrogen peroxide, and dissolve the fusion cake with heatings.

12. Boil the solution vigorously for 10 min with occasional swirling.

13. Cool in a cold water bath for 10 min. Transfer the contents of the flask, except the boiling chip, to a centrifuge tube and centrifuge.

14. After centrifugation decant and discard the supernate.

15. Wash the precipitate with 25 ml of the lead sulfate wash solution, centrifuge and discard the supernate.

16. Proceed to the "Radium Separation" as described in Appendix B-4.5.

Appendix B-4.5

B-4.5 Radium Separation

NOTE: The lead sulfate contains radium, actinium, and thorium which are subsequently separated from lead and from each other.

Procedure

1. Dissolve the lead sulfate in 15 ml of 0.17 M DTPA with stirring and heating.

2. Centrifuge the solution if silica or other insoluble material is present.

3. Transfer the supernate to a 40 ml conical centrifuge tube containing 2 ml of 0.45% barium chloride dihydrate solution, 1 ml of 20% sodium sulfate solution, and dilute with H_2O to 28 ml.

4. While swirling the solution, add 2 ml of 6 M acetic acid.

5 Heat the sample in a bath of boiling water for 5 min with occasional swirling during the digestion.

6. Cool the sample for 5 min in a cold water bath.

7. While swirling the sample continuously, add 4 drops of 0.45% barium chloride dihydrate solution with 5 sec intervals between drops.

8. Cool for another 10 min and then centrifuge. Decant suprnate to waste. Add 1 ml H_2O and store.

9. Dissolve the barium sulfate in the 40 ml centrifuge tube in 7.5 ml of 0.17 DTPA with heat and stirring.

10. Add 1 ml of 20% sodium sulfate and dilute with water to 19 ml.

11. Reprecipitate the barium sulfate by adding 1 ml of 6 M acetic acid.

12. Repeat steps 5-8.

13. Dissolve the barium sulfate in 7.5 ml of 0.17 M DTPA with heat and stirring.

14. Transfer the sample to the plastic scintillation vial; rinse the tube several times with a small amount of 0.17 M DTPA solution.

15. Equalize the volume in all plastic vials using 0.17 M DTPA solution.

16. Put a few ml of 0.17 M DTPA solution in a new plastic vial, add 1 ml of Ba-133 tracer and bring the volume to the same level as in samples. (Standard).

17. Fill a new plastic vial with DTPA solution to the same level as in samples. (Background).

18. Count in the gamma counter for at least 6000 sec.

19. Transfer the solution (samples only) to a radon bubbler using EDTA (30%) solution to rinse the vial and proceed with analysis as described in "Emanation Procedure for Radium-226," Appendix B-5.

References:

Radioassay Procedures for Environmental Samples, U.S. Department of Health, Education and Welfare. Environmental Health Series, January 1967.

HASL Procedures Manual, HASL-300, 1972. J.H. Harley, Editor.

Donald R. Percival and Don B. Martin. Sequential Determinatin of Radium-226, Radium-228, Acinium-227, and Thorium Isotopes in Environmental and Process Waste Samples. Health Services Laboratory, U.S. Atomic Energy Commission, Idaho Falls, Idaho. Analytical Chemistry. Vol. 46, No. 12, pp.1742-1949, October, 1974.

B-5

RADIUM-226 BY RADON-222 EMANATION METHOD

Appendix B-5

B-5 Ra-226 by Rn-222 Emanation Method

Principle of Method

Solution containing radium-barium salt is transferred to an emanation tube (radon bubbler), de-emanated with aged air or helium, and stored for 14 to 28 days to allow for radon-222 ingrowth. After ingrowth period, the radon-222 is removed to a scintillation cell by de-emanating the bubbler. The cell is stored for at least 30 min to allow for actinon (Rn-219) and thoron (Rn-220) and its daughters to decay. Then Rn-222 and its daughters, Po-214 and Po-218 are counted in a radon counter.

Apparatus

Drying tube, 5-mm diameter by 10 cm long
Emanation apparatus: radon bubbler, manometer, vacuum line as shown in Figures B-1 and B-2.
Radon counter
Scintillation cell, as shown in Figure B-3.

Procedure

1. Immerse radon bubbler to the same level as sample in a beaker with ice and water (chilling facilitates formation of smaller bubbles).

2. With tubing, connect a tank of dry, aged air or helium to the radon bubbler (as shown in Figure B-1). Limit the gas pressure to 1-2 pounds. Caution: Needle valve should be closed at this stage.

3. Open stopcock No. 3.

4. Open stopcock No. 4 very slowly to prevent a pressure surge if needle valve is not closed completely.

5. Open needle valve very slowly. Adjust flow rate to produce steady formation of bubbles but do not allow bubbles to rise to stopcock No. 3.

6. De-emanate for 20 min.

7. After 20 min close needle valve, stopcock No. 4 and stopcock No. 3 in that order. RECORD THE DATE AND TIME AS BEGINNING OF Rn-222 INGROWTH.

8. Store the bubbler from 14 to 28 days. After the ingrowth period, prepare and use the emanation apparatus as described in the following steps.

9. Attach a scintillation cell to a U-tube manometer as shown in Figure B-1.

NOTE: Glass joints with O-ring seals are used at Hazleton laboratory because they require less stopcock grease than other types.

10. Fill the drying tube half full of Ascarite; then fill to the top with anhydrous magnesium perchlorate. Attach the drying tube to the emanation tube (radon bubbler) containing the sample solution with a short piece of tubing. With another piece of tubing, attach the drying tube to a short length of thermometer capillary tubing, and attach the thermometer tubing to the manometer.

11. Open Stopcock No. 1, and apply a vacuum to the system.

12. When the mercury in the right-hand leg of the manometer reaches its maximum height, close Stopcock No. 1.

13. Leave the system in this configuration for 3 to 5 min to test for leaks. If the mercury begins to drop, check the glass joints and tubing connections for leaks. If necessary, apply a very light coating of silicone grease to the leaking connections. Then repeat Steps 12 and 13.

14. Open Stopcocks No. 1 and No. 2 and allow the mercury in the right-hand leg of the manometer (as shown in Figure B-1) to reach its maximum height. Close Stopcock No. 1 and check for leaks as in Step 13.

15. With tubing, connect a tank of dry, aged air or helium to the radon bubbler. Limit the gas pressure to 1-2 pounds. A needle valve is placed between the air tank regulator and the bubbler to regulate the pressure.

16. Open Stopcock No. 3 slowly to prevent a pressure surge. Open Stopcock No. 4 very slowly. Open needle valve very slowly. RECORD THE DATE AND TIME of the beginning of de-emanation.

