Molycorp, Inc.
A Unocal Company
1201 West 5th Street, P.O. Box 54945
Los Angeles, California 90054
Telephone (213) 977-7524

UNOCAL 76
MOLYCORP

November 20, 1985

Warren N. Warhol
Vice President, Manufacturing

Mr. John D. Kinneman, Chief
Nuclear Materials Safety Section A
Division of Radiation Safety and Safeguards
U.S. Nuclear Regulatory Commission, Region I
631 Park Avenue
King of Prussia, PA 19406

License No. SMB-1408

Dear Mr. Kinneman:

Further to my letter to you dated May 28, 1985, we are performing research and development work on a process which has the potential to convert the majority of the drummed residue at the York plant to the following:

1. A thorium-free mixed rare earth product.
2. Fewer than 100 drums of unsaleable thorium-uranium concentrate.
3. More than 3,000 drums of residue containing less than 0.04% thorium-uranium.

We would appreciate your helping us determine (1) whether an amendment to our source materials license will be necessary before this process could be implemented at the York plant, and (2) what permitting procedures the NRC would require for the disposal of the 0.04% thorium residue to an appropriate chemical waste disposal site other than Barnwell, Beatty or Hanford.

Although we could not have the process designed and equipment installed and operating until 1987 we would appreciate your response as soon as possible.

Sincerely,

Warren N. Warhol

WNW:jb
cc: W. E. Doyle
T. A. Wilson

EG&G ENERGY MEASUREMENTS

THE
REMOTE
SENSING
LABORATORY
OPERATED FOR THE U.S.
DEPARTMENT OF ENERGY BY EG&G/EM

EG&G/EM SURVEY REPORT
NRC-8412
OCTOBER 1984

AN AERIAL RADIOLOGICAL SURVEY OF THE

MOLYCORP, INC. FACILITY

AND SURROUNDING AREA

YORK, PENNSYLVANIA

DATE OF SURVEY: JULY 1984

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MOLYCORP, INC. FACILITY

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E. L. Feimster
Project Scientist

REVIEWED BY

W. J. Tipton

W. J. Tipton, Head
Nuclear Radiation Physics Section

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G P Stobie

G. P. Stobie
Classification Officer

This work was performed by EG&G/EM for the United States Nuclear Regulatory Commission through an EAO transfer of funds to Contract Number DE-AC08-83NV10282 with the United States Department of Energy.

ABSTRACT

An aerial radiological survey was conducted over the Molycorp, Inc. facility, located in York, Pennsylvania, during the period 17 to 23 July 1984. The survey encompassed a 38-square-kilometer (15-square-mile) area centered on the Molycorp, Inc. facilities. Inferred exposure rates were due primarily to naturally occurring gamma-emitting radionuclides and cosmic ray activity (estimated at 4.0 μR/h). The exposure rates ranged from 4 to 34 μR/h throughout the survey area. Approximately one-half the area surveyed had an inferred exposure rate range of 8 to 10 μR/h; this area included about three-fourths of the city of York. An exposure rate range of 10 to 15 μR/h was encountered over the remaining half, which included an area of about 4 square miles adjacent to the northern city limits of York and an area of about 3 square miles that contained York's southern city limits. One area of higher activity was encountered over the Molycorp, Inc. facility. The maximum inferred exposure rate over this area was 34 μR/h. Spectral analysis revealed gamma-emitting radionuclides of the thorium decay chain as the primary contributors to this elevated activity. Low concentrations of thorium are present in an ore called bastnaesite, a material from which Molycorp, Inc. extracts rare earth elements. Ground-based measurements made in several areas were in good agreement with the aerial data. This was the first aerial radiological survey conducted over this area.

CONTENTS

Appendix

1.0 INTRODUCTION

An aerial radiological survey of the Molycorp, Inc. facility was performed during the period 17 to 23 July 1984. The survey was conducted using the Aerial Measuring System (AMS), operated for the United States Department of Energy (DOE) by EG&G Energy Measurements, Inc. Since 1958, the AMS has been utilized to document background radiation levels throughout the United States.[1] In addition to nuclear detectors, AMS aircraft have been equipped with multispectral camera arrays for aerial photography, thermal mappers for infrared imagery, a broad array of meteorological sensors, and air sampling systems for particulate and gas measurements.

Aerial radiological detection systems average the radiation levels due to gamma ray emitting radionuclides existing over an area of several acres. The systems are capable of detecting anomalous gamma count rates and determining the specific radionuclides causing the anomalies; however, because of averaging over a large area, they tend to underestimate the magnitude of localized sources as compared with ground-based readings.

The results of the survey are reported as radiation exposure rates in microroentgens per hour (μR/h) at 1 meter above the ground surface. Approximate annual radiation dose levels expressed as millirem per year (mrem/y) are obtained by multiplying μR/h by 8.76. The aerial survey results apply only to the external radiation dose component.

The aerial radiological survey of the Molycorp, Inc. facility covered a 38-square-kilometer (15-square-mile) area. Ground-based measurements were made at four locations within the survey area. Figure 1 shows the boundaries of the survey area and the locations of the ground-based measurements.

2.0 BACKGROUND RADIATION

Natural background radiation originates from radioactive elements present in the earth (i.e., the terrestrial component), airborne radon, and cosmic rays entering the earth's atmosphere from space. The terrestrial gamma radiation originates primarily from the uranium decay chain, the thorium decay chain, and radioactive potassium. Annual dose equivalents from the terrestrial component of background radiation are as low as 15 to 35 millirems (mrems) (2 to 4 μR/h) for the Atlantic and Gulf Coastal Plains and as high as 75 to 140 mrems (9 to 16 μR/h) on the Colorado Plateau.[2]

One member of both the uranium and thorium decay chains is an isotope of radon, a noble gas, which can both diffuse through the soil and travel through the air to other locations. Therefore, the level of airborne radiation due to these radon isotopes and their daughter products at any specific location depends on a variety of factors, including meteorological conditions and soil permeability. Typically, airborne radiation contributes between 1 and 10 percent of the natural background radiation levels.

Cosmic rays interact with the elements of the earth's atmosphere and soil to produce an additional natural source of gamma radiation. The intensity of this radiation source depends on the altitude and, to a lesser extent, on latitude. In general, the cosmic ray contribution to the natural background radiation is largest at high altitudes and high latitudes. Annual dose equivalents in the United States due to cosmic rays range from about 26 mrems (3 μR/h) in southern Florida to about twice that value in Wyoming.

External radiation may also be received from radioactive elements in building materials. Naturally occurring radioactive materials can be concentrated in a particular location due to building or road construction. In structures made of stone, concrete or brick, the radiation dose is generally higher than in nearby wooden buildings. Thus, radiation doses due to background sources are highly variable and depend upon a number of factors.

3.0 SURVEY EQUIPMENT AND PROCEDURES

The equipment and procedures used to conduct the aerial radiological survey, the data analysis techniques, and the ground-based measurements are discussed briefly in this section. A more detailed description of the AMS and data reduction procedures can be found in separate publications.[1,3]

3.1 Aerial Measurements

The aerial measurements were made with a detector array and data acquisition system mounted in a Messerschmitt-Bolkow-Blohm

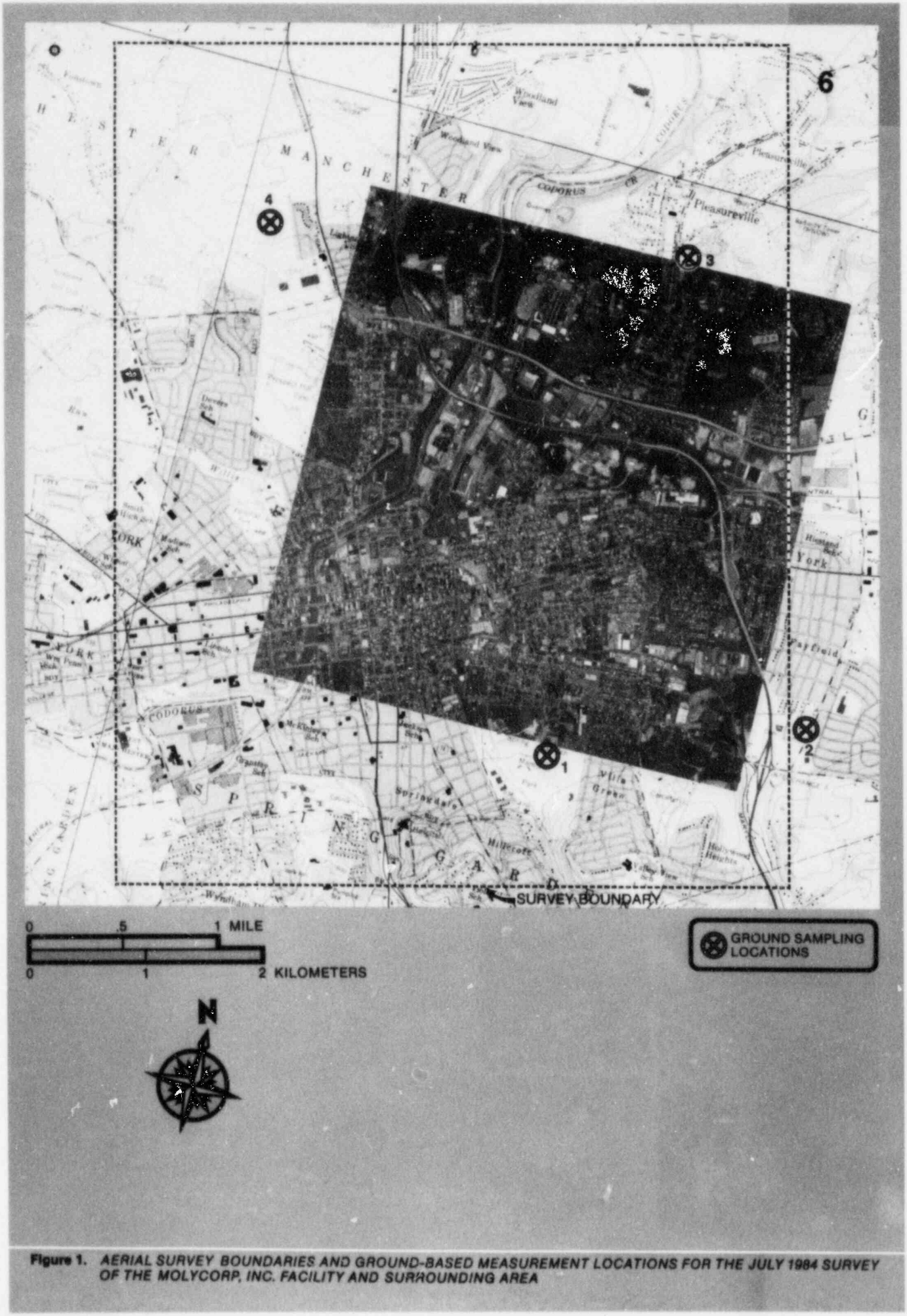


Figure 1. *AERIAL SURVEY BOUNDARIES AND GROUND-BASED MEASUREMENT LOCATIONS FOR THE JULY 1984 SURVEY OF THE MOLYCORP, INC. FACILITY AND SURROUNDING AREA*

(MBB) BO-105 helicopter. The radiation detector package consisted of an array of 20 sodium iodide (thallium-activated), NaI(Tl), scintillation crystals. Each NaI(Tl) crystal was 12.7 cm in diameter and 5.1 cm thick (5 in. × 2 in.). Two detector pods, each containing ten crystals, were mounted on the exterior of the helicopter (Figure 2). A photomultiplier tube mounted to each NaI(Tl) crystal converted the scintillation pulses to voltage pulses. The voltage pulses from 19 crystals were normalized and combined in summing amplifiers to produce a single gamma ray energy spectrum with high sensitivity. The remaining single tube was used to provide a spectrum with lower sensitivity to be used if areas with greatly enhanced radiation levels were encountered. Both spectra were simultaneously acquired and recorded, resulting in a wide operating range.

Figure 2. *MBB BO-105 HELICOPTER WITH DETECTOR PODS*

The outputs of the summing amplifier and the single tube signal were analyzed in separate analog-to-digital converters (ADCs) in the Radiation and Environmental Data Acquisition and Recorder (REDAR) system (Figure 3). The REDAR system is a multi-microprocessor, portable data acquisition and real-time analysis system. It has been designed to operate in the demanding environments associated with helicopters and fixed-wing aircraft. A block diagram of the REDAR system is shown in Figure 4.

The ADC signals were adjusted so that the photopeaks from a ^{22}Na calibration source appeared in preselected channels of the multichannel analyzers (MCAs). Each MCA collected a 1024-channel gamma ray energy spectrum once every second. The collected spectrum was scaled to 4 keV per channel. The 1024-channel spectrum was compressed into 256 channels, as summarized in

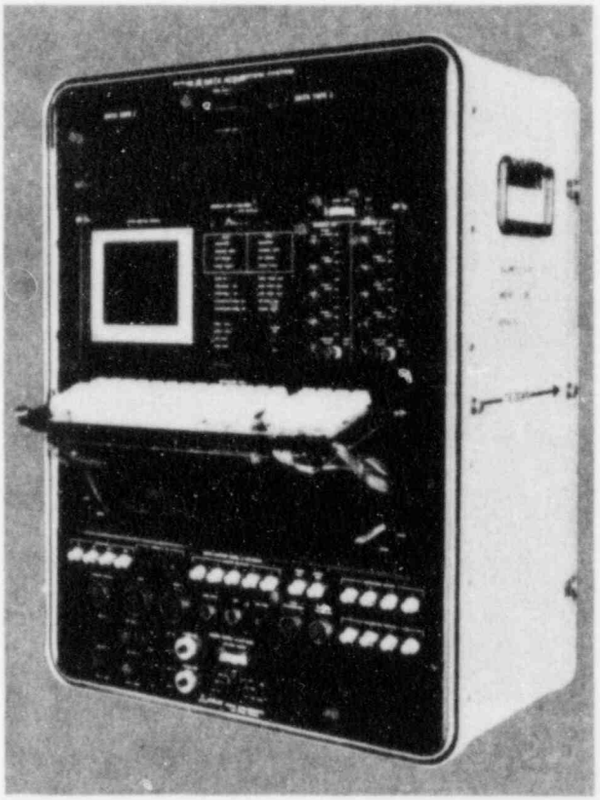


Figure 3. *RADIATION AND ENVIRONMENTAL DATA ACQUISITION AND RECORDER (REDAR) SYSTEM*

Table 1, before storage on magnetic tape. The energy resolution of the NaI(Tl) crystals varies with energy, permitting the compression of the spectral data without compromising photopeak identification and data analysis techniques. This spectral compression technique reduces the data storage requirement by a factor of four.

All 1-second data acquired by the REDAR were placed into a buffer and recorded as a 4-second record on magnetic tape. In addition to gamma ray spectral data, other information acquired and recorded by the REDAR system included gross count data (gamma ray activity integrated over the energy range 0.04 to 3.0 MeV), aircraft position data, system live time information, and environmental conditions; i.e., absolute barometric pressure and outside air temperature.