17. Regulate the gas flow through the bubbler at a fairly constant rate by occasionally adjusting the pressure with the needle valve.

18. With the needle valve control the flow of gas through the bubbler so that the transfer of radon is completed within 20-25 min.

19. When the level of mercury in both legs of the manometer is the same (at atmospheric pressure), close the needle valve and Stopcocks No.s 4, 3, and 2 in that order. RECORD THE DATE AND TIME.

20. Remove the scintillation cell and store it in a light-tight cabinet for 30 min to allow any actinon or thoron to decay out.

21. Remove the purged bubbler. The emanation system is ready for the next sample.

22. Count the alpha activity of the scintillation cell in a radon counter.

23. Calculate Ra-226 in pCi per gram using computer program Ra-226.

NOTE: Hazleton computer program allows for simultaneous decay calculation of Rn-222 and ingrowth of its daughters after 30 min storage time. If the formula, as given below, is used, store the cell for 4 hr to allow the daughters to reach secular equilibrium with their parent, Rn-222.

Calculation

$$\text{radium 226 activity (pCi/gram of sample)} = \frac{A \times B}{C \times D \times E \times F}$$

where

A = net alpha count rate of radon 222 and daughters in counts per hour (cph)

B = multiplicative correction factor ($e^{-\lambda t}$ /1-$e^{-\lambda t}$) for radon-222 decay during the counting period in hours and λ is the radon-222 decay constant

C = efficiency of the scintillation cell and counter for radon-222 detection obtained experimentally for each cell-counter system ($cph^{222}Rn/pCi^{226}Ra$)

D = correction factor $1-e^{-\lambda t_2}$ for radon-222 buildup in the radon bubbler; where, t_2 is the time from the beginning of the storage period to the final de-emanation (Step 19), and λ is the decay constant for radon-222

E = correction factor $e^{-\lambda t_3}$ for radon-222 decay from the final de-emanation (Step 19) to the beginning of the counting period (Step 22) where t_3 is the time in hours from final de-emanation to the beginning of the count, and λ is the radon-222 decay constant

F = weight of sample

Note that the decay constants must be expressed in reciprocal hours in this formula, and that the count rate is the average count rate over the entire counting period expressed in counts per hour.

The efficiency term C takes into account the 3 to 1 ratio of alpha counts per radon-222 disintegration. This efficiency or calibration factor must be determined experimentally for each cell counted on each radon counter to be used. A value of about 0.8 can be expected.

NOTE: Efficiency of de-emanation need not be determined as long as the bubbler is de-emanated over at least a 20 min period. Under these conditions efficiency of de-emanation is 100 percent.

References: Radioassay Procedures for Environmental Samples, U.S. Department of Health, Education and Welfare. Environmental Health Series, January 1967.

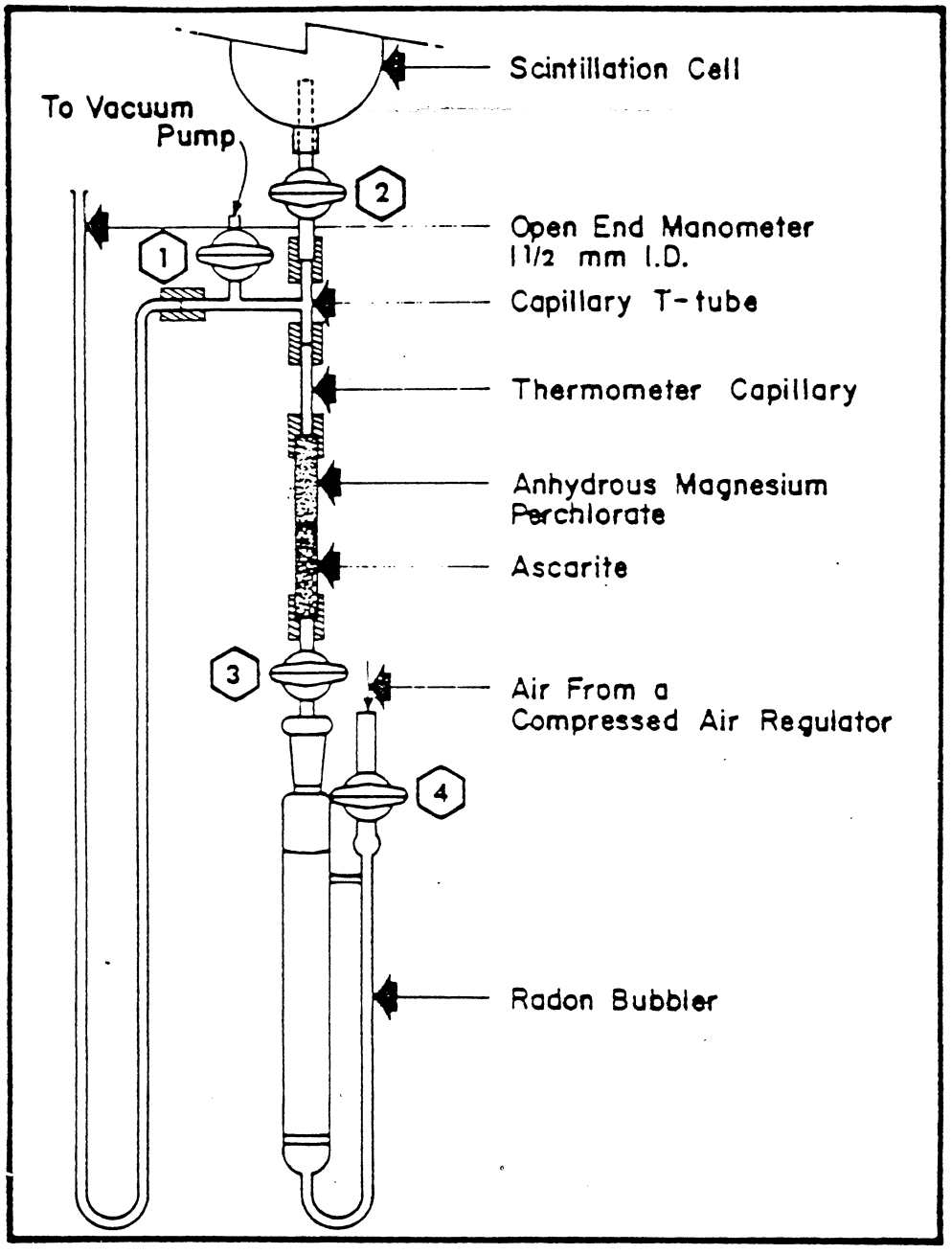

Figure B-1. Radon emanation apparatus with scintillation cell.