The helicopter position was established by two systems: a trisponder ultrahigh frequency (UHF) ranging system (URS) and a radar altimeter. The URS ranging system consisted of two remotely-located transponders and an on-board interrogator. The on-board interrogator used the transit

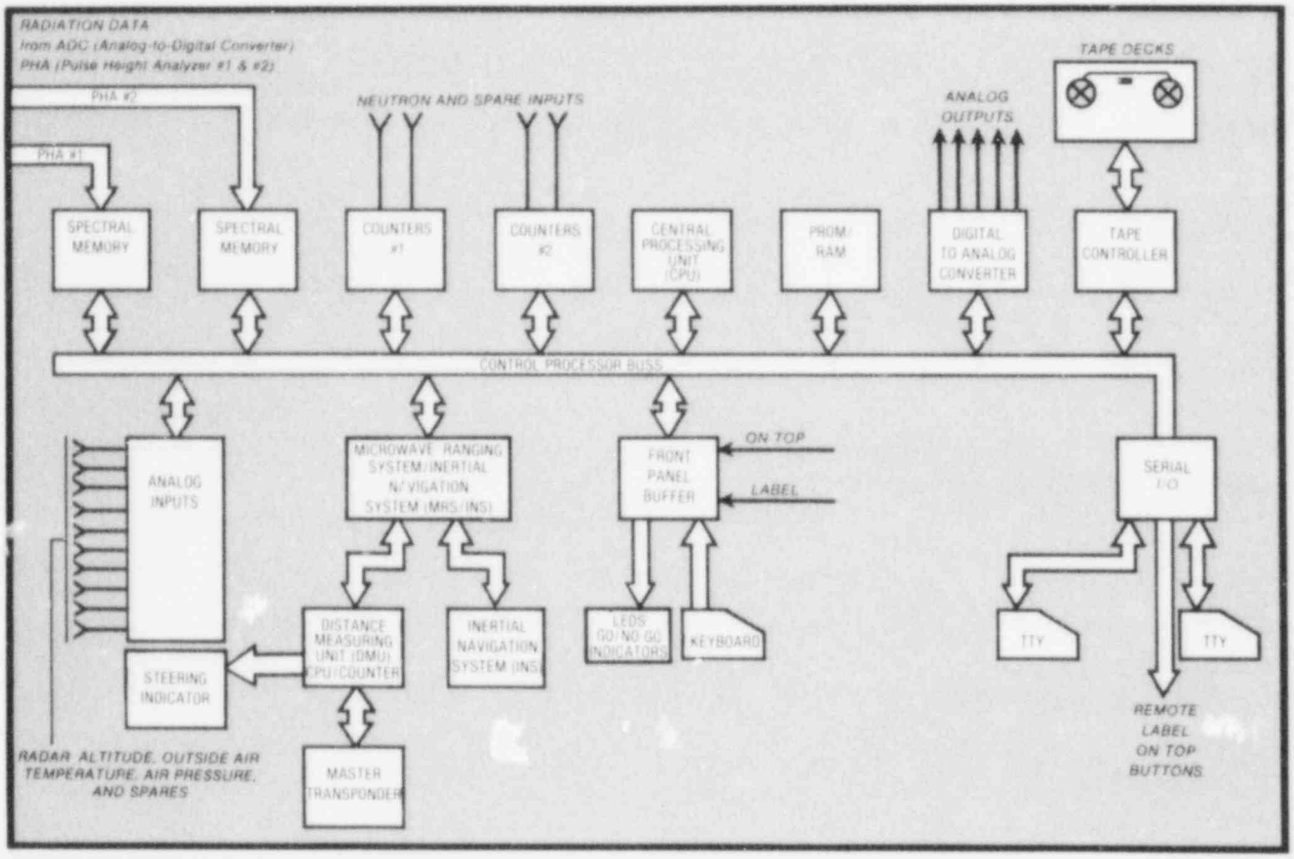


Figure 4. *BLOCK DIAGRAM OF THE REDAR SYSTEM*

time of a UHF pulse to obtain the distance from the aircraft to each remote unit. The radar altimeter similarly measured the time lag for the return of a pulsed signal and converted this delay to aircraft altitude above ground level. In addition to being recorded on magnetic tape, position and altitude information were also processed in real time by the steering microprocessor. These data provided steering information to the pilot for flying predetermined flight lines at the desired altitude.

The BO-105 helicopter was flown over the York, Pennsylvania survey area at an altitude of 76 meters (250 feet) and with a ground speed of 36

Table 1. Partitioning Scheme Utilized for Gamma Ray Energy Data Compression

Eγ (keV)	Channel Input	Energy Coefficient ΔE (keV/channel)	Compressed Channel Output
0 - 300	0 - 75	4	0 - 75
304 - 1620	76 - 405	12	76 - 185
1624 - 4068	406 - 1017	36	186 - 253
4072 - 4088	1018 - 1022	N/A	254
>4088 - Analog Cutoff	1023	N/A	255

meters per second (70 knots). A 38-square-kilometer (15-square-mile) area was covered with 96 flight lines, 6 kilometers (3.8 miles) in length and spaced 76 meters (250 feet) apart. During each survey flight, the airborne system was flown over the Susquehanna River. The background radiation contributions from all non-terrestrial sources were estimated from these measurements. These data enabled the removal of those contributions from the aerial measurements and provided a check on flight-to-flight variations in the levels of airborne radon.

3.2 Data Processing

The processing of the magnetic tapes with recorded data from each flight began in the field utilizing the Radiation and Environmental Data Analyzer and Computer (REDAC) system. This data analysis system was built into a 5-ton step van which was parked at York Aero in Thomasville, Pennsylvania, the base of operations during the survey. The interior of this van is shown in Figure 5, and a block diagram of the processing system is shown in Figure 6. The REDAC system consisted primarily of a Data General NOVA 840 computer and peripherals. An extensive inventory of software routines was available for the preliminary data analysis, accomplished in the field, and the final analysis, accomplished after the completion of all field operations.

An exposure rate contour map was derived from the gross count data. The gross count energy "window" extended from 0.04 to 3.0 MeV, which included all significant gamma rays due to natural sources of background radiation. Several corrections were applied to the measured gross counting rates before converting them to exposure rates:

$$GC = [(A_e \bullet W_{GC} \bullet LT) - C] \bullet AH$$

where

- GC = Normalized gross counting rate corrected for system live time and altitude variations.
- A_e = Detector effective area normalization.
- W_{GC} = Measured gross counting rate.
- LT = Live time counting loss correction.
- C = Non-terrestrial contributions to the gross counting rates.
- AH = Correction for altitude variations.

The non-terrestrial background counting rates included contributions from: (1) sources of radiation on board the helicopter, (2) airborne radon and daughter products, and (3) cosmic rays. These combined contributions were determined from gross count measurements made while flying over the Susquehanna River.

The resulting net counting rates due to terrestrial sources of radiation were converted to exposure rates at 1 meter above the ground level. This was

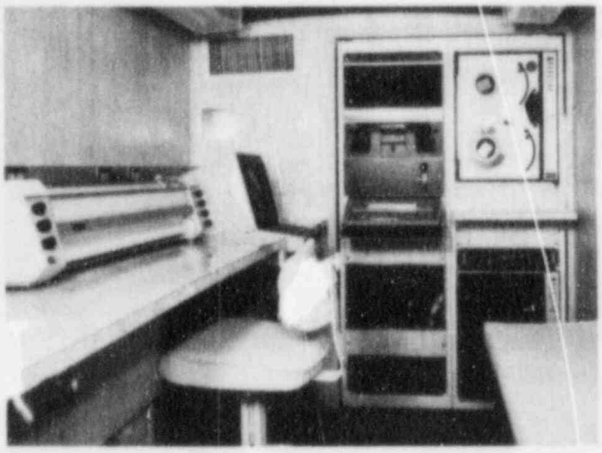


Figure 5. *INTERIOR OF THE MOBILE DATA ANALYSIS LABORATORY*

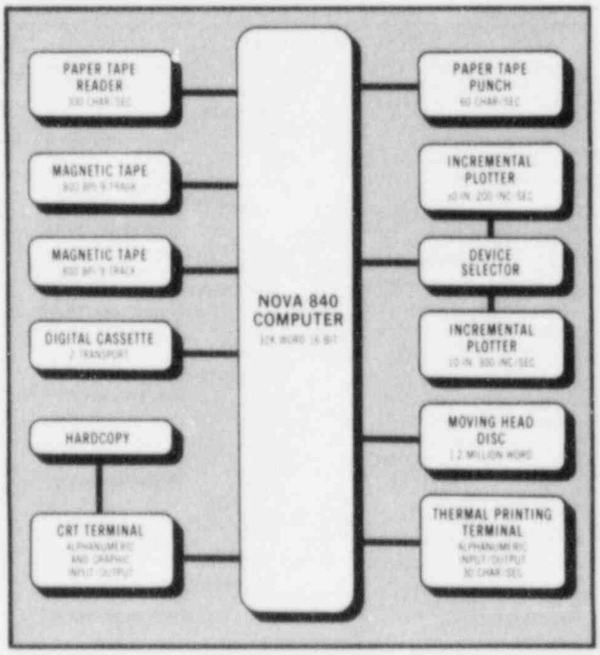


Figure 6. *BLOCK DIAGRAM OF THE REDAC SYSTEM*

accomplished by applying a conversion factor of 825 counts per second per microroentgen per hour (cps/μR/h). This factor was derived from many measurements made over areas with known concentrations of naturally occurring radioisotopes. The total exposure rate at 1 meter above the ground level minus any contribution from airborne radon was then derived by adding the estimated cosmic ray contribution of 4.0 μR/h. The resulting values were rounded to the nearest μR/h.

Contour lines of equal exposure rate were plotted utilizing the processed gross count data along with the recorded positional information. The generated contours were overlaid on a composite of an aerial photograph and a set of U.S. Geological Survey (USGS) maps of the surrounding area. The resulting overlay map shows both the spatial distribution and intensity of the terrestrial gamma ray emitters emanating from the survey area as inferred from the aerial data.

The gamma ray spectral data were utilized to determine the identity of the radionuclides within the survey area. These spectra were collected in 1-second intervals, and the specific radionuclides responsible for any regions of elevated exposure rates were identified.

3.3 Ground-Based Measurements

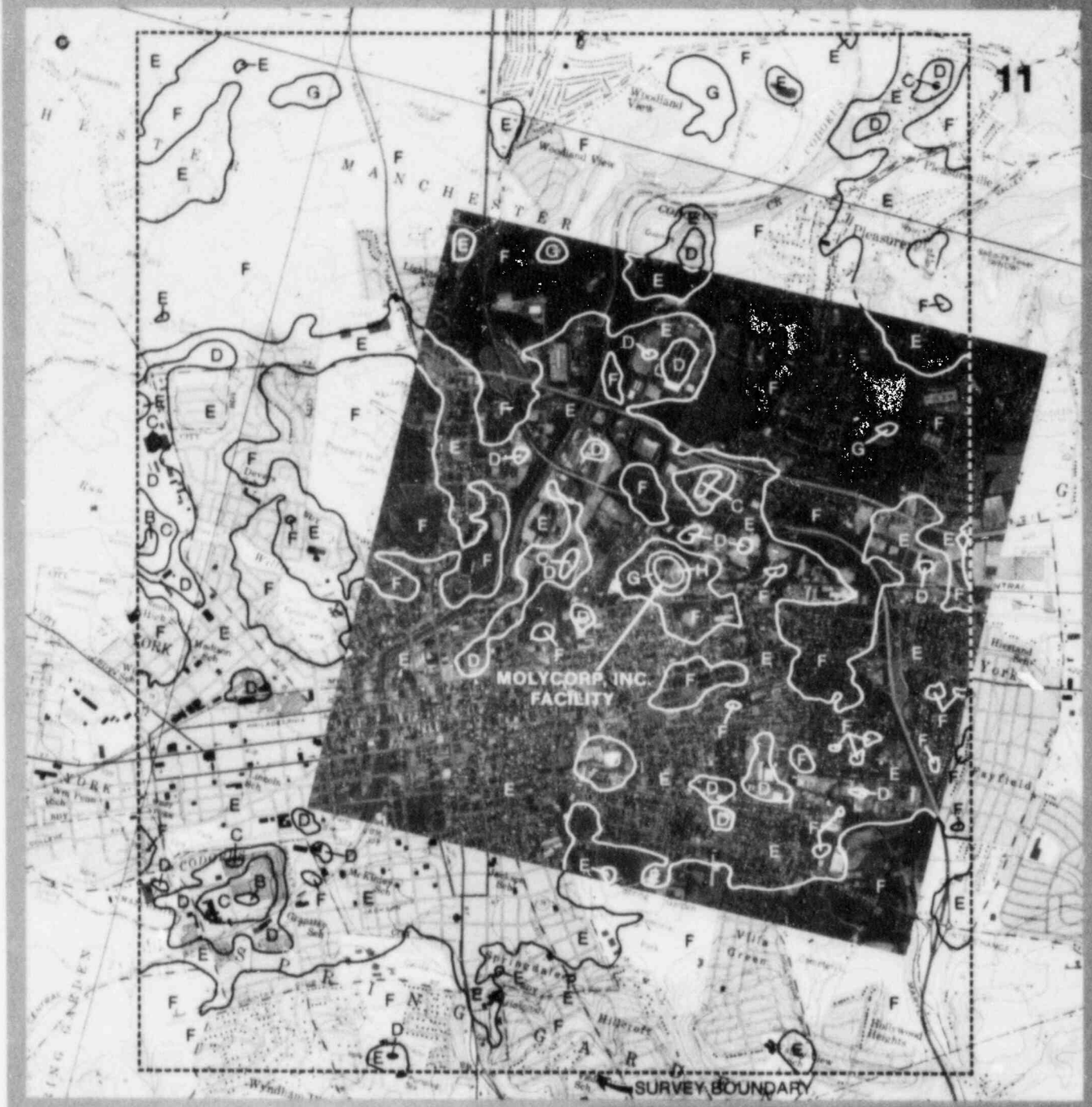
Ground-based measurements were made at four locations, shown in Figure 1, within the boundaries of the survey area. Exposure rates were measured with a pressurized ionization chamber for comparison to the values inferred from the aerial data. Soil samples were taken at each ground sampling point to determine the radionuclide concentrations typical of the natural background in the area. In addition, estimates of the exposure rates due to these radionuclide concentrations were made from the soil sample analyses. The soil samples were analyzed and the results tabulated for this report by scientists at EG&G/EM's Santa Barbara Laboratory. Systems and procedures for soil sample data collection and analysis are outlined in a separate publication.[4]

4.0 RESULTS

The results of the aerial radiological survey of the Molycorp, Inc. facility and surrounding area are shown in Figure 7. The exposure rate levels measured within the survey area ranged from 4 to 34 μR/h. As illustrated in Figure 7, one-half the surveyed area, about three-fourths the city of York, Pennsylvania, had an exposure rate range of 8 to 10 μR/h. The remaining one-half of the surveyed area had an exposure rate range of 10 to 15 μR/h, which included an area of approximately 4 square miles adjacent to the northern city limits of York and a section of about 3.5 square miles that contained the southern tip of York. These values include an estimated cosmic ray value of 4.0 μR/h. Over the Molycorp, Inc. facility, the maximum exposure rate was 34 μR/h, about twice the highest background value encountered in the areas mentioned above. Elevated exposure rates over the Molycorp, Inc. facility were due to gamma-emitting radionuclides of the thorium decay chain, as shown in Figure 8. According to officials of Molycorp, Inc., the source of the thorium is an ore called bastnaesite, which is mined in Mountain Pass, California and shipped to the Molycorp, Inc. facility in York. Bastnaesite is an ore that contains about 70 percent rare earth elements, which are extracted by Molycorp, Inc. using a leaching process. The residue from this leaching process contains about 40 percent rare earth elements and a low concentration of thorium. The residue is stored in 55-gallon drums on the surface of the grounds of the Molycorp, Inc. facility.

The contours around the area of elevated activity shown in Figure 7 are symmetrical around the center level; this is typical of airborne detector response to a highly localized source of terrestrial radioactivity. The actual physical location of the elevated activity is probably within the center level contour area. The adjacent levels are simply an artifact arising from the fact that the uncollimated airborne detectors "see" the radiation from a localized source before actually arriving over the source. Because of the large-area averaging property of the airborne system, the actual 1-meter exposure rate levels at the source will be higher than the levels inferred from the aerial data for a localized source such as that observed over the Molycorp, Inc. facility. No other areas of unusual radioactivity, either natural or man-made, were observed within the survey area.