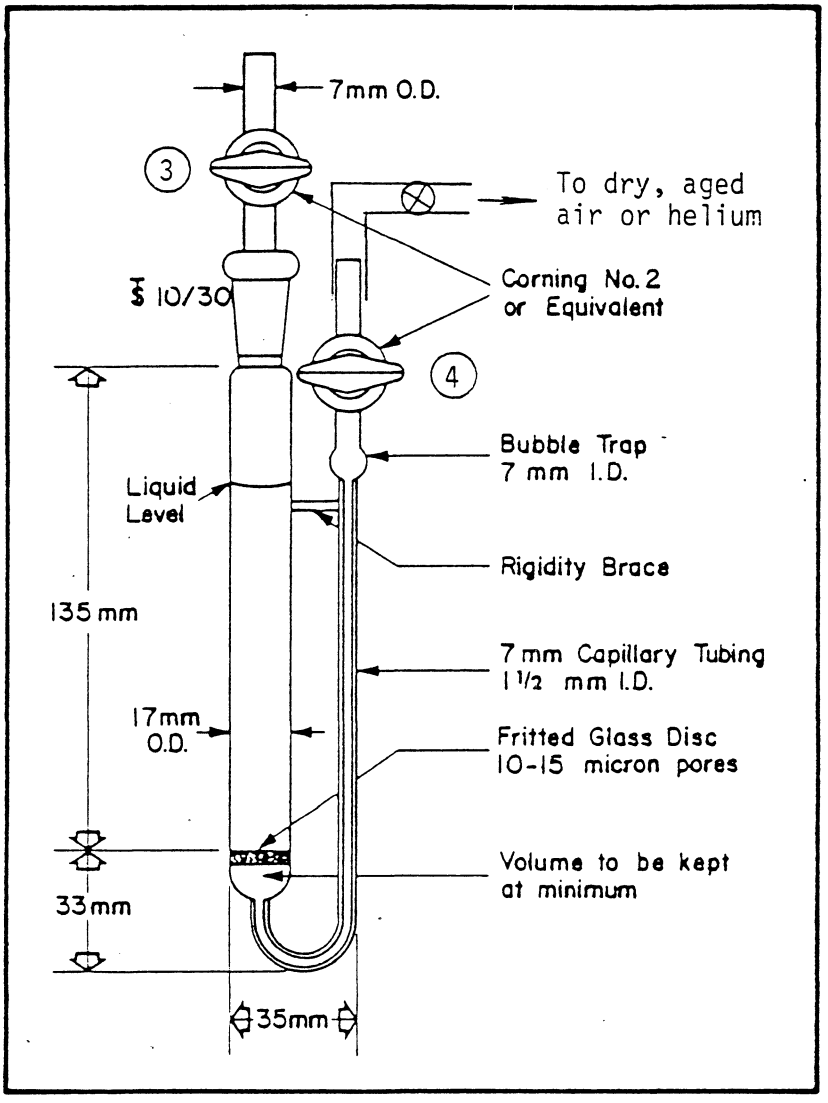

Figure B-2. A radon bubbler (emanation tube).

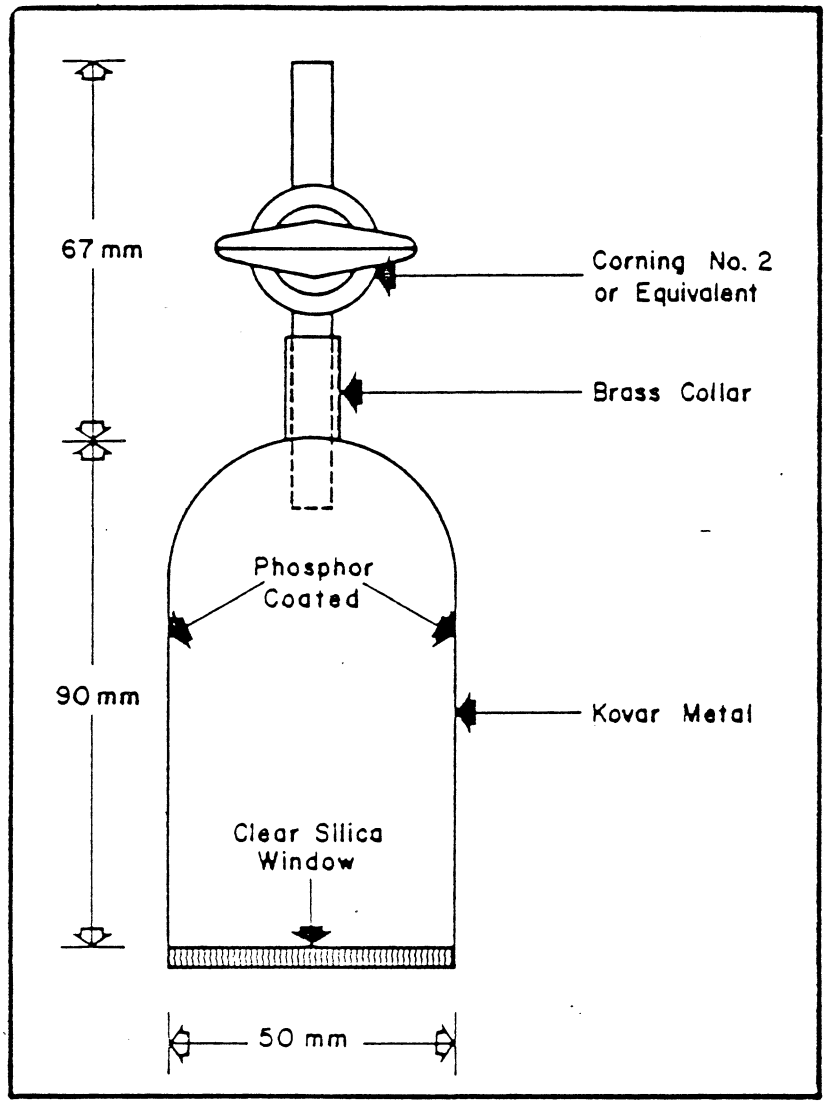

Figure B-3. A typical scintillation cell for radon counting.

B-6

TOTAL URANIUM

Appendix B-6

Total Uranium

A 0.5 gram sample was digested with nitric, sulfuric, percholic, and hydrofluoric acid and evaporated until dry. The residue was dissolved in dilute nitric acid and extracted with ethyl acetate. An aliquot of the organic layer was pipeted onto a NaF-LiF pellet and fused using a Geoco fusion burner. The pellet was exposed to ultraviolet light and the fluorescence measured using a fluorometer. The results are presented in pCi/g and ppm. Calculation information is provided in the reference cited below.

Reference: Harley (1975)

Instrument: G-M Fluorometer (Jarrel-Ash Model 26-000) - CDM

B-7

TOTAL THORIUM

Appendix B-7

Total Thorium

The sample was digested in nitric, sulfuric, and hydrofluoric acid. The digested sample (0.25 to 2.0 grams) was evaporated and diluted with nitric acid. The thorium was separated by passing the solution through an ion exchange column. After washing, the thorium was eluted from the column with hydrochloric acid and transferred to a stainless steel planchet for alpha counting. The results are presented in pCi/g and ppm. Calculation information is provided in the reference cited below.

Reference: Latimer et al. (1940)

Instrument: Internal Proportional Counter/Scaler, PCC-ITT/DS-2 - CDM

APPENDIX C

Radiation Survey Data

Appendix C

Radiation Survey Data

Crandon Project

Contained in this appendix are data obtained from a beta-gamma survey of diamond drill hole ore samples using a Ludlum Model 12 survey meter with a Ludlum End Window G.M. Model 44-7 detector. These data were obtained on April 7 through 9, 1981.

When referring to the Table C-1, the column heading, Gross β-γ (cpm), refers to the total count rate of the sample plus background. The column heading, Bkg (cpm), indicates the variation in the background count rate. Three numbers are listed under the background column heading showing upper, lower and median values for the background count rate. The median background rate was used to determine the net sample count rate (i.e., gross count rate minus median background count rate). These data are presented in the column headed Net β-γ (cpm). Some values found in the net column are positive, non-zero numbers. It should be noted, that in order for these values (as measured on unconcentrated samples) to be considered as a real indication of activity present in the sample, the gross sample count rate would have to exceed the upper limit range of the background count rate.

Appendix C

Table C-1
BETA-GAMMA SURVEY MEASUREMENTS
OF DIAMOND DRILL HOLE ORE SAMPLES FOR THE
RADIOLOCIGAL TESTING PROGRAM, CRANDON PROJECT
April 7-9, 1981

Survey Meter - Ludlum Model 12 Detector - Ludlum End Window G.M. Model 44-7

Hole #	Interval (ft)	Sample #	Ore Type*	Gross β-γ (cpm)	Bkg (cpm)	Net β-γ (cpm)
75	443-452	3	M	30	15←25cpm→35	5
75	492-497	11	S	25		0
75	497-502	12	S	30		5
75	502-507	13	S	25		0
75	507-512	14	S	25		0
75	512-517	15	S	25		0
75	517-522	16	S	25		0
75	522-527	17	S	25	25	0
75	527-532	18	S	30		5
75	532-537	19	S	25		0
75	537-542	20	S	30		5
75	542-547	21	S	25		0
75	547-552	22	S	25		0
75	552-557	23	S	25	25	0
75	557-562	24	S	25		0
75	562-567	25	S	25		0
75	567-572	26	S	30		5
75	572-577	27	S	25		0
75	577-582	28	S	25		0
75	582-587	29	S	25		0
75	587-592	30	S	25		0
75	592-597	31	S	25		0
75	597-602	32	S	25		0
75	602-607	33	S	25		0
75	607-612	34	S	25		0
75	612-617	35	S	25		0
75	617-622	36	S	25		0
75	622-627	37	S	25		0
75	627-632	38	S	25	25	0
75	632-637	39	S	25		0
7	356-361	24	M	25	25	0
7	361-366	25	M	25		0
7	1125-1130	113	S	25		0
7	1130-1135	114	S	25		0
8	850-855	74	S	25	25	0
8	855-860	75	S	25		0
8	860-865	76	S	25		0
8	865-870	77	S	25		0
8	870-875	78	S	25		0
8	875-880	79	S	25		0
8	880-885	80	S	25		0
8	885-890	81	S	25		0

*M = massive ore S = stringer ore

Table C-1 (continued)

Hole #	Interval (ft)	Sample #	Ore Type	Gross β-γ (cpm)	Bkg (cpm)	Net β-γ (cpm)
8	890-895	82	S	30	15←25→35	5
8	895-900	83	S	25		0
8	900-905	84	S	25		0
8	905-910	85	S	30	15←25→35	5
8	910-915	86	S	25		0
8	915-920	87	S	25		0
8	920-925	88	S	25		0
8	925-930	89	S	30		5
8	930-935	90	S	30		5
8	935-940	91	S	25		0
8	940-945	92	S	25		0
8	945-950	93	S	25		0
8	950-955	94	S	25		0
8	955-960	95	S	30		5
78	781-786	11	S	25	15←25→35	0
78	786-791	12	S	30		5
78	791-796	13	S	30		5
78	840-845	23	S	25		0
78	845-850	24	S	30		5
78	850-855	25	S	25		0
78	905-910	33	S	25		0
78	910-915	34	S	25		0
78	915-920	35	S	25		0
78	953-958	39	S	25		0
78	958-965	40	S	25		0
86	342-347	11	M	25	15←25→40	0
86	347-352	12	M	25		0
86	352-357	13	M	30		5
86	357-362	14	M	25		0
86	362-367	15	M	25		0
86	367-372	16	M	25	15←25→35	0
86	372-377	17	M	25		0
86	377-382	18	M	30		5
86	382-387	19	M	25		0
86	387-392	20	M	30		5
86	392-397	21	M	25		0
86	397-402	22	M	25		0
86	402-407	23	M	25		0
86	407-412	24	M	25		0
86	412-417	25	M	30		5
95	385-390	1	M	25	15←25→35	0
95	390-395	2	M	30		5
95	395-400	3	M	30		5

Table C-1 (continued)