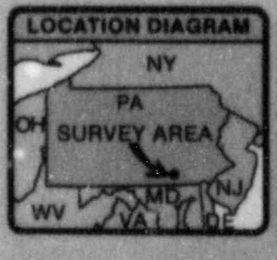
Results of the ground-based measurements are presented in Tables 2 and 3. Table 2 shows the results of the soil sample analyses. Only naturally occurring radionuclides and ^{137}Cs typical of that expected from world-wide fallout were present in these samples. Exposure rate results, obtained



0 .5 1 MILE
0 1 2 KILOMETERS

N

LOCATION DIAGRAM



CONVERSION SCALE	
LETTER LABEL	EXPOSURE RATE AT 1 m AGL* (μR/h)
A	> 5
B	5 - 6
C	6 - 7
D	7 - 8
E	8 - 10
F	10 - 15
G	15 - 21
H	21 - 34

*Calculated from aerial data obtained at an altitude of 76 m (250 ft). Values include an estimated 4.0 μR/h due to cosmic ray contributions.

Figure 7. *EXPOSURE RATE CONTOUR MAP OF THE MOLYCORP, INC. FACILITY AND SURROUNDING AREA*

directly from the ion chamber measurements and inferred from the soil sample analyses and the aerial measurements, are presented in Table 3. The fact that the aerial system measures an area several thousand times larger than a typical ion chamber measurement taken at 1 meter and several million times larger than a typical soil sample should be considered when comparing these different types of measurements. The values given in Table 3 show that good agreement was obtained between the different measurement techniques used for the survey of the Molycorp, Inc. facility and surrounding area.

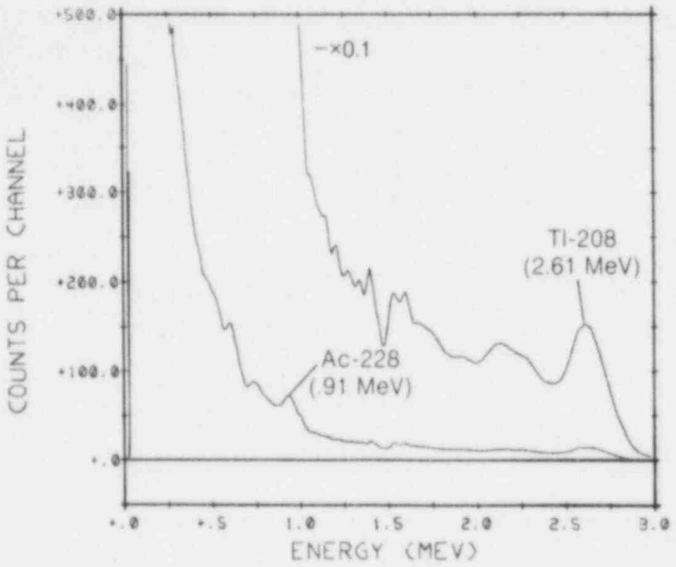


Figure 8. *BACKGROUND-SUBTRACTED GAMMA RAY SPECTRUM OBTAINED OVER THE MOLYCORP, INC. FACILITY*

Table 2. Soil Sample Analysis Results

Site Number[1]	U-238 (ppm)	Th-232 (ppm)	Cs-137 (pCi/g)	K-40 (pCi/g)
1	2.9 ± 0.4	10.3 ± 1.6	0.37 ± 0.22	21.4 ± 2.8
2	3.4 ± 0.4	12.2 ± 0.9	0.51 ± 0.06	20.3 ± 3.3
3	3.4 ± 0.5	14.9 ± 3.1	0.15 ± 0.15	25.3 ± 6.9
4	3.3 ± 0.7	13.3 ± 1.4	0.12 ± 0.12	29.8 ± 12.0

[1] See Figure 1.

Table 3. Comparison of Aerial and Ground-Based Exposure Rate Measurement Results

Site Number[1]	Soil Moisture (%)	Ground Survey Total Exposure Rate (μR/h)		Aerial Survey Total Exposure Rate (μR/h)[2]
		Ion Chamber	Soil Analysis Estimates[2]	
1	10	11.8 ± 0.8	11.1 ± 0.8	10 - 15
2	16	11.9 ± 0.8	10.6 ± 0.8	10 - 15
3	23	12.9 ± 1.6	10.9 ± 0.5	10 - 15
4	13	14.2 ± 2.2	14.4 ± 0.5	10 - 15

[1] See Figure 1.

[2] Includes an estimated 4.0 μR/h due to cosmic rays.

APPENDIX A

SURVEY PARAMETERS

Site:	Molycorp, Inc.
Location:	York, Pennsylvania
Survey Date:	17 to 23 July 1984
Base of Operation:	Thomasville Airport York Aero Thomasville, Pennsylvania
Survey Coverage:	38 km^2 (6 km × 6 km)
Lines Surveyed:	96
Line Spacing:	76 m (250 ft)
Survey Altitude:	76 m (250 ft)
Project Scientist:	E.L. Feimster
Survey Aircraft:	MBB BO-105 Helicopter
Acquisition System:	REDAR IV
Detector Array:	Twenty 12.7-cm diameter by 5.1-cm thick NaI(Tl) detectors (Cd-band shielded)

Data Processing:

Energy Window: 0.04 to 3.0 MeV

Conversion Factor: 825 cps per μR/h

Cosmic Ray Contribution: 4.0 μR/h

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MOLYCORP, INC. FACILITY
YORK, PENNSYLVANIA
NRC-8412
DATE OF SURVEY: JULY 1984
DATE OF REPORT: OCTOBER 1984

Prepared by
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RADIOLOGICAL MEASUREMENTS AT THE MOLYBDENUM CORPORATION OF AMERICA PLANT YORK, PENNSYLVANIA

A. J. BOERNER

Radiological Site Assessment Program
Manpower Education, Research, and Training Division

FINAL REPORT

November 1985

RADIOLOGICAL MEASUREMENTS AT THE MOLYBDENUM CORPORATION OF AMERICA PLANT YORK, PENNSYLVANIA

Prepared for

Safeguards and Materials Program Branch
Division of Inspection Programs
Office of Inspection and Enforcement
U.S. Nuclear Regulatory Commission
Region I Office

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FINAL REPORT

November 1985

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RADIOLOGICAL MEASUREMENTS AT THE MOLYBDENUM CORPORATION OF AMERICA PLANT YORK, PENNSYLVANIA

INTRODUCTION

Since the middle 1960's, Molybdenum Corporation of America (Molycorp) has operated a plant in York, Pennsylvania for the production of rare earth materials - primarily compounds of cerium and yttrium. The raw materials include Bastnasite ore and concentrated cerium ore; both of these ores contain low levels of naturally occurring thorium and uranium. Radionuclides from these decay series remain in the residues following separation processes; storage of these residues requires licensing by the Nuclear Regulatory Commission (NRC).

As part of the continuing regulatory and inspection process, the NRC routinely monitors its licensees to assure compliance with established radiation protection guidelines. At the request of the Nuclear Regulatory Commission, Region I Office, the Radiological Site Assessment Program of Oak Ridge Associated Universities performed independent radiological monitoring of the York Molycorp plant. This report presents the procedures and results of that survey.

SITE DESCRIPTION

The Molycorp plant is located at 350 N. Sherman Street, Spring Garden Township, in York, Pennsylvania (Figure 1). The site (Figure 2) occupies approximately 2.4 hectares and is bounded by Sherman, Olive and Hudson streets and the Pennsylvania Railroad. A drainage ditch parallels Sherman Street on the east side of the site. The land is generally level, sloping towards the northern and eastern portions of the property. There are several buildings on the property which are in active use for plant operations. Residues from plant processes are stored onsite in drums, many of which are badly deteriorating. Most of these containers are located on the northeast and northwest portions of the property. In addition, a large quantity of Th-232, Ra-226, and U-238 contaminated residues (estimated at 460-690 m^3) is located in a pile near the southeast corner of the site.

SURVEY PROCEDURES

The survey of the York Molycorp plant was conducted by the Radiological Site Assessment Program of Oak Ridge Associated Universities (ORAU) from June 3-12, 1985.

Objectives

The objectives of the survey were to measure radionuclide concentrations in air and water process effluents and to evaluate the potential for migration of radioactive materials from the plant site. Data to be obtained included:

1. direct radiation levels outside the licensee's perimeter fence;

2. radionuclide concentrations in surface and subsurface soil and water, both on the site and outside the plant perimeter;

3. radionuclide concentrations in sediment samples collected onsite and outside the plant perimeter;

4. radionuclide concentrations in air samples collected from main process stacks; and

5. flow charts and material balances for processes involving the thorium and uranium containing ores.

Procedures

A. Reference Measurements

1. The system used to reference survey measurements consisted of two coordinates derived as follows: twenty meter intervals were established around the site perimeter fence, originating at the Olive Street gate entrance to the plant and continuing in a counter clockwise rotation (Figure 2). The second coordinate was determined based on the distance (in meters) outside the perimeter fence that the sample or radiation measurement was

taken. At several locations, additional points were selected at less than 20 m intervals to reference major site landmarks more easily and to provide additional sampling and radiation measurement locations.

B. External Radiation Measurements

1. Walkover gamma surface scans using NaI(Tl) scintillation probes attached to portable ratemeters were performed around the plant perimeter to identify possible areas of surface contamination due to spillage or run-off. Roads, drainage ditches and railroad access areas to the plant were emphasized.

2. Gamma exposure rate measurements were made at the surface and 1 m above the surface at 20 m intervals around the perimeter fence, at other locations along the fence used as reference landmarks, and at locations identified by the surface scan. NaI(Tl) gamma scintillation detectors were used for exposure measurements. Conversion to exposure rates in microroentgens per hour (μR/h) was in accordance with cross calibration measurements obtained with a pressurized ionization chamber at 16 locations at the Molycorp site (Figure 3).

C. Sampling

1. Soil and Sediment Sampling

a. Surface (0-15 cm) soil samples of approximately 1 kg each were collected at 20 m intervals around the plant perimeter, at an additional 24 locations around the perimeter, and at locations identified by the walkover surface scan.

b. Subsurface soil samples were collected at eight borehole locations drilled to provide representative coverage of the site. The locations of these boreholes are shown on Figure 4. The boreholes were drilled using hollow-stem augers supplied by Site Engineers of Cherry Hill, New Jersey.

Gamma radiation scans were performed in boreholes to identify elevated radiation levels, which might indicate subsurface residues. Radiation profiles were determined by measuring gamma radiation at 30 cm intervals between the surface and the hole bottom. A shielded gamma scintillation detector was used for these measurements. Soil samples were collected from various depths in the holes by scraping the sides of each borehole with an ORAU designed sampling tool or by split-spooning through the auger.

c. Sediment samples were collected from 9 onsite and perimeter locations (Figures 5 and 6). Sampling points included onsite drainage ditches, a drainage basin, and clarifier tank. Offsite samples were collected from a sanitary sewer, drainage ditches, and a quarry and creek located north of the plant.

2. Liquid Monitoring

a. Two surface water samples were collected from onsite drainage ditches (Figure 7).

b. Samples of treated process water were obtained from onsite clarifier and neutralizing tanks and from a city sewer west of the plant's perimeter (Figure 7).

c. One water sample was collected from an overflow groundwater discharge point (Figure 7).

d. Three surface water samples were collected from an offsite drainage ditch, quarry and creek (Figure 6).

e. Samples of water were collected from three boreholes and five site monitoring wells (Figure 8). Samples were collected using a hand bailer.

3. Stack Monitoring

Two major process stacks, representing a cross section of plant operations, were selected for monitoring. Sampling was performed outside the "Tank" building at a chlorine scrubber location and outside the "REC" (Rare Earth Chloride) building at a single scrubber location (see Figure 9). Another scrubber location situated outside the "Moly" building could not be sampled due to its design. This scrubber discharges an acid mist through a large open vent. Sampling, therefore, would have been both difficult and impractical. It should be noted that all three of the plant's dust collectors were out of operation, either due to mechanical breakdowns or other reasons associated with plant operations, and therefore could not be monitored.

a. Stack locations were selected to provide representative sampling. At the Tank building scrubber location, sampling was performed along a horizontal section of duct (0.25 m diameter). Stack monitoring outside the REC building was conducted along vertical ductwork (0.30 m diameter). At both locations, access ports were drilled at least 8 duct diameters downstream of the nearest transition, bend or other disturbance in order to minimize variations in air flow patterns at the sampling points.

b. Preliminary velocity measurements were taken throughout the cross-sectional area of each stack to detect any significant air flow variations. An Alnor velometer was used for the measurements. Velocity measurements at pre-determined locations in the ducts were then performed based on recommendations found in EPA Standard Method #1.[1] Figure 10 summarizes the criteria for selection of air flow measurement locations in circular ducts. On the basis of duct diameters, measurements outside the Tank and REC buildings were performed on an 8-point traverse.

c. Velocity distribution measurements and calculations of corresponding nozzle diameter sizes were performed to determine appropriate flow rates for isokinetic sampling. The nozzles were connected to probes supported by metal plates held in place by flexible straps.

d. One sampling probe was installed at the centerline of the Tank and REC building ducts. The probes were maintained in this fixed position for the duration of sample collection.

e. Following installation of the probe assemblies and connection of the vacuum, control, and measurement equipment, air flow through each probe was adjusted to the desired isokinetic sampling rates. Actual flow rates were 15 lpm (liters per minute) at the Tank building scrubber and 21 lpm at the REC building scrubber. Times and flow rates were noted; periodic flow rate checks were made to assure that the desired flow was being maintained. Sampling periods were approximately 24 hours in duration for five days.

f. Collection media used by ORAU at both stack locations were moisture (vacuum) traps and impingers filled with distilled water to a starting volume of 200 ml (Figure 11).

4. Background Measurements

Seven soil, four water and four sediment samples were collected from the York area (but not from the site or adjacent properties) to provide baseline concentrations of radionuclides of interest for comparison purposes. Direct background radiation levels were measured at locations where samples were collected. The locations of the baseline samples and background measurements are shown on Figure 12.

Sample Analyses and Interpretation of Results

Soil and sediment samples were analyzed by gamma spectrometry. Major

radionuclides of concern were Ra-226, Th-232, Th-228, and U-238; however, spectra were reviewed for other identifiable photopeaks.

Water samples were analyzed for gross alpha and gross beta concentrations. Four of the samples were also analyzed for Ra-226, Ra-228, and uranium and thorium isotopic concentrations.

Air sampling solutions (impingers and moisture traps) were analyzed for gross alpha and beta levels. Data comparison with the licensee was not possible because monitoring at scrubber and dust collector locations is not performed at the present time.

Additional information concerning major instrumentation, sampling equipment and analytical procedures is provided in Appendices A and B. A summary of radiation protection guidelines applicable to this site is presented in Appendix C.

Flow diagrams were developed for plant processes involving the uranium and thorium containing ores. This information is presented in Appendix D. Plant personnel were unable to provide data necessary for performing a materials balance on any of these processes.

RESULTS

Background Levels and Baseline Concentrations

Background exposure rates and baseline radionuclide concentrations in soil and sediment, determined for several locations (Figure 12) in the vicinity of the Molycorp plant, are presented in Tables 1A and 1B, respectively. Exposure rates ranged from 8 to 11 μR/h (typical levels for Pennsylvania). Concentrations of radionuclides in soil were: Ra-226, 0.75 to 1.12 pCi/g (picocuries per gram); Th-232, 1.14 to 1.90 pCi/g; Th-228, 1.10 to 1.93 pCi/g; and U-238, <0.98 to 2.98 pCi/g. Concentrations of radionuclides in sediment were: Ra-226, 0.76 to 1.10 pCi/g; Th-232, 0.82 to 1.59 pCi/g; Th-228, 1.20 to 1.79 pCi/g; and U-238, <0.95 to 2.36 pCi/g. These concentrations are typical of the radionuclide levels normally encountered in surface soils.