Hole #	Interval (ft)	Sample #	Ore Type	Gross β-γ (cpm)	Bkg (cpm)	Net β-γ (cpm)
69	1528-1533	4	M	25	15←25→35	0
69	1533-1538	5	M	25		0
69	1538-1543	6	M	25		0
69	1543-1548	7	M	30		5
69	1548-1553	8	M	30	15←30→40	0
69	1553-1558	9	M	35		5
69	1558-1563	10	M	25		0
69	1563-1568	11	M	30		0
69	1568-1573	12	M	30		0
69	1573-1578	13	M	30		0
69	1578-1583	14	M	30		0
69	1583-1588	15	M	30		0
69	1588-1593	16	M	25		0
69	1593-1598	17	M	25		0
69	1598-1603	18	M	25		0
69	1603-1608	19	M	30		0
69	1608-1613	20	M	30		0
69	1613-1618	21	M	25		0
69	1618-1623	22	M	25		0
69	1626-1631	23	S	30		0
69	1631-1636	24	S	25		0
69	1636-1641	25	S	25		0
159	1915-1920	7	M	30	15←30→40	0
159	1920-1925	8	M	30		0
159	1925-1930	9	M	25		0
159	1930-1935	10	M	30		0
159	1935-1940	11	M	35		5
159	1940-1945	12	M	30		0
159	1945-1950	13	M	35		5
159	1950-1955	14	M	25		0
159	1955-1960	15	M	30		0
159	1960-1965	16	M	30		0
159	1965-1970	17	M	30		0
159	1970-1975	18	M	30		0
159	1975-1980	19	M	30		0
159	1980-1985	20	M	30		0
159	1985-1990	21	M	30		0
159	1990-1995	22	M	30		0
159	1995-2000	23	M	25		0
159	2000-2005	24	M	25		0
159	2005-2010	25	M	30		0
159	2010-2015	26	M	25		0
159	2015-2020	27	M	30		0
159	2020-2025	28	M	25		0
159	2025-2030	29	M	25		0
159	2030-2035	30	M	30		0

Table C-1 (continued)

Hole #	Interval (ft)	Sample #	Ore Type	Gross β-γ (cpm)	Bkg (cpm)	Net β-γ (cpm)
159	2035-2040	31	M	30	15←30→40	0
159	2040-2045	32	M	25		0
159	2045-2050	33	M	25		0
159	2050-2055	34	M	30		0
159	2055-2060	35	M	25		0
159	2060-2065	36	M	30		0
159	2065-2070	37	M	30		0
159	2070-2075	38	M	30		0
159	2075-2080	39	M	30		0
159	2080-2085	40	M	30		0
159	2085-2090	41	M	30		0
159	2090-2095	42	M	25		0
159	2275-2280	79	S	30	15←30→40	0
159	2280-2285	80	S	30		0
159	2285-2290	81	S	30		0
159	2290-2295	82	S	30		0
159	2295-2300	83	S	35		5
159	2375-2380	99	S	25		0
159	2380-2385	100	S	25		0
159	2385-2390	101	S	30		0
159	2390-2395	102	S	25		0
122	2439-2444	246	M	25		0
122	2444-2449	247	M	25		0
122	2449-2454	248	M	30		0
122	2454-2459	249	M	30		0
122	2459-2464	250	M	30		0
122	2509-2514	260	S	30		0
122	2514-2519	261	S	25		0
122	2519-2524	262	S	30		0
122	2524-2529	263	S	30		0
122	2529-2534	264	S	25		0
122	2534-2539	265	S	30		0
122	2614-2619	281	S	30		0
122	2619-2624	282	S	25		0
122	2624-2629	283	S	25		0
122	2629-2634	284	S	35		5
122	2634-2639	285	S	30		0
122	2639-2644	286	S	30		0
122	2644-2649	287	S	25		0
122	2649-2654	288	S	30		0
122	2774-2779	313	S	25		0
122	2779-2784	314	S	25		0

Table C-1 (continued)

Hole #	Interval (ft)	Sample #	Ore Type	Gross β-γ (cpm)	Bkg (cpm)	Net β-γ (cpm)
64	1445-1450	15	M	25	15←30→40	0
64	1450-1455	16	M	25		0
64	1455-1460	17	M	30		0
64	1460-1465	18	M	30		0
64	1465-1470	19	M	30		0
64	1470-1475	20	M	25		0
64	1475-1480	21	M	30		0
64	1480-1485	22	M	25		0
188	620-625	30	S	30	15←30→40	0
188	625-630	31	S	30		0
188	630-635	32	S	30		0
188	635-640	33	S	30		0
188	640-645	34	S	25		0
188	645-650	35	S	25		0
188	650-655	36	S	25		0
188	655-660	37	S	25		0
188	660-665	38	S	25		0
188	665-670	39	S	30		0
188	670-675	40	S	30		0
188	675-680	41	S	25		0
188	680-685	42	S	25		0
188	685-690	43	S	30		0
188	690-695	44	S	25		0
188	695-700	45	S	25		0
188	700-705	46	S	25		0
188	705-710	47	S	30		0
188	710-715	48	S	30		0
188	715-720	49	S	30		0
188	760-765	58	S	30		0
188	765-770	59	S	35		5
188	770-775	60	S	25		0
188	775-780	61	S	25		0
188	795-800	65	S	30		0
188	800-805	66	S	25		0
188	820-825	70	S	25		0
188	825-830	71	S	25		0
188	830-835	72	S	35		5
188	835-840	73	S	30		0
188	840-845	74	S	25		0
188	845-850	75	S	30		0
188	895-900	85	S	30		0
188	900-905	86	S	25		0
188	905-910	87	S	25		0
188	910-915	88	S	25		0
188	915-920	89	S	30		0

Table C-1 (continued)

Hole #	Interval (ft)	Sample #	Ore Type	Gross β-γ (cpm)	Bkg (cpm)	Net β-γ (cpm)
160	2604-2609	12	S	35	15←30→40	5
160	2609-2614	13	S	30		0
160	2614-2619	14	S	25		0
160	2619-2624	15	S	25		0
160	2624-2629	16	S	30		0
160	2629-2634	17	S	25		0
160	2634-2639	18	S	35		5
160	2639-2644	19	S	25		0
160	2644-2649	20	S	30		0
160	2649-2654	21	S	30		0
160	2654-2659	22	S	25		0
160	2659-2664	23	S	25		0
160	2664-2669	24	S	25		0
160	2669-2674	25	S	25		0
160	2674-2679	26	S	35		5
160	2679-2684	27	S	25	20←30→40	0
160	2684-2689	28	S	30		0
160	2689-2694	29	S	25		0
160	2774-2779	45	S	35		5
160	2779-2784	46	S	25		0
160	2819-2824	54	S	25		0
160	2824-2829	55	S	30		0
160	2829-2834	56	S	30		0
188	501-506	7	M	30	15←30→40	0
188	506-511	8	M	30		0
188	511-516	9	M	25		0
188	516-521	10	M	25		0
188	521-526	11	M	35		5
188	526-531	12	M	25		0
188	531-536	13	M	35		5
188	536-541	14	M	25		0
188	541-546	15	M	35		5
188	546-551	16	M	30		0
64	1523-1528	28	S	25	15←30→40	0
64	1528-1533	29	S	25		0
64	1533-1538	30	S	30		0
64	1538-1543	31	S	25		0
64	1543-1548	32	S	30		0
64	1548-1553	33	S	25		0
64	1553-1558	34	S	30		0
64	1558-1563	35	S	25		0
64	1563-1568	36	S	25		0
64	1620-1625	44	S	25		0
64	1625-1630	45	S	25		0
64	1650-1655	48	S	25		0
64	1740-1745	63	S	25		0
64	1745-1750	64	S	25		0
64	1750-1755	65	S	30		0
64	1755-1760	66	S	25		0
64	1760-1765	67	S	25		0

Table C-1 (continued)

Hole #	Interval (ft)	Sample #	Ore Type	Gross β-γ (cpm)	Bkg (cpm)	Net β-γ (cpm)
145	1220-1225	13	S	30	15←30→40	0
145	1225-1230	14	S	25		0
145	1230-1235	15	S	30		0
145	1235-1240	16	S	30		0
123	1414-1419	139	M	25	15←30→40	0
123	1419-1424	140	M	25		0
123	1424-1429	141	M	30		0
123	1429-1434	142	M	25		0
123	1434-1439	143	M	30		0
123	1439-1444	144	M	25		0
123	1444-1449	145	M	30		0
123	1449-1454	146	M	25		0
131	1640-1645	8	M	30	15←30→40	0
131	1645-1650	9	M	30		0
131	1650-1655	10	M	35		5
131	1655-1660	11	M	25		0
131	1660-1665	12	M	25		0
131	1665-1670	13	M	30		0
131	1670-1675	14	M	25		0
131	1675-1680	15	M	30		0
131	1680-1687	16	M	30		0
149	1810-1815	23	M	30	15←30→40	0
149	1815-1820	24	M	25		0
149	1820-1825	25	M	30		0
149	1825-1830	26	M	25		0
149	1880-1885	37	S	30		0
149	1885-1890	38	S	30		0
149	1890-1895	39	S	25		0
149	1895-2000	40	S	30		0
149	2000-2005	41	S	30		0
149	2005-2010	42	S	30		0
149	2010-2015	43	S	30		0
149	2015-2020	44	S	25		0
149	2020-2025	45	S	25		0
149	2025-2030	46	S	30		0
149	2030-2035	47	S	30		0
149	2035-2040	48	S	25		0
149	2040-2045	49	S	35		5
149	2045-2050	50	S	30		0
169	602-607	5	M	25	15←30→40	0
169	607-612	6	M	25		0
169	612-617	7	M	30		0
169	617-622	8	M	30		0
169	622-627	9	M	30		0
169	627-632	10	M	30		0
169	632-637	11	M	30		0
169	637-642	12	M	25		0
169	730-735	28	M	30		0

Table C-1 (continued)

Hole #	Interval (ft)	Sample #	Ore Type	Gross β-γ (cpm)	Bkg (cpm)	Net β-γ (cpm)
169	735-740	29	M	30	15←30→40	0
169	740-745	30	M	25		0
169	745-750	31	M	25		0
169	750-755	32	M	30		0
169	755-760	33	M	35		5
169	760-765	34	M	35		5
169	765-770	35	M	25		0
169	770-775	36	M	25		0
169	775-780	37	M	25		0
169	780-785	38	M	25		0
169	785-790	39	M	25		0
169	790-795	40	M	25		0
169	795-800	41	M	30		0
169	800-805	42	M	30		0
169	805-810	43	M	25		0
169	810-815	44	M	35		5
169	815-820	45	M	30		0
169	820-825	46	M	25		0
169	825-830	47	M	30		0
169	830-835	48	M	25		0
169	835-840	49	M	25		0
169	840-845	50	M	30		0
169	845-850	51	M	30		0
169	850-855	52	M	25		0
169	855-860	53	M	25		0
169	860-865	54	M	30		0
169	865-870	55	M	35		5
169	870-875	56	M	30		0
169	875-880	57	M	35		5
169	880-885	58	M	30		0
176	1062-1067	27	M	30	15←30→40	0
176	1067-1072	28	M	30		0
176	1072-1077?	29	M	30		0
176	1160-1165	41	M	25		0
176	1165-1170	42	M	30		0
176	1170-1175	43	M	25		0
176	1175-1180	44	M	25		0
176	1180-1185	45	M	30		0
62	864-869	5	M	30	15←30→40	0
62	869-874	6	M	25		0
62	874-879	7	M	30		0
62	879-884	8	M	30		0
25	1855-1860	7	M	25	15←30→40	0
25	1860-1865	8	M	25		0
25	1935-1940	23	S	30		0
25	1940-1945	24	S	25		0
25	1945-1950	25	S	25		0
25	1950-1955	26	S	25		0
25	1955-1960	27	S	30		0
25	1960-1965	28	S	25		0

Table C-1 (continued)

Hole #	Interval (ft)	Sample #	Ore Type	Gross β-γ (cpm)	Bkg (cpm)	Net β-γ (cpm)
124	1774-1779	36	M	30	15←30→40	0
124	1779-1784	37	M	25		0
124	1784-1789	38	M	30		0
124	1789-1794	39	M	30		0
124	1794-1799	40	M	25		0
124	1799-1804	41	M	25		0
124	1804-1809	42	M	25		0
124	1809-1814	43	M	30		0
124	1814-1819	44	M	30		0
124	1819-1824	45	M	25		0
124	1824-1829	46	M	35		5
124	1829-1834	47	M	25		0
124	1834-1839	48	M	30		0
124	1839-1844	49	M	30		0
124	1844-1849	50	M	30		0
124	1849-1854	51	M	25		0
124	1874-1879	56	S	25	15←25→35	0
124	1879-1884	57	S	25		0
124	1884-1889	58	S	25		0
124	1889-1894	59	S	25		0
124	1894-1899	60	S	25		0
124	1899-1904	61	S	30		0
124	1904-1909	62	S	25		0
124	1909-1914	63	S	25		0
124	1914-1919	64	S	25		0
65	1359-1364	4	M	<25		0
65	1364-1369	5	M	25		0
65	1369-1374	6	M	25		0
65	1374-1379	7	M	25		0
65	1379-1384	8	M	30		5
65	1384-1389	9	M	25		0
65	1389-1394	10	M	25		0
65	1621-1626	46	S	25	15←30→40	0
65	1626-1631	47	S	25		0
65	1631-1636	48	S	25		0
65	1713-1718	59	S	25		0
65	1718-1723	60	S	25		0
65	1723-1728	61	S	30		0
17	1915-1920	4	M	25	15←25→40	0
17	1920-1925	5	M	25		0
17	1925-1930	6	M	30		5
17	1930-1935	7	M	30		5
17	1935-1943	8	M	25		0
17	1943-1950	9	M	25		0
17	1950-1955	10	M	25		0
17	1955-1960	11	M	25		0
17	1960-1965	12	M	25		0