Radioactivity levels in baseline water samples are presented in Table 1C. Gross alpha and gross beta concentrations ranged from <0.45 to 1.08 pCi/l (picocuries per liter) and 2.03 to 5.60 pCi/l, respectively. These levels are typical of concentrations normally occurring in surface water.

Direct Radiation Levels

Direct radiation levels, measured around the site perimeter, are presented in Table 2. Gamma exposure rates at 1 m above the surface ranged from 8 to 70 μR/h. Surface contact gamma exposure rates ranged from 8 to 96 μR/h. The highest levels were recorded at coordinate 480, 2.5 on the southeast portion of the site and were due to the presence of a contaminated pile of residue stored onsite. Higher than background exposure levels were present at many other locations around the site perimeter because of the storage of drums of low-level waste.

The walkover gamma surface scan identified numerous small areas and isolated spots of elevated contact radiation levels. These locations are indicated on Figure 13 and associated radiation levels are presented in Table 3. Surface contact gamma exposure rates ranged from 24 to 490 μR/h; maximum levels were recorded on a slag-like rock at coordinate 460, 4.5. Exposure rates at 1 m above the surface ranged from 10 to 59 μR/h. Contact exposure rates were reduced by soil sampling at approximately half of the locations. At other locations, the levels were unchanged or increased as a result of surface sampling.

A walkover gamma scan was also performed along the portions of Hudson, Olive and N. Sherman streets that surround the Molycorp site. No locations of elevated activity were noted.

Radionuclide Concentrations in Surface Soil

Table 4 lists the concentrations of radionuclides measured in surface soil around the site perimeter. Several of the samples contained combined levels of Th-228 plus Th-232 exceeding 10 pCi/g. The highest level was 57.6 pCi/g at 460, 3 in the vicinity of the residue pile. Levels of U-238 ranged from <0.89 to 34.1 pCi/g. The highest concentration was found at

location 480, 2.5. Samples contained Ra-226 concentrations ranging from 0.46 to 6.21 pCi/g. The highest level was also in the sample collected from location 480, 2.5. Several other samples contained Ra-226 concentrations exceeding those in the baseline soil; however, only two samples (from coordinates 440, 1.5 and 480, 2.5) contained greater than 5 pCi/g above the baseline level.

Radionuclide concentrations in samples from locations of elevated contact radiation levels are presented in Table 5. High levels of Th-232 and Th-228 were present in several samples. The highest level of Th-232 (320 pCi/g) and Th-228 (350 pCi/g) was found at coordinate 265, 1 in a sample of pink colored material. Levels of U-238 were elevated in most of the samples with a maximum concentration of 110 pCi/g also noted at location 265, 1. Concentrations of Ra-226 in these samples ranged from 0.78 to 88.1 pCi/g; the maximum concentration was measured at location 242, 3.5.

Gamma spectroscopy was performed on several slag-like rocks collected from the southeast perimeter of the plant between the residue pile and the railroad tracks. These rocks contain elevated levels of Ra-226, Th-232, Th-228 and U-238. Because of their geometry only qualitative analyses were conducted on these samples. It should be noted that many of these rocks remain scattered throughout the area.

Radionuclide Concentrations in Subsurface Soil

Table 6 presents radionuclide concentrations measured in split-spoon and borehole soil samples. Boreholes H1 - H6 were drilled in areas considered representative of general property conditions. Gamma logging of these holes did not identify any locations of elevated subsurface activity. Soil sample analysis confirmed these findings: levels of Ra-226, Th-232 plus Th-228, and U-238 were slightly elevated but all were less than 4 pCi/g. Boreholes H7 and H8 were drilled in close proximity to and directly on the residue pile located in the southeast corner of the property, respectively. Surface (0-15 cm) contamination was present at borehole H7; elevated levels of Ra-226, Th-232, Th-228 and U-238 were present to a depth of 1.5 - 2.1 m at borehole location H8.

Radionuclide concentrations in subsurface soil from locations identified by the walkover scan outside the site perimeter are presented in Table 7. Contamination extended to as deep as 0.75 - 0.90 m. At locations 3 (265, 1), 5 (342, 0.5), 7 (488, 4), 8 (498, 5.5), and 9 (532, 2), subsurface obstacles prevented the collection of soil samples from depths below the region of contamination.

Radionuclide Concentrations in Water

Surface Water

Table 8 presents gross alpha and beta concentrations in surface (standing) water from the York site and the nearby plant vicinity. Results of alpha spectroscopy performed on selected samples is presented in Table 9. Samples W1 and W2 were collected near the REC building and a drainage basin on the north end of the plant, respectively. Gross alpha levels were 4.29 (W1) and 7.86 (W2) pCi/l; gross beta levels for W1 and W2 were 8.40 and 18.7 pCi/l.

Samples W3 and W4 were collected from the onsite clarifier and neutralizing tanks. High minimum detectable activities, caused by high concentrations of dissolved solids, inhibited gross alpha and beta analyses. Isotopic radium, uranium, and thorium analyses for W3 indicated 0.16 pCi/l, Ra-226; 0.70 pCi/l, Ra-228; 0.25 pCi/l, Th-232; 0.25 pCi/l, Th-228; 12.8 pCi/l, U-234; and 13.5 pCi/l, U-238. Sample W4 contained 0.09 pCi/l, Ra-226; 2.08 pCi/l, Ra-228; <0.07 pCi/l, Th-232; <0.07 pCi/l, Th-228; 13.4 pCi/l, U-234; and 13.4 pCi/l, U-238.

Sample W5 was collected from a sanitary sewer on the west side of the plant. Gross alpha analysis resulted in a high minimum detectable activity (<27.6 pCi/l). Subsequent isotopic analyses indicated levels of 0.15 pCi/l, Ra-226; 0.79 pCi/l, Ra-228; 0.04 pCi/l, Th-232; 0.04 pCi/l, Th-228; 24.0 pCi/l, U-234; and 24.4 pCi/l, U-238.

Sample W6 was collected from an overflow groundwater discharge drain. Gross alpha and beta levels were 1.99 and 6.99 pCi/l, respectively.

Sample W7 - W9 were collected from locations outside the site perimeter but were not associated with background samples discussed earlier. Sample W7 was collected from a nearby quarry; samples W8 and W9 were collected from a site adjacent drainage ditch and its discharge point into Mill Creek, respectively. Gross alpha levels ranged from <1.24 to 2.35 pCi/l; gross beta levels ranged from 2.59 to 12.5 pCi/l.

Subsurface Water

Water samples W10 - W12, collected from boreholes H5 - H7, respectively, contained <2.22 to 3.46 pCi/l of gross alpha and <2.81 to 9.50 pCi/l of gross beta (refer to Table 8).

Samples W13 - W17 were collected from five site monitoring wells. Gross alpha concentrations ranged from <0.75 to 11.8 pCi/l. Gross beta levels ranged from 3.43 to 41.6 pCi/l. Isotopic analyses were performed on sample W16 collected near the clarifier effluent tank (Table 9). Radium-226 and Ra-228 levels were <0.05 and 1.04 pCi/l, respectively; other concentrations were Th-232, 0.36 pCi/l; Th-228, 0.36 pCi/l; U-234, 11.1 pCi/l; and U-238, 11.8 pCi/l.

Radionuclide Concentrations in Sediment Samples

Radionuclide concentrations in sediment samples are presented in Table 10. Samples S1 - S4 were collected onsite from locations near the Rare Earth Chloride and Tank buildings, a drainage basin on the north end of the plant site, and the top of the clarifier effluent tank. All four samples were elevated in Ra-226 (6.31 to 14.6 pCi/g), Th-232 (81.0 to 190 pCi/g), Th-228 (56.2 to 170 pCi/g), and U-238 (30.7 to 140 pCi/g).

For comparison, sediment samples S5 - S9 were collected within short distances from the site boundary. Radionuclide concentrations in these samples, though slightly higher in some cases than baseline levels, were all less than 3.3 pCi/g.

Stack Monitoring - Tank and REC Buildings

Tables 11 and 12 present velocity profiles measured in the Tank and REC building scrubber exhausts and subsequently determined air sampling flow rates and volumes, respectively.

Results of monitoring at the Tank building scrubber are presented in Table 13. Gross alpha concentrations ranged from $<7.50 \times 10^{-15}$ to $3.12 \pm 0.64 \times 10^{-13}$ µCi/ml. Gross beta concentrations ranged from $<1.48 \times 10^{-14}$ to $2.87 \pm 1.08 \times 10^{-13}$ µCi/ml. Table 14 presents the results of stack monitoring at the REC building scrubber. Gross alpha concentrations ranged from $3.80 \pm 5.00 \times 10^{-15}$ to $3.46 \pm 2.86 \times 10^{-14}$ µCi/ml. Gross beta concentrations ranged from $<5.10 \times 10^{-15}$ to $9.98 \pm 3.38 \times 10^{-14}$ µCi/ml. (Because of these very low levels, isotopic determinations were not performed.)

It should be mentioned that discharges from the Tank and REC building scrubbers occur on an intermittent basis at the Molycorp plant because of a non-continuous production schedule. At the time of the ORAU survey, processing operations resulted in releases at the Tank building scrubber on three of the five sampling dates (6/7, 6/10, and 6/11/85). Sampling at the REC building scrubber was valid only on 6/10 and 6/11/85 (analysis on the 6/10 data was not performed due to an equipment malfunction).

COMPARISON OF RESULTS WITH GUIDELINES

Radiation protection guidelines applicable to the York Molycorp plant are presented in Appendix C.

Maximum radiation exposures in unrestricted areas permitted by the Nuclear Regulatory Commission are 2 mrem/hr or 100 mrem in any consecutive 7 day period. These guidelines are met at the Molycorp plant. Exposure rates exceeding twice background are present 1 m above the surface along the length of Olive Street, along the southwest and southeast portions of the site, and along N. Sherman Street. These elevated exposure rates are due in most cases to the onsite storage of low-level waste drums and a residue pile located in the southeast corner. Areas along Hudson Street are less than 20 µR/h. A

maximum exposure rate of 490 μR/h was found on contact with an isolated area of surface contamination.

A few small areas and isolated locations of elevated surface readings identified during the walkover scan contain Ra-226 concentrations in excess of the 5 pCi/g guideline. Guideline levels for Th-232 plus Th-228 (10 pCi/g total) and uranium (35 pCi/g total) are also exceeded at several locations. Levels of Th-232 plus Th-228 and U-238 exceed the criteria in subsurface soil at some locations.

Elevated concentrations of radium, thorium, and uranium exceeding the criteria were found in onsite sediment samples. Samples collected outside the plant perimeter, however, are only slightly above the range of baseline levels.

Gross alpha concentrations in surface water collected onsite and in the near vicinity of the plant are below the 15 pCi/l criteria established by the Environmental Protection Agency (EPA) for community drinking water systems. Concentrations in ground water collected from boreholes and site monitoring wells are also below this level. It should be noted that the EPA limits are used only for comparison and that they are not directly applicable because the water of interest is not from a drinking water supply.

Isotopic analyses were performed on samples of treated process water collected from onsite clarifying and neutralizing tanks and an offsite sanitary sewer. Results are below the respective guideline values for Ra-226 (4×10^{-7} μCi/ml), Ra-228 (8×10^{-7} μCi/ml), Th-232 (5×10^{-5} μCi/ml), Th-228 (2×10^{-4} μCi/ml), U-234 (9×10^{-4} μCi/ml), and U-238 (1×10^{-3} μCi/ml). Similar results were obtained on a sample collected from an onsite monitoring well.

Very low gross alpha and beta concentrations were measured in samples collected from the Tank and REC building scrubber locations. These results indicate that the concentrations meet the guideline values established by the NRC for radium, thorium, and uranium in air released to unrestricted areas.

SUMMARY

At the request of the Nuclear Regulatory Commission, Oak Ridge Associated Universities performed radiological measurements at the Molybdenum Corporation of America (Molycorp) plant in York, Pennsylvania. The survey took place from June 3-12, 1985. The objective of the survey was to evaluate the potential for releases and migration of radioactive materials from the plant site. Radiological information collected included direct radiation exposure rates, locations of contaminated surface residues, and concentrations of radionuclides in surface and subsurface soil, in ground water, in surface water and sediment, in treated process water and in stack discharges.

The results of the survey indicate small areas and isolated locations of contamination outside the perimeter fence resulting in elevated direct radiation levels. Concentrations of Ra-226, Th-232, Th-228, and U-238 exceed guideline values in surface and subsurface soil. Elevated exposure rates were also noted on contact with slag-like rocks concentrated on the southeast corner of the site.

Radionuclide concentrations in water samples collected from surface and subsurface locations are within the guideline values.

Air monitoring at two process stacks indicated that radioactive emissions from plant operations were within acceptable limits. Both stacks were operating intermittently during the five day sampling period, however, and the results may thus not be representative of normal operations.

Based on the results of this survey, it is ORAU's conclusion that water and air process discharges are within acceptable levels at the York Molycorp Plant. There is no evidence of surface or ground water contamination or abnormal air releases to the environment.

The survey results also indicate, however, that spillage or limited runoff of radioactive material has occurred, contaminating surface and near surface soil immediately outside the plant perimeter fence, particularly in the area south and southeast of the residue storage pile.

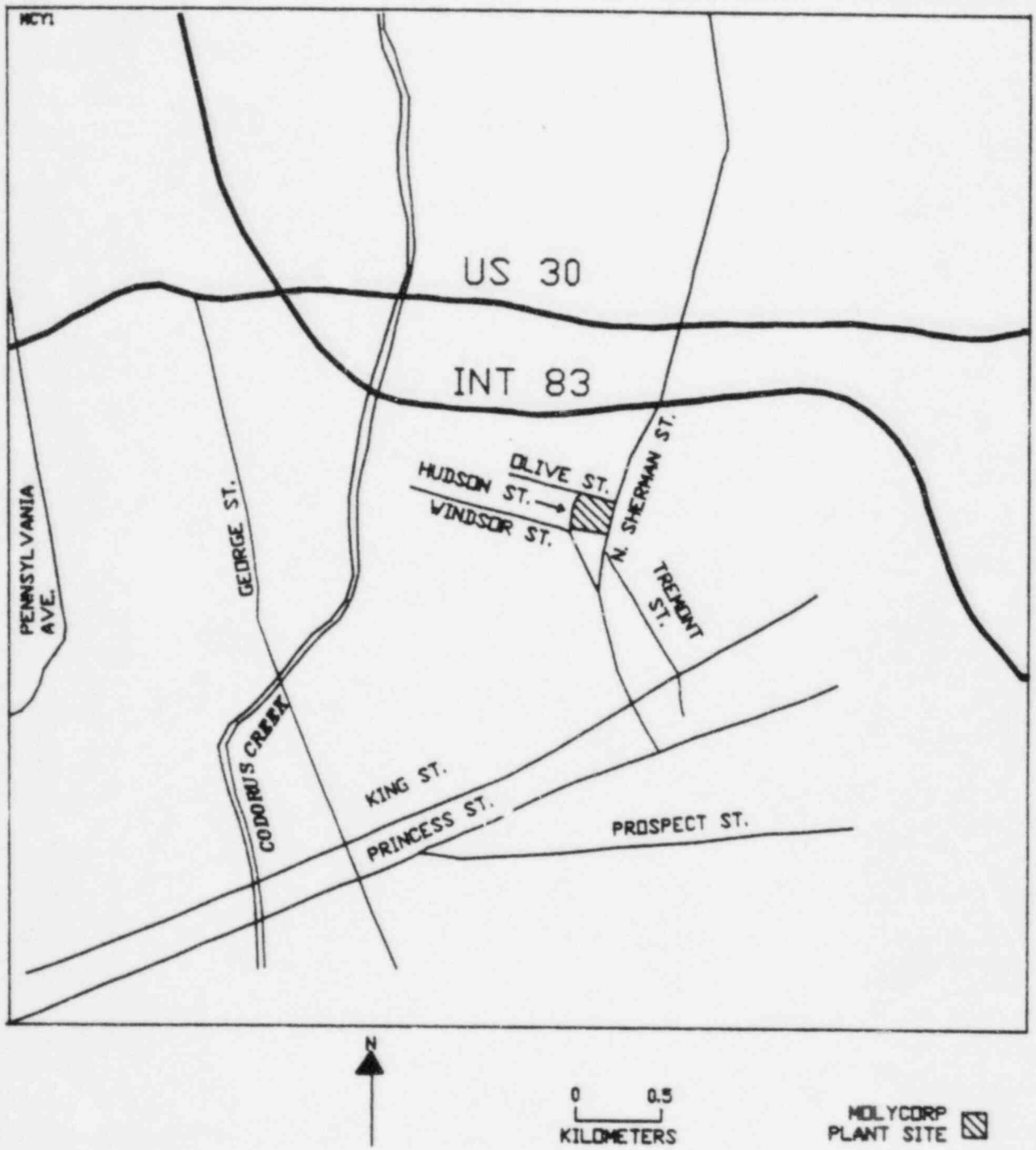

FIGURE 1: Map of the York, Pennsylvania Area Indicating the Location of the Molybdenum Corporation of America Plant Site.