APPENDIX D

Laboratory Data

TABLE D-1

DESCRIPTION OF SAMPLES FOR THE RADIOLOGICAL TESTING PROGRAM
CRANDON PROJECT

Sample Description	Exxon Sample Code	Lab*	Lab Code	Date Collected
1.0 Bedrock				
1.1 Waste Rock				
Mine Shaft	U-1	HES	SPS-396	8-07-80
Ventilation Raise	U-2	HES	SPS-397	8-07-80
Hanging Wall Composite	U-3	HES	SPS-398,564	8-07-80
Footwall Composite	U-4	CDM/ HES	SPS-399,566	8-01-81
1.2 Mineralized				
1.2.1 Massive Ore				
Total Orebody Composite	1	HES	SPS-554,572	4-14-81 and
	3	HES	SPS-555,573	4-15-81
	5	CDM/HES	SPS-557,574	
Above 350 L Composite	7	HES	SPS-559	4-14-81 and 4-15-81
Below 350 L Composite	11	HES	SPS-561	4-14-81 and 4-15-81
1.2.2 Stringer Ore				
Total Orebody Composite	4	HES	SPS-556	4-14-81
	6	CDM/HES	SPS-558	
Above 350 L Composite	8	HES	SPS-560	4-14-81 and 4-15-81
Below 350 L Composite	12	HES	SPS-562,576	4-14-81 and
	14	HES	SPS-563	4-15-81
2.0 Other				
2.1 Granite Outcrop	U-5	HES	SPS-400	8-07-80
2.2 Surficial Soil				
Site 40	15	HES	SPS-567,577	4-30-81 and 5-01-81
Site 41	21	HES	SPS-568	4-30-81 and
	23	HES	SPS-569,578	5-01-81
Mine/Mill Complex	27	HES	SPS-570	4-30-81 and
	29	CDM	SPS-571	5-01-81

* Responsible laboratories for the radiological analyses: Hazleton Environmental Sciences (HES); Camp, Dresser, McKee (CDM). HES was the primary laboratory and CDM was responsible for cross-check analyses and also performed total uranium and total thorium measurements.

TABLE D-2

GROSS ALPHA, GROSS BETA, RADIUM-226, URANIUM AND THORIUM LEVELS IN COMPOSITE SAMPLES OF WASTE ROCK AND MASSIVE AND STRINGER ORE FOR THE RADIOLOGICAL TESTING PROGRAM CRANDON PROJECT

Sample Description	pCi/g dry wt.[a] Gross Alpha	Gross Beta	Ra-226 (by Rn-222)	Responsible[b] Laboratory	Sample Description	pCi/g dry wt.[a] Total Uranium	Total Thorium	Responsible Laboratory
Waste Rock								
U-1	3.2±3.1	17.0±3.4	0.87±0.05	HES	U-1	NA[c]	1.8±0.3	CDM
					U-1	NA	1.9±0.3	CDM
					U-1	1.58	NA	HES
U-2	5.4±3.5	19.9±3.2	0.71±0.04	HES	U-2	NA	1.9±0.3	CDM
					U-2	1.19	NA	HES
U-3	8.6±4.2	15.5±3.0	0.96±0.10	HES	U-3	1.07	NA	HES
U-3	8.5±4.7	19.6±4.2	0.59±0.03	HES	U-3	0.56	1.4±0.3	CDM
					U-3	< 0.56	NA	CDM
U-4	7.0±4.0	13.2±3.0	0.40±0.10	HES	U-4	0.96	NA	HES
U-4	5.4±3.9	16.1±3.9	0.62±0.07	HES	U-4	0.56	1.3±0.2	CDM
U-4	6.0±4.0	14.0±4.0	0.50±0.20	CDM				
U-4	8.0±4.0	14.0±4.0		CDM				
Mean ± s.d.	6.5±1.9	16.2±2.5	0.66±0.20		Mean ± s.d.	0.99±0.39	1.66±0.29	
Massive Ore								
1	3.7±3.5	5.4±3.2	0.80±0.07	HES	1	0.56	0.8±0.2	CDM
1	4.8±3.5	4.5±3.2	0.70±0.04	HES				
3	5.0±3.8	5.4±3.0	1.30±0.08	HES	3	1.13	0.8±0.2	CDM
3	3.7±3.6	3.5±3.0	0.73±0.07	HES				
5	4.5±4.0	< 4.1	0.60±0.10	HES	5	1.13	0.7±0.2	CDM
5	4.0±3.9	< 4.2	0.70±0.10	HES				
5	4.0±4.0	6.0±4.0	0.60±0.20	CDM				
5	6.0±4.0	4.0±4.0	0.80±0.20	CDM				
7	7.2±4.6	8.1±3.7	0.69±0.06	HES	7	1.13	1.0±0.2	CDM
					7	NA	1.0±0.2	CDM
11	4.5±3.7	2.5±2.9	0.48±0.03	HES	11	0.56	0.8±0.2	CDM
Mean ± s.d.	4.7±1.1	4.9±1.7	0.74±0.22		Mean ± s.d.	0.90±0.31	0.85±0.12	
Stringer Ore								
4	< 3.2	6.9±3.4	0.28±0.02	HES	4	< 0.56	0.7±0.2	CDM
					4	NA	0.6±0.2	CDM
6	3.9±3.8	4.5±3.3	0.20±0.10	HES	6	< 0.56	0.7±0.2	CDM
6	2.0±3.0	9.0±4.0	0.40±0.10	CDM	6	< 0.56	NA	CDM
8	3.6±3.4	5.2±3.1	0.24±0.02	HES	8	< 0.56	0.6±0.2	CDM
8	< 3.2	< 3.7	0.23±0.02	HES	8	< 0.56	NA	CDM
12	< 3.2	6.8±3.4	0.28±0.04	HES	12	< 0.56	0.6±0.2	CDM
12	< 2.7	6.3±2.4	0.28±0.02	HES		< 0.56	0.7±0.2	CDM
14	< 3.2	5.7±3.3	0.28±0.02	HES	14	0.56	0.7±0.2	CDM
Mean ± s.d.	3.2±1.0	6.3±1.5	0.27±0.06		Mean ± s.d.	< 0.56	0.65±0.05	

[a] The error given is the probable counting error at the 95 percent confidence level.
[b] Hazleton Environmental Sciences (HES); Camp, Dresser, McKee (CDM).
[c] Not analyzed.