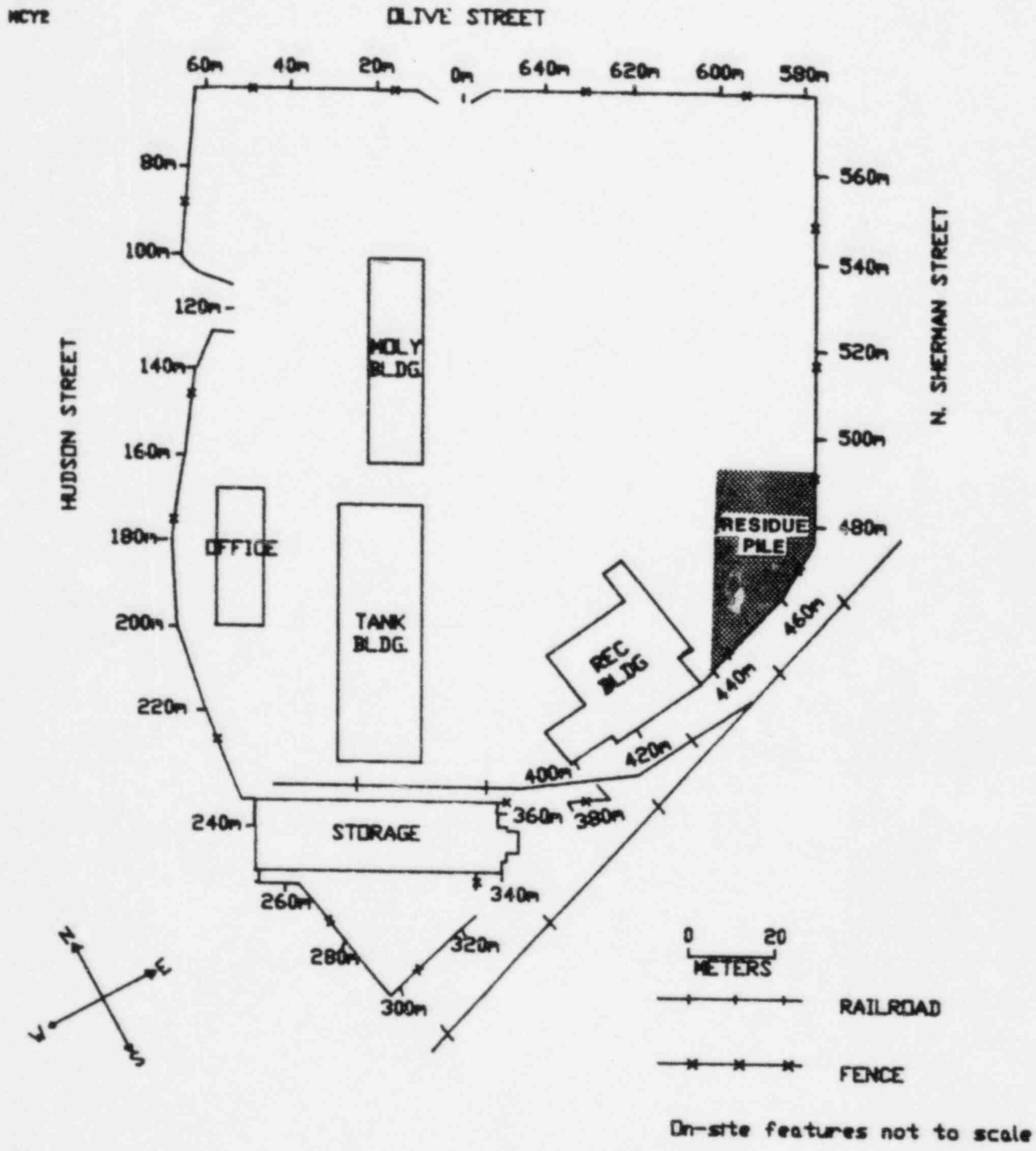

FIGURE 2: Map of the Layout of the Molybdenum Corporation of America Plant Indicating Prominent Surface Features and the Reference System Used for Survey Measurements.

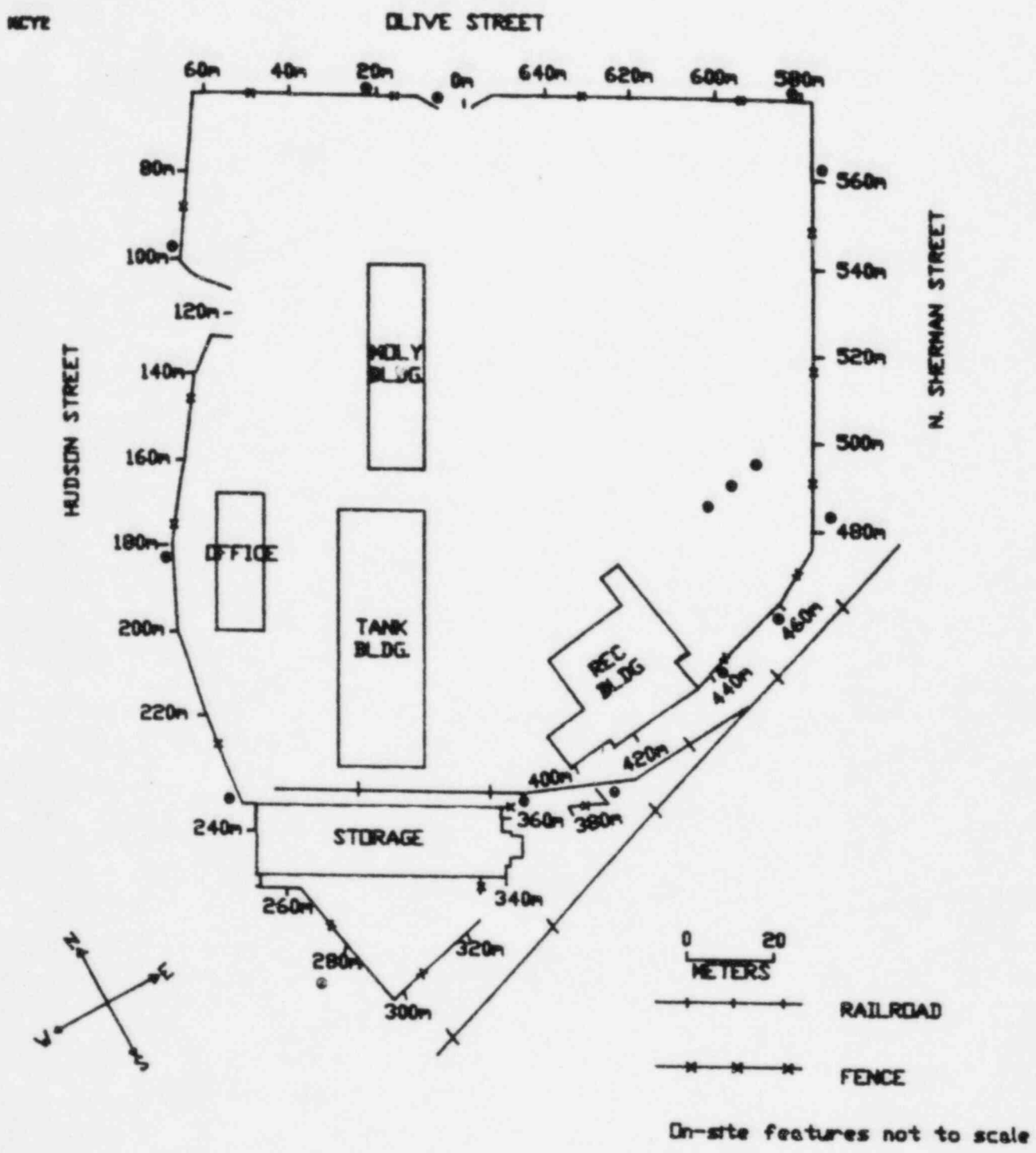

FIGURE 3: Locations (●) of Measurements for Calibration of the NaI Scintillation Detectors.

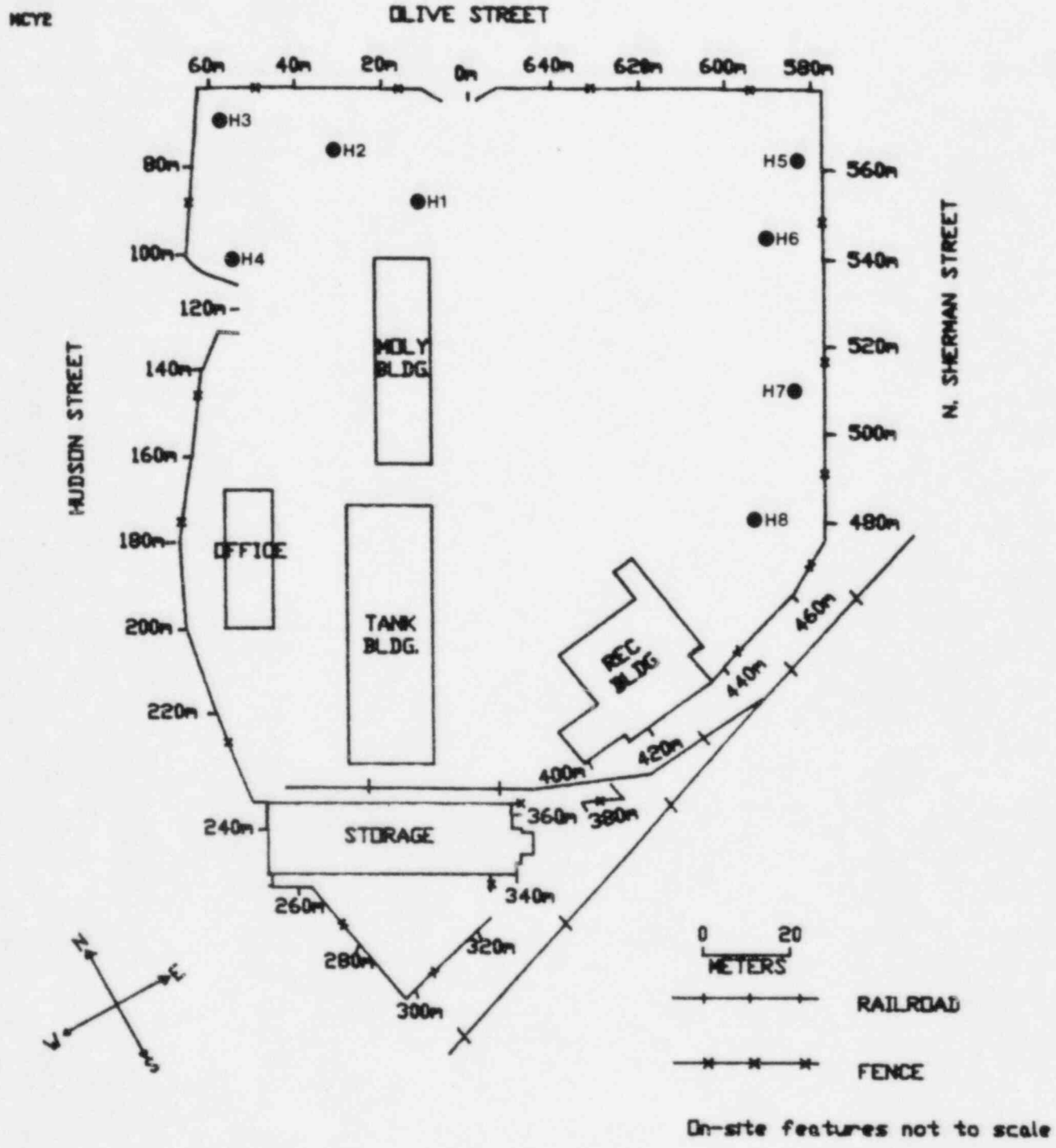

FIGURE 4 Locations of Boreholes for Subsurface Investigations.

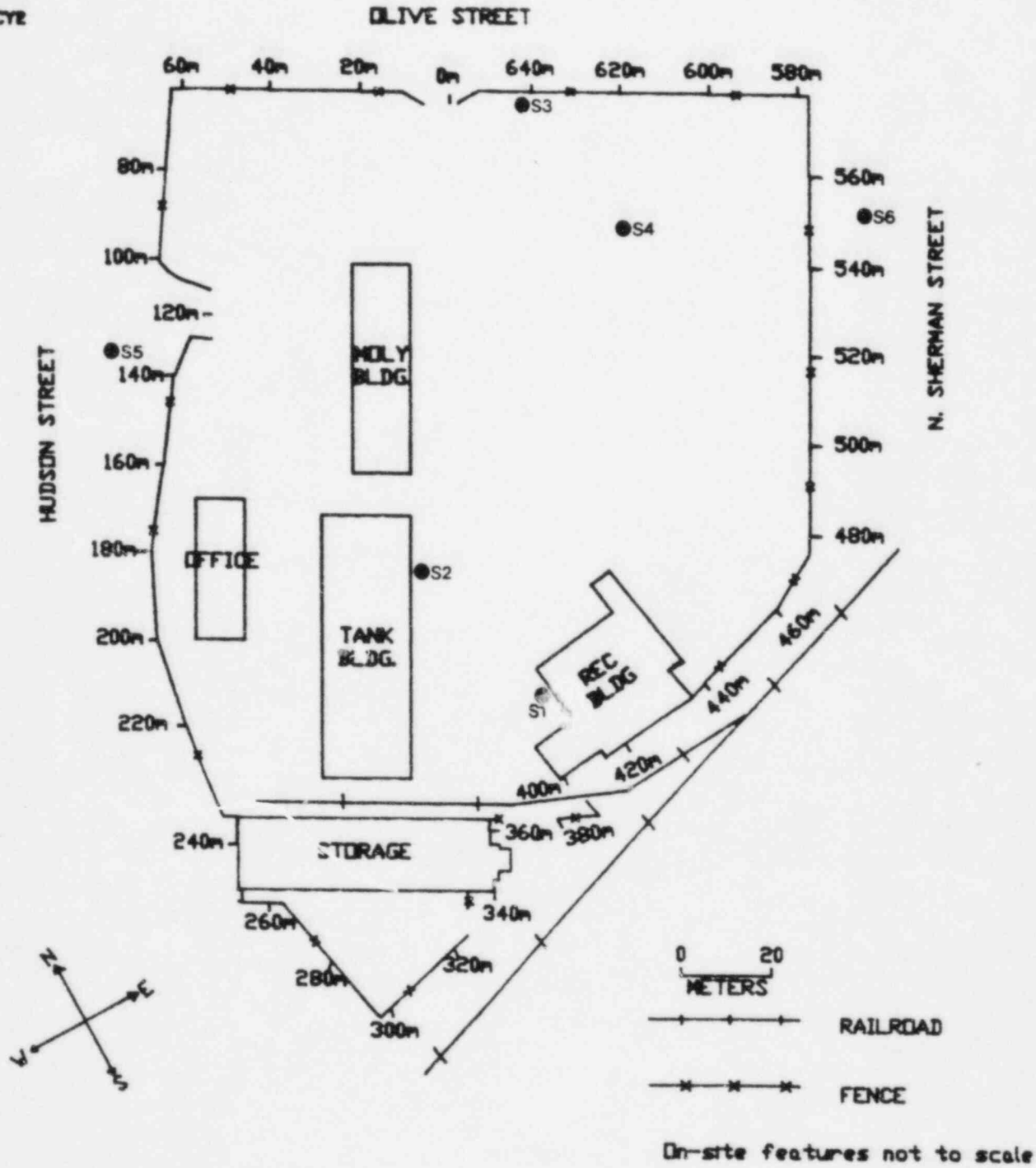

FIGURE 5: Locations of Sediment Samples.

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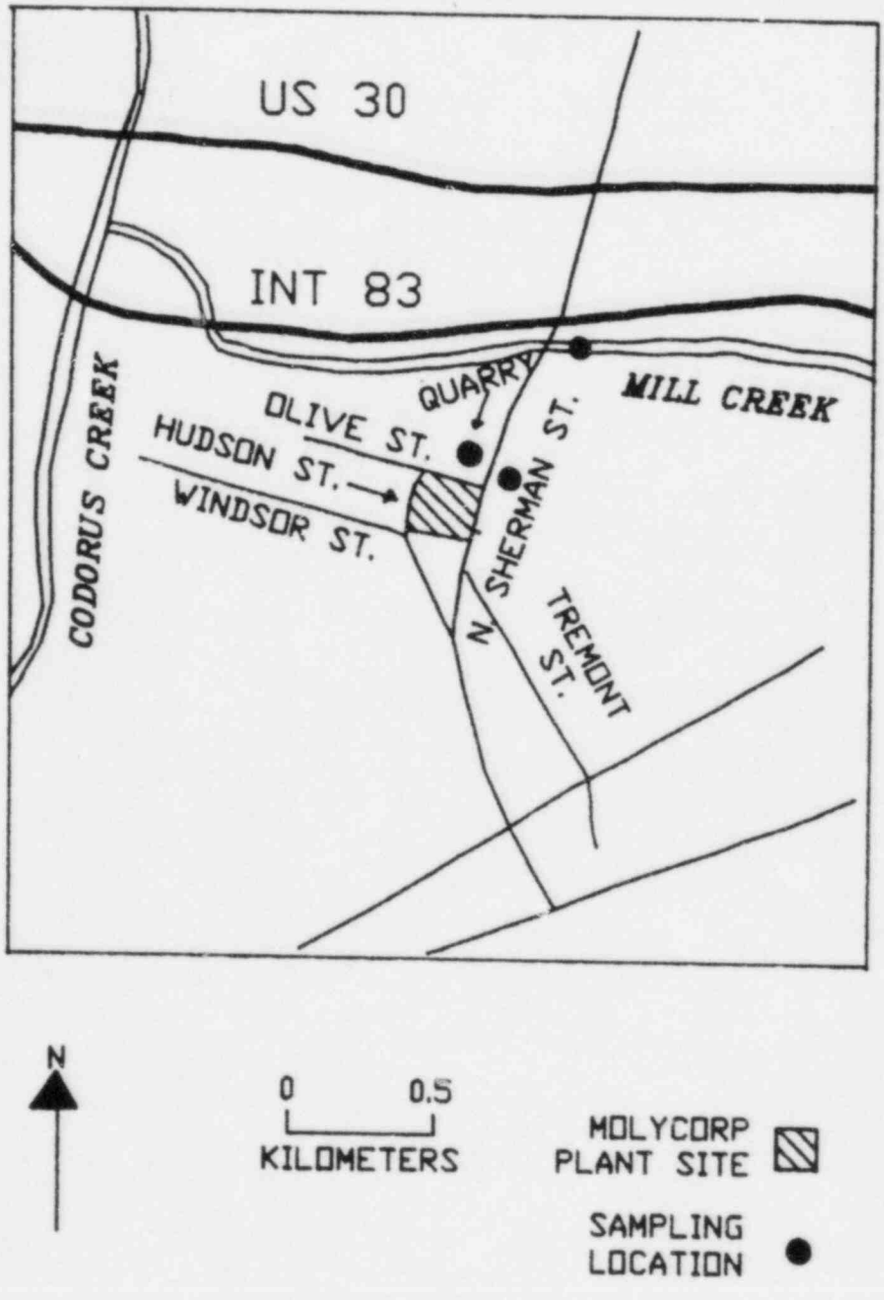


FIGURE 6: Locations of Offsite Sediment and Water Samples.

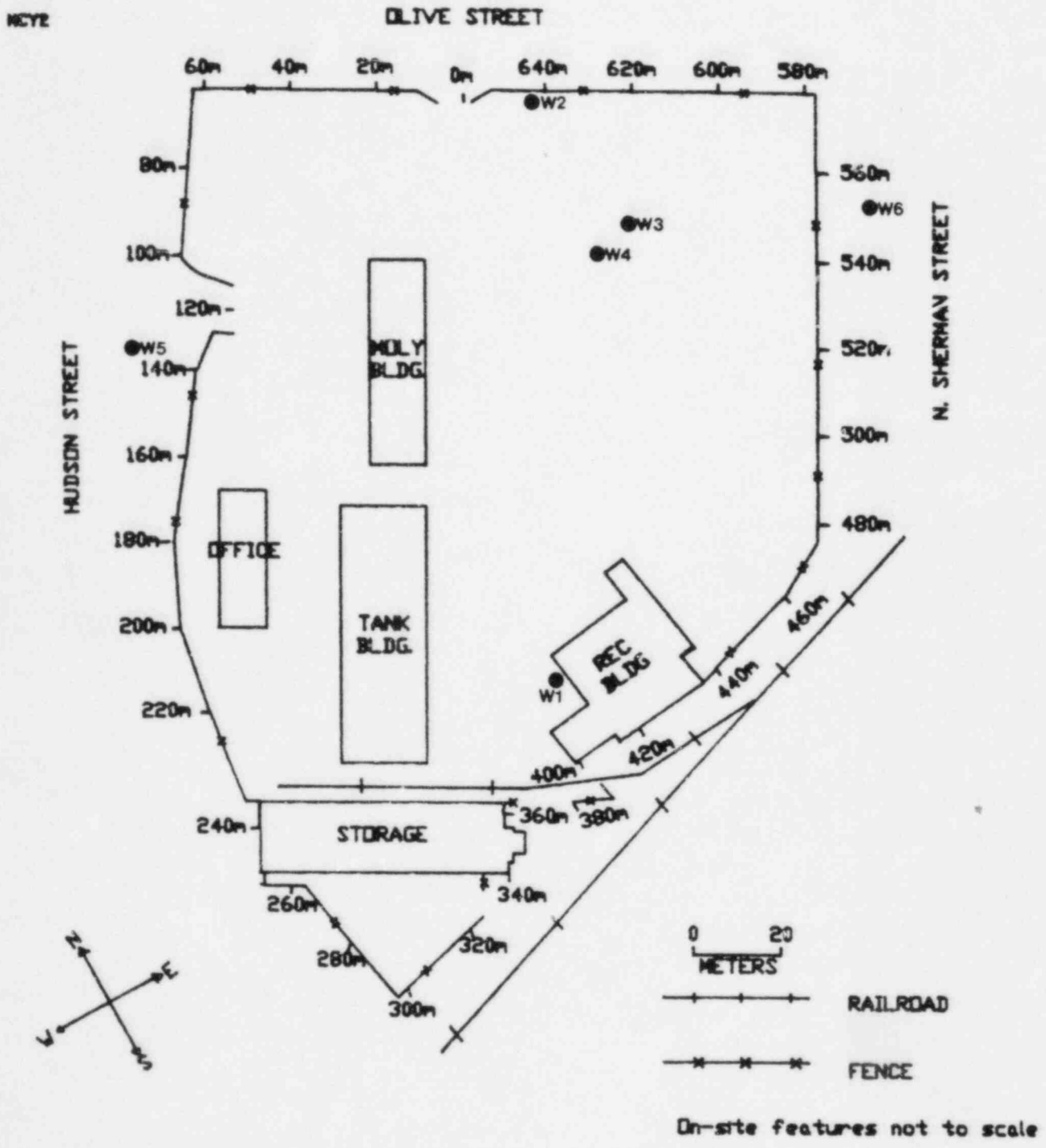


FIGURE 7: Locations of Surface Water Samples.

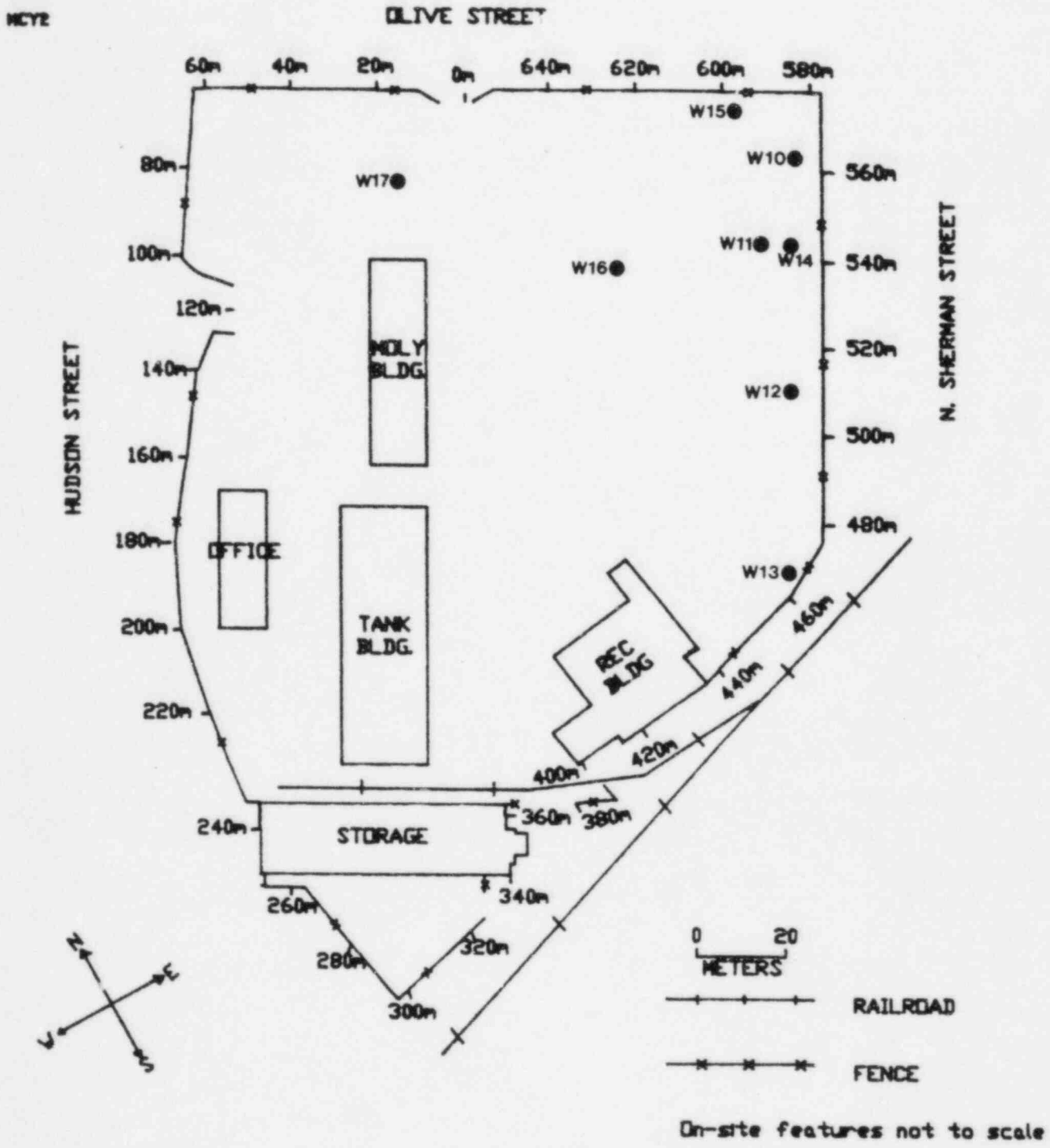


FIGURE 8: Locations of Subsurface Water Samples.

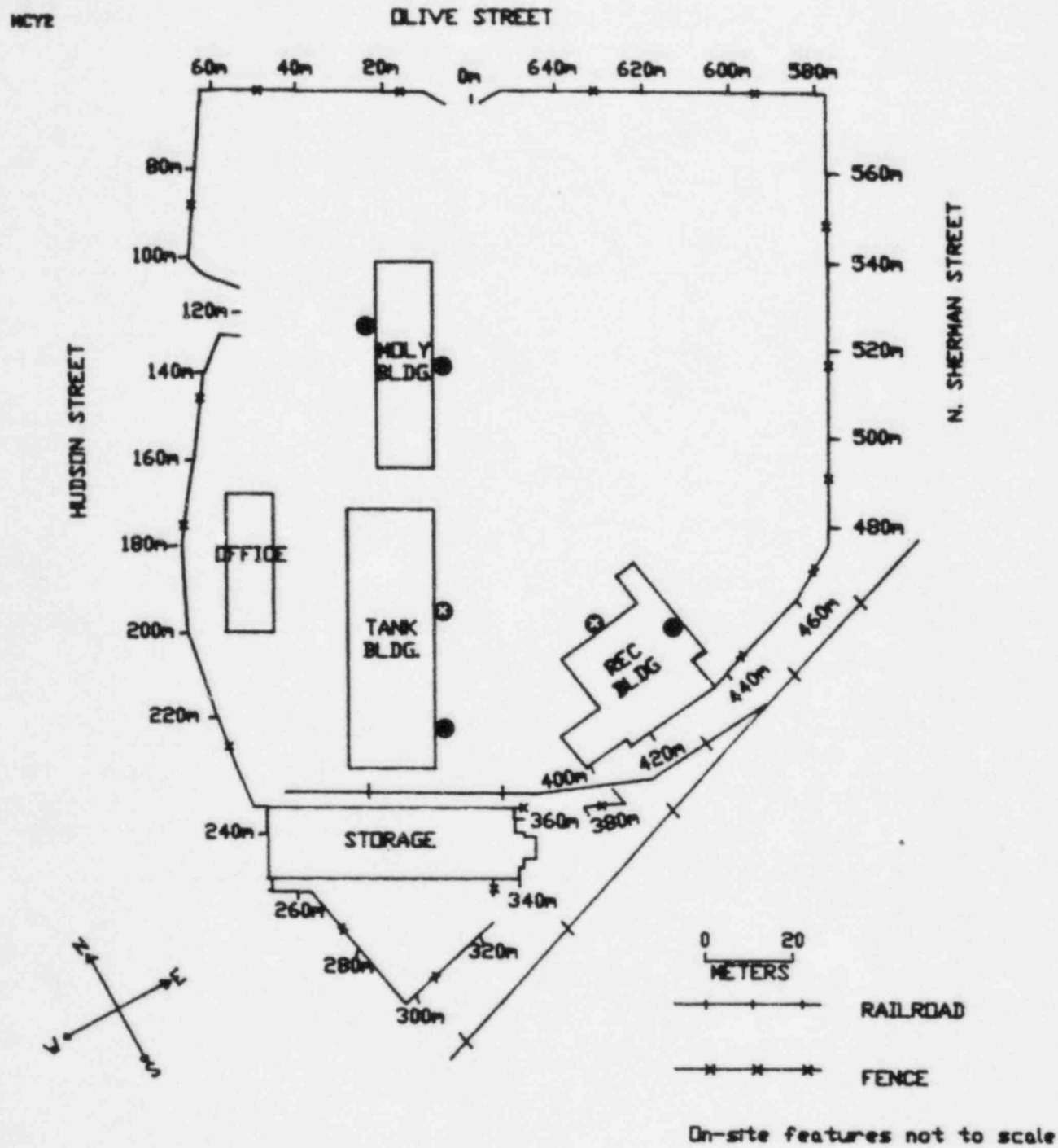
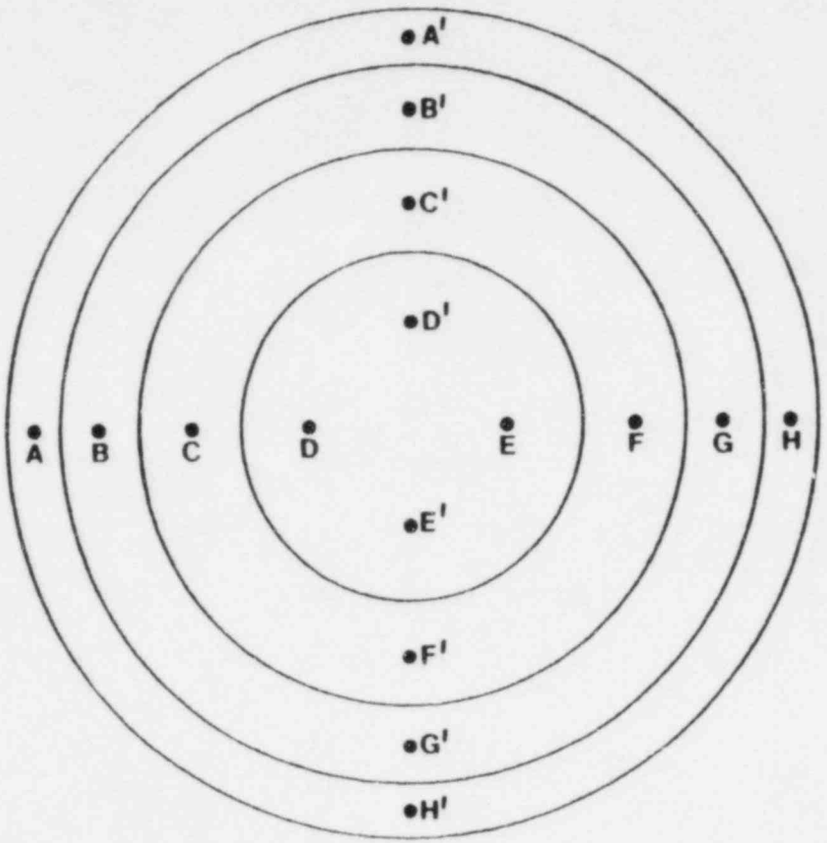