TABLE D-3

GAMMA SPECTROSCOPIC ANALYSIS OF COMPOSITE SAMPLES OF WASTE ROCK AND MASSIVE AND STRINGER ORE FOR THE RADIOLOGICAL TESTING PROGRAM CRANDON PROJECT

Sample Description	pCi/g dry wt.[a] Ra-226	Th-228	K-40	Cs-137	Responsible[b] Laboratory
Waste Rock					
U-1	0.85±0.11	0.82±0.12	18.0±1.2	< 0.02	HES
U-2	0.72±0.08	0.70±0.11	22.4±1.1	< 0.03	HES
U-3	0.80±0.10	0.83±0.12	21.8±1.2	< 0.02	HES
U-3	0.50±0.08	0.55±0.21	15.4±1.3	< 0.04	HES
U-4	0.69±0.07	0.68±0.10	15.4±0.9	< 0.02	HES
U-4	0.49±0.12	< 0.21	13.1±1.1	< 0.04	HES
U-4	0.34±0.51	0.36±0.33	14.0±4.0	< 0.22	CDM
Mean ± s.d.	0.63±0.19	0.66±0.18	17.2±3.70	< 0.22	
Massive Ore					
1	0.79±0.19	< 0.30	< 2.1	< 0.05	HES
1	0.51±0.14	< 0.17	< 1.1	< 0.06	HES
3	0.51±0.10	0.27±0.13	2.5±0.7	< 0.03	HES
3	0.39±0.11	0.17±0.12	2.0±0.8	< 0.04	HES
5	0.12±0.37	0.31±0.25	1.3±1.2	< 0.22	CDM
5	0.40±0.10	< 0.2	3.5±1.2	< 0.06	HES
5	0.50±0.10	< 0.1	3.5±0.7	< 0.06	HES
7	0.42±0.09	< 0.14	< 1.0	< 0.02	HES
11	0.42±0.06	< 0.09	1.4±0.5	< 0.02	HES
Mean ± s.d.	0.45±0.17	0.25±0.07	1.8±0.6	< 0.22	
Stringer Ore					
4	< 0.18	< 0.24	< 2.1	< 0.06	HES
6	0.17±0.40	0.17±0.20	2.8±1.8	< 0.22	CDM
6	< 0.1	< 0.1	4.1±0.8	< 0.06	HES
8	0.27±0.08	< 0.10	3.4±0.7	< 0.04	HES
8	< 0.12	< 0.17	3.2±0.9	< 0.03	HES
12	< 0.11	< 0.18	3.6±0.9	< 0.04	HES
12	0.23±0.04	0.08±0.05	3.6±0.4	< 0.01	HES
14	0.20±0.09	< 0.16	3.7±0.9	< 0.03	HES
Mean ± s.d.	0.22±0.04	< 0.18	3.5±0.4	< 0.22	

[a] The error given is the probable counting error at the 95 percent confidence level.

[b] Hazleton Environmental Sciences (HES); Camp, Dresser, McKee (CDM).

TABLE D-4

GROSS ALPHA, GROSS BETA, RADIUM-226, URANIUM AND THORIUM LEVELS IN GRANITE OUTCROP AND SURFICIAL SOILS FOR THE RADIOLOGICAL TESTING PROGRAM
CRANDON PROJECT

Sample Description	pCi/g dry wt.[a] Gross Alpha	Gross Beta	Ra-226 By Rn-222	Responsible[b] Laboratory	pCi/g dry wt.[a] Total Uranium	Total Thorium	Responsible Laboratory
Granite Outcrop							
U-5	20.7±6.3	43.0±4.5	1.54±0.05	HES	2.94	4.9±0.5	CDM/HES
Soil							
15	7.6±4.5	23.4±4.4	0.74±0.04	HES	< 0.56	2.0±0.3	CDM
15	10.1±5.2	22.4±4.4	0.71±0.03	HES		2.2±0.3	CDM
21	7.1±4.4	22.1±4.4	0.86±0.08	HES	0.56	2.7±0.4	CDM
23	10.2±5.2	24.7±4.6	0.70±0.04	HES	0.56	2.2±0.4	CDM
23	11.6±5.2	26.1±4.8	0.82±0.07	HES	< 0.56		CDM
27	9.5±5.0	23.8±4.5	0.78±0.04	HES	0.56	2.7±0.4	CDM
27	---	---	---			2.1±0.3	CDM
29	10.0±4	24.0±5	0.8±0.2	CDM	0.56	1.7±0.3	CDM
29					0.56		CDM
Soil Mean ± s.d.	9.4±1.6	23.8±1.4	0.77±0.06		0.56±0.00	2.2±0.4	

[a] The error given is the probable counting error at the 95 percent confidence level.
[b] Hazleton Environmental Sciences (HES); Camp, Dresser, McKee (CDM).

TABLE D-5

GAMMA SPECTROSCOPIC ANALYSIS OF GRANITE OUTCROP AND SURFICIAL SOILS
FOR THE RADIOLOGICAL TESTING PROGRAM
CRANDON PROJECT

Sample Description	pCi/g dry wt.[a] Ra-226	Th-228	K-40	Cs-137	Ru-106	Responsible[b] Laboratory
Granite Outcrop						
U-5	2.01±0.12	3.02±0.18	46.8±1.5	< 0.029	< 0.28	HES
Soil						
15	0.79±0.10	0.87±0.13	20.4±1.3	0.42±0.05	0.70±0.18	HES
15	0.72±0.08	0.85±0.12	19.8±1.1	0.36±0.04	0.60±0.17	HES
21	0.66±0.08	1.09±0.14	21.8±1.3	0.41±0.05	0.74±0.20	HES
23	0.85±0.09	0.90±0.12	21.8±1.1	0.44±0.05	< 0.22	HES
23	0.87±0.09	0.93±0.12	20.7±1.2	0.46±0.05	< 0.37	HES
27	0.88±0.10	0.99±0.13	20.5±1.2	0.25±0.04	0.68±0.19	HES
29	0.26±0.39	0.28±0.22	21.0±4.0	< 0.22	---	CDM
Soil Mean ± s.d.	0.72±0.22	0.84±0.26	20.9±0.7	0.39±0.08	0.68±0.06	

[a] The error given is the probable counting error at the 95 percent confidence level.
[b] Hazleton Environmental Sciences (HES); Camp, Dresser, McKee (CDM).