FIGURE 9: Layout of the Molybdenum Corporation of America Plant Showing Dust Collector and Scrubber Locations. (Locations marked with an "X" indicate ORAU sampling points.)



Duct Diameter (cm)	# Of Points Per Traverse	DISTANCES OF POINTS FROM DUCT WALL (fraction of duct diameter)											
		A	B	C	D	E	F	G	H	I	J	K	L
<61	8	.032	.105	.194	.323	.677	.806	.895	.968	-	-	-	-
>61	122	.021	.067	.118	.177	.250	.356	.644	.750	.823	.882	.933	.979

FIGURE 10: EPA Standard Method 1 Criteria for Performing Air Velocity Measurements in Circular Ducts.

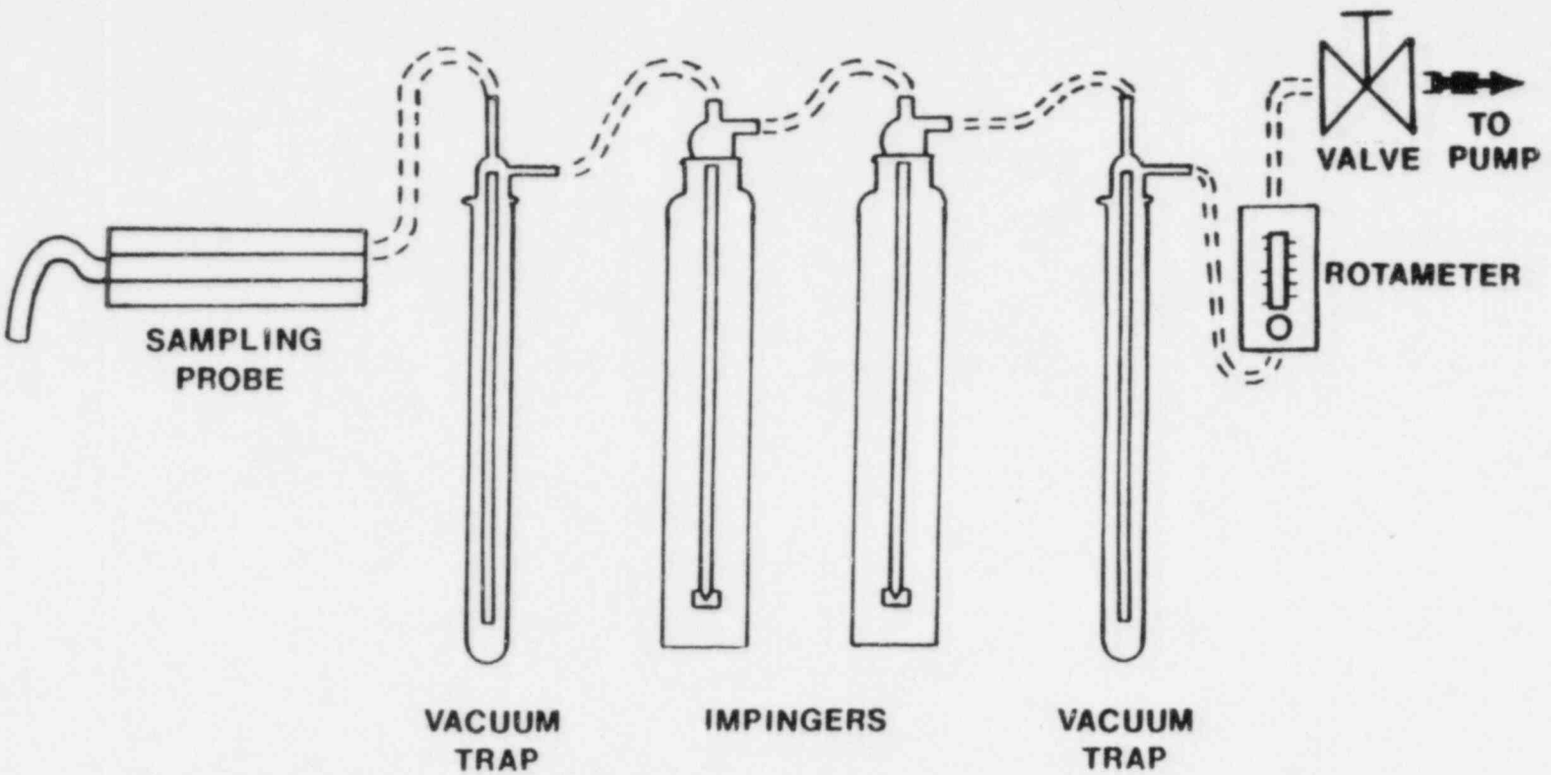


FIGURE 11: Diagram of the Sampling System for the Tank and REC Building Scrubbers.

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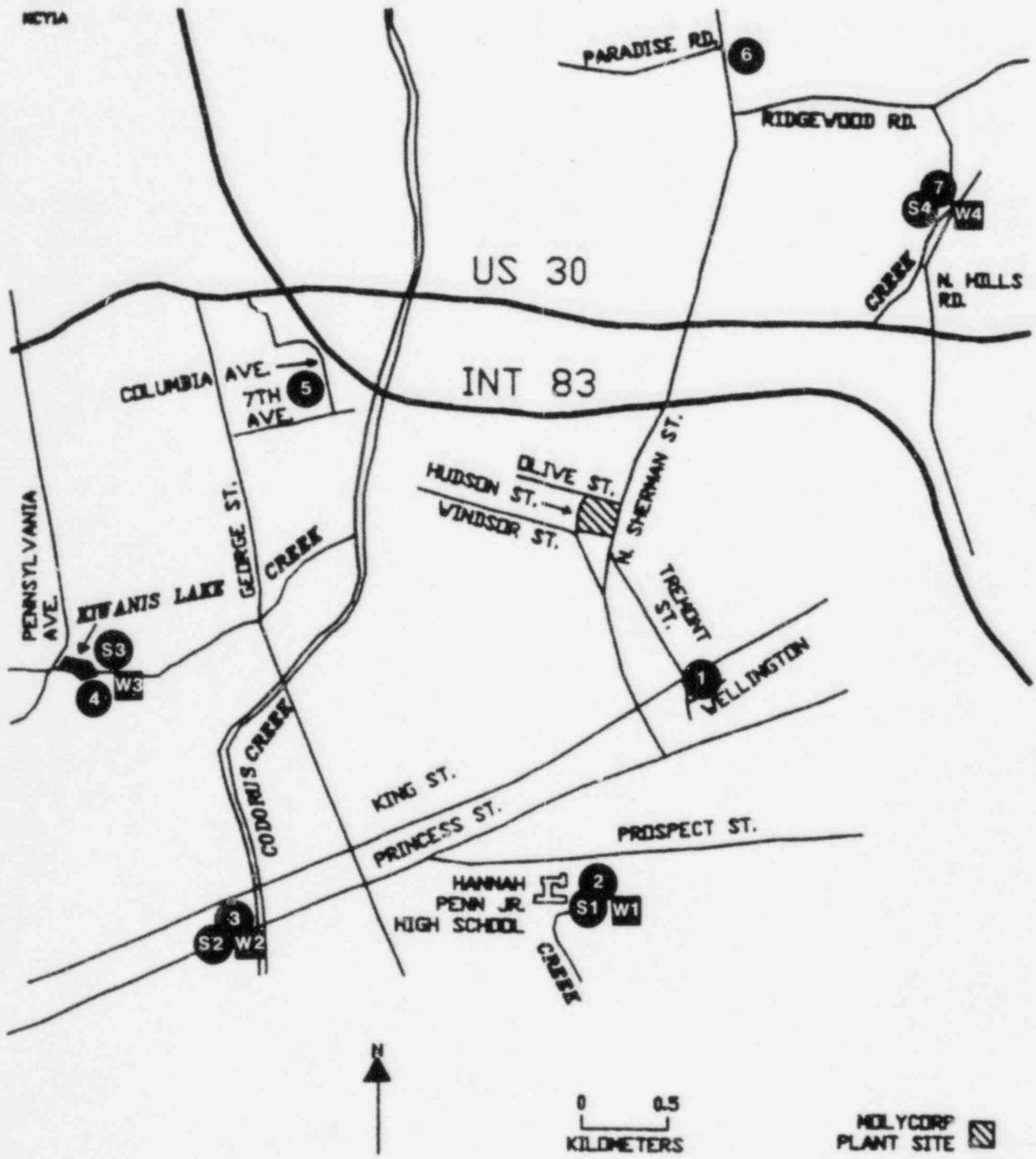


FIGURE 12: Map of the York, Pennsylvania Area Showing the Locations of Background Measurements and Baseline Samples. (#1-7: soil samples and direct measurements; S1-S4: sediment samples; W1-W4: water samples.)

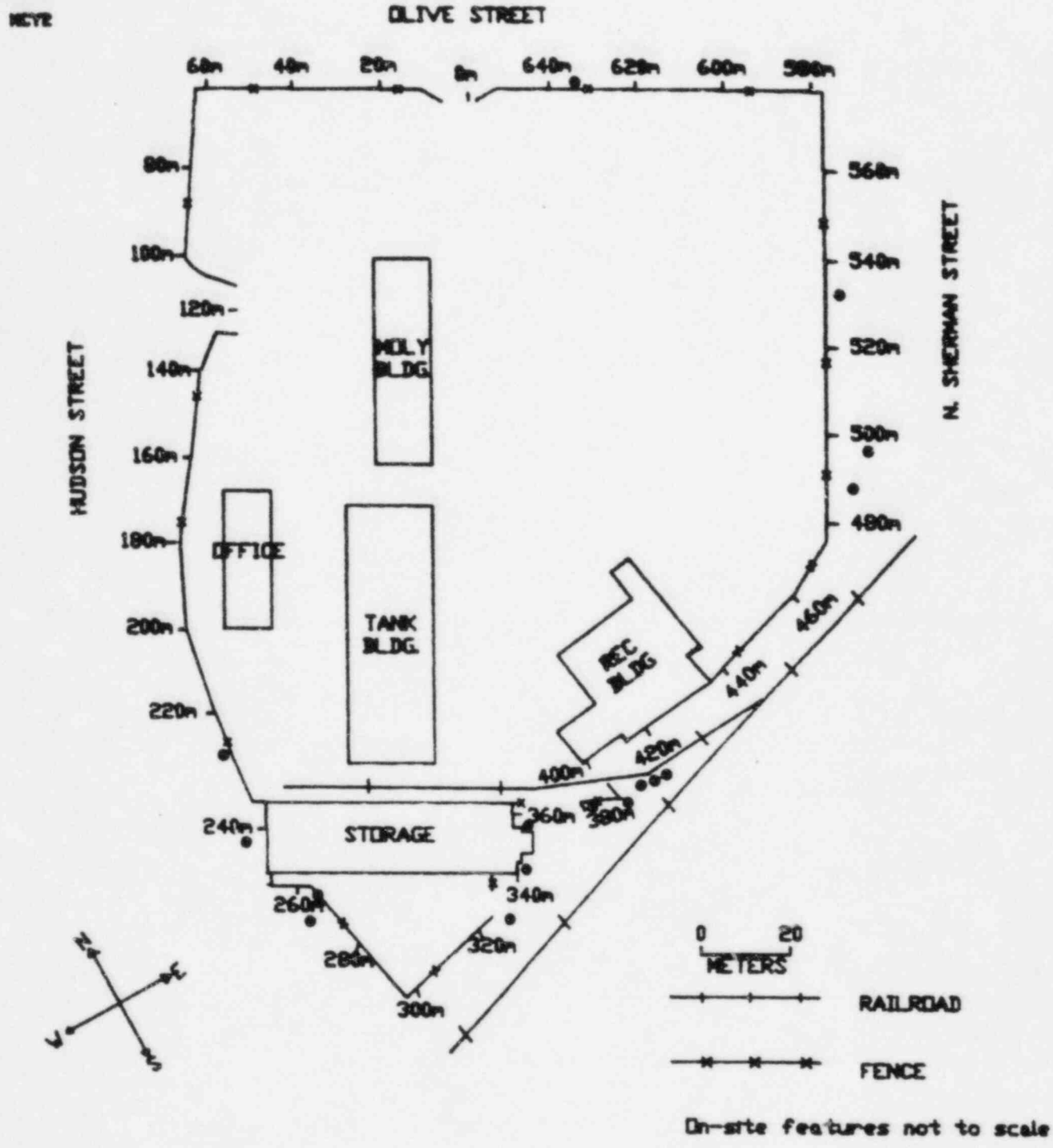


FIGURE 13: Locations (●) of Areas of Elevated Direct Radiation Identified by the Walkover Surface Scan.

TABLE 1A

BACKGROUND EXPOSURE RATES AND RADIONUCLIDE
CONCENTRATIONS IN BASELINE SOIL SAMPLES
MOLYBDENUM CORPORATION OF AMERICA
YORK, PENNSYLVANIA

Location[a]	Exposure Rate[b] (μR/h)	Radionuclide Concentrations (pCi/g)			
		Ra-226	Th-232	Th-228	U-238
1	9	0.75 ± 0.35[c]	1.90 ± 0.66	1.92 ± 0.52	2.98 ± 2.82
2	10	0.96 ± 0.31	1.32 ± 0.47	1.10 ± 0.42	1.24 ± 1.88
3	8	1.00 ± 0.23	1.14 ± 0.52	1.35 ± 0.44	1.12 ± 2.06
4	10	1.12 ± 0.25	1.34 ± 0.59	1.59 ± 0.38	2.35 ± 1.19
5	9	0.75 ± 0.28	1.65 ± 0.50	1.21 ± 0.54	2.43 ± 2.24
6	10	0.82 ± 0.41	1.56 ± 0.54	1.93 ± 0.43	2.61 ± 1.80
7	11	0.85 ± 0.21	1.63 ± 0.53	1.33 ± 0.45	<0.98

[a]Refer to Figure 12.
[b]Measured at 1 m above the surface.
[c]Errors are 2σ based on counting statistics.

TABLE 1B

RADIONUCLIDE CONCENTRATIONS IN BASELINE SEDIMENT SAMPLES
MOLYBDENUM CORPORATION OF AMERICA
YORK, PENNSYLVANIA

Location[a]	Radionuclide Concentrations (pCi/g)			
	Ra-226	Th-232	Th-228	U-238
S1	0.96 ± 0.26[b]	1.19 ± 0.63	1.64 ± 0.44	<1.04
S2	1.05 ± 0.28	1.37 ± 0.55	1.79 ± 0.43	1.98 ± 1.89
S3	0.76 ± 0.34	0.82 ± 0.34	1.37 ± 0.51	2.36 ± 1.87
S4	1.10 ± 0.22	1.59 ± 0.45	1.20 ± 0.34	<0.95

[a]Refer to Figure 12.
[b]Errors are 2σ based on counting statistics.

TABLE 1C

RADIONUCLIDE CONCENTRATIONS IN BASELINE WATER SAMPLES
MOLYBDENUM CORPORATION OF AMERICA
YORK, PENNSYLVANIA

Location[a]	Radionuclide Concentrations (pCi/l)	
	Gross Alpha	Gross Beta
W1	<0.45	2.68 ± 1.07[b]
W2	<0.59	5.60 ± 1.23
W3	1.08 ± 1.09	2.03 ± 1.56
W4	0.91 ± 0.59	3.13 ± 0.89

[a]Refer to Figure 12.
[b]Errors are 2σ based on counting statistics.

TABLE 2

DIRECT RADIATION LEVELS MEASURED OUTSIDE THE SITE PERIMETER
MOLYBDENUM CORPORATION OF AMERICA
YORK, PENNSYLVANIA

Location[a]	Gamma Exposure Rates at 1 m Above the Surface (μR/h)	Gamma Exposure Rates at the Surface (μR/h)
0,0	29	28
5,0.5	28	24
20,1	35	32
40,1	32	26
60,0.5	18	16
80,1.5	20	18
100,1	18	18
116,0	18	16
120,0	16	13
125,0	15	13
130,0	15	15
140,1.5	16	16
160,1.5	15	15
180,2	15	15
200,2.5	15	16
220,3.5	13	13
231,1.5	12	13
234,0	13	11
240,2.5	12	13
250,2	13	16
254,1	11	11
260,0.5	24	30
280,6	20	20
297,2	13	13
300,1	11	12
320,1.5	12	13
324,2	13	13
331,3	13	14
334,0	13	13
340,1	13	15
341,1	13	14
343,0	13	13
346,0	13	15
351,0	13	13
354,0	13	13
360,0	12	12
363,0	11	13
378,0	13	14
380,0.5	16	18
392,0.5	13	13
400,0	8	8
406,3	13	15

TABLE 2 (Continued)

DIRECT RADIATION LEVELS MEASURED OUTSIDE THE SITE PERIMETER
MOLYBDENUM CORPORATION OF AMERICA
YORK, PENNSYLVANIA

Location	Gamma Exposure Rates at 1 m Above the Surface (μR/h)	Gamma Exposure Rates at the Surface (μR/h)
420,1	15	15
433,1.5	18	18
440,1.5	42	53
460,3	67	56
476,3	42	45
480,2.5	70	96
500,1.5	26	24
520,0.5	26	24
540,3.5	20	20
560,4	24	22
578,5	16	16
580,1	16	16
600,1	28	22
620,1	28	28
640,1	29	29
654,0.5	29	28
658,0	30	30
660,0	26	30

[a]Refer to Figure 2.

TABLE 3

DIRECT RADIATION LEVELS AT LOCATIONS IDENTIFIED BY THE WALKOVER SURFACE SCAN OUTSIDE THE SITE PERIMETER - MOLYBDENUM CORPORATION OF AMERICA YORK, PENNSYLVANIA

Location[a]	Exposure Rate (μR/h)		Contact Exposure[b] Rate After Sample Removal (μR/h)
	Contact	1 m Above Surface	
227,0.5	28	13	73
242,3.5	37	13	220
247,4	24	10	- c
265,1	200	37	200
268,4	82	26	93
326-327,0-1.5	30-37	-	-
327,1.5	37	15	37
342,0.5	28	16	130
352,0.5	30	12	15
382,2	26	16	12
387,2	26	16	18
409,2.5	32	12	22
414,2	42	12	35
417,2	70	20	48
438-457,0-2	42-56	-	-
440,3	99	24	12
446,0.5	300	45	79
457-476,0-3	42-150	-	-
460,4.5	490	45	13
477,4	150	37	45
478,2	150	59	70
479-498,0-6	25-130	-	-
482,3	130	59	70
488,2.5	82	59	70
488,4	59	42	50
498,5.5	59	22	88
530-532,1-2.5	37-62	-	-
532,2	59	32	85
629-634,0-1.5	42-56	-	-
632,0.5	76	45	93

[a] Refer to Figure 13.
[b] Radionuclide concentrations in samples are presented in Table 7.
[c] Dash indicates measurement or sampling not performed.

TABLE 4

RADIONUCLIDE CONCENTRATIONS IN SURFACE SOIL SAMPLES
COLLECTED OUTSIDE THE SITE PERIMETER
MOLYBDENUM CORPORATION OF AMERICA
YORK, PENNSYLVANIA

Location[a]	Radionuclide Concentrations (pCi/g)			
	Ra-226	Th-232	Th-228	U-238
0, 0	1.44 ± 0.46[b]	7.51 ± 1.15	6.17 ± 0.91	3.32 ± 3.48
5, 0.5	0.68 ± 0.20	2.04 ± 0.48	2.11 ± 0.52	1.50 ± 1.96
20, 1	0.81 ± 0.24	1.12 ± 0.48	0.86 ± 0.38	1.04 ± 0.62
40, 1	0.92 ± 0.31	1.18 ± 0.40	1.20 ± 0.46	2.11 ± 1.76
60, 0.5	1.17 ± 0.27	1.56 ± 0.44	1.71 ± 0.51	<1.09
80, 1.5	0.98 ± 0.24	2.15 ± 0.62	1.34 ± 0.46	<1.13
100, 1	0.83 ± 0.23	1.14 ± 0.32	1.21 ± 0.35	2.28 ± 1.37
116, 0	0.72 ± 0.19	1.64 ± 0.35	1.59 ± 0.34	1.10 ± 0.47
120, 0	c	c	c	c
125, 0	0.63 ± 0.36	1.49 ± 0.46	1.56 ± 0.38	<1.06
130, 0	0.78 ± 0.27	1.03 ± 0.57	1.27 ± 0.37	1.87 ± 0.94
140, 1.5	1.31 ± 0.38	2.17 ± 0.63	1.91 ± 0.60	3.33 ± 2.28
160, 1.5	0.98 ± 0.25	1.37 ± 0.43	1.09 ± 0.47	1.39 ± 0.64
180, 2	1.06 ± 0.37	2.20 ± 0.62	1.83 ± 0.56	2.95 ± 2.48
200, 2.5	1.48 ± 0.25	2.00 ± 0.45	2.26 ± 0.50	1.61 ± 1.89
220, 3.5	0.99 ± 0.29	1.98 ± 0.54	1.58 ± 0.32	3.12 ± 1.20
231, 1.5	1.34 ± 0.36	2.11 ± 0.65	1.69 ± 0.71	4.46 ± 1.81
234, 0	0.61 ± 0.17	1.47 ± 0.45	0.81 ± 0.36	<0.89
240, 2.5	1.31 ± 0.28	1.98 ± 0.60	1.47 ± 0.62	0.74 ± 3.32
250, 2	1.32 ± 0.33	5.60 ± 0.72	5.22 ± 0.72	6.29 ± 1.14
254, 1	1.20 ± 0.24	2.50 ± 0.65	2.36 ± 0.47	3.17 ± 0.80
260, 0.5	1.68 ± 0.35	11.0 ± 1.4	10.9 ± 1.2	3.19 ± 5.39
280, 6	1.24 ± 0.36	1.63 ± 0.71	1.73 ± 0.54	2.43 ± 3.21
296.5, 2	0.87 ± 0.34	1.22 ± 0.36	1.12 ± 0.43	1.11 ± 1.23
300, 1	0.85 ± 0.28	2.81 ± 0.66	2.02 ± 0.18	<1.08
320, 1.5	2.56 ± 0.34	4.73 ± 0.74	4.05 ± 0.57	4.35 ± 1.29
324, 2	1.86 ± 0.54	5.71 ± 0.88	5.95 ± 0.76	2.69 ± 2.52
331, 3	1.74 ± 0.37	2.52 ± 0.57	2.62 ± 0.49	2.97 ± 0.85
334, 0	1.43 ± 0.32	2.54 ± 0.65	2.23 ± 0.43	<1.20
340, 1	1.50 ± 0.31	3.40 ± 0.62	3.70 ± 0.48	3.83 ± 0.88
341, 1	1.41 ± 0.39	5.55 ± 0.74	5.82 ± 0.85	2.66 ± 2.58
343, 0	0.52 ± 0.23	2.05 ± 0.49	2.13 ± 0.47	1.41 ± 1.96
346, 0	1.00 ± 0.25	4.28 ± 0.66	4.96 ± 0.56	4.08 ± 1.29
351, 0	0.86 ± 0.22	2.07 ± 0.42	2.09 ± 0.44	1.81 ± 1.92
354, 0	0.49 ± 0.17	1.84 ± 0.38	1.89 ± 0.36	0.37 ± 0.82
360, 0	c	c	c	c
380, 0.5	1.52 ± 0.31	8.46 ± 0.83	8.36 ± 0.78	7.52 ± 1.13
392, 0.5	1.43 ± 0.55	8.98 ± 1.25	9.62 ± 0.93	3.36 ± 4.22
400, 0	c	c	c	c
406, 3	0.46 ± 0.16	3.25 ± 0.52	3.24 ± 0.45	1.37 ± 2.00
420, 1	1.22 ± 0.27	2.76 ± 0.54	3.16 ± 0.63	1.42 ± 2.62

TABLE 4 (Continued)

RADIONUCLIDE CONCENTRATIONS IN SURFACE SOIL SAMPLES
COLLECTED OUTSIDE THE SITE PERIMETER
MOLYBDENUM CORPORATION OF AMERICA
YORK, PENNSYLVANIA

Location	Radionuclide Concentrations (pCi/g)			
	Ra-226	Th-232	Th-228	U-238
433, 1.5	1.72 ± 0.40	2.34 ± 0.72	2.23 ± 0.67	3.32 ± 3.22
440, 1.5	5.93 ± 0.56	15.7 ± 1.2	17.1 ± 1.2	18.2 ± 2.7
460, 3	4.75 ± 0.55	29.4 ± 2.0	28.2 ± 0.7	16.1 ± 6.5
476, 3	4.14 ± 0.83	14.2 ± 1.4	14.2 ± 3.4	9.28 ± 5.64
480, 2.5	6.21 ± 0.70	21.3 ± 1.5	24.0 ± 1.5	34.1 ± 4.6
500, 1.5	3.35 ± 0.65	2.68 ± 0.93	2.37 ± 0.72	<2.24
520, 0.5	2.37 ± 0.43	6.99 ± 1.12	5.78 ± 1.08	6.06 ± 4.14
540, 3.5	1.77 ± 0.36	1.62 ± 0.58	1.81 ± 0.47	2.44 ± 2.10
560, 4	1.02 ± 0.44	1.30 ± 0.81	1.62 ± 0.55	<1.25
578, 5	1.01 ± 0.38	1.55 ± 0.60	1.76 ± 0.65	<1.11
580, 1	0.62 ± 0.19	1.78 ± 0.38	1.77 ± 0.36	0.91 ± 1.61
600, 1	1.10 ± 0.39	2.02 ± 0.89	2.45 ± 0.64	<1.25
620, 1	1.54 ± 0.46	6.18 ± 1.10	7.26 ± 0.99	5.04 ± 2.19
640, 1	1.61 ± 0.35	4.98 ± 0.89	5.36 ± 0.89	<1.85
654, 0.5	1.53 ± 0.69	13.8 ± 1.8	15.8 ± 1.6	<2.96
658, 0	0.97 ± 0.49	5.41 ± 1.88	4.88 ± 0.91	4.93 ± 3.40
660, 0	[c]	[c]	[c]	[c]

[a]Refer to Figure 2.
[b]Errors are 2σ based on counting statistics.
[c]No sample collected due to asphalt.

TABLE 5

RADIONUCLIDE CONCENTRATIONS IN SURFACE SOIL SAMPLES
FROM LOCATIONS IDENTIFIED BY THE WALKOVER SCAN
OUTSIDE THE SITE PERIMETER
MOLYBDENUM CORPORATION OF AMERICA
YORK, PENNSYLVANIA

Location[a]	Radionuclide Concentrations (pCi/g)[b]			
	Ra-226	Th-232	Th-228	U-238
227, 0.5	4.47 ± 0.57[c]	2.64 ± 0.78	2.20 ± 0.90	4.59 ± 3.56
242, 3.5	88.1 ± 1.9	0.96 ± 1.41	4.02 ± 1.40	<4.02
265, 1	23.1 ± 2.2	320 ± 10	350 ± 10	110 ± 10
268, 4	2.48 ± 0.85	67.7 ± 2.8	66.7 ± 2.8	50.5 ± 6.0
327, 1.5	1.73 ± 0.43	28.3 ± 1.5	30.2 ± 1.4	17.0 ± 2.9
342, 0.5	0.78 ± 0.30	2.80 ± 0.53	2.85 ± 0.61	<1.15
352, 0.5	1.77 ± 0.38	22.1 ± 1.2	20.7 ± 1.1	1.97 ± 3.84
382, 2	8.11 ± 0.73	120 ± 2	120 ± 2	18.8 ± 3.6
387, 2	2.48 ± 0.54	31.0 ± 1.7	29.1 ± 1.6	2.78 ± 5.38
409, 2.5	2.97 ± 0.63	61.2 ± 1.9	65.4 ± 1.9	18.9 ± 3.6
414, 2	3.82 ± 0.94	72.1 ± 2.8	70.5 ± 2.7	17.3 ± 5.1
417, 2	4.69 ± 0.86	103 ± 3	97.7 ± 2.6	13.4 ± 5.9
488, 4	4.27 ± 1.08	90.6 ± 3.7	80.3 ± 3.4	6.27 ± 11.04
498, 5.5	4.01 ± 0.70	7.84 ± 1.50	8.08 ± 1.15	6.60 ± 5.00
532, 2	3.61 ± 0.82	39.2 ± 1.8	41.9 ± 1.8	32.5 ± 4.0
632, 0.5	3.96 ± 0.83	57.5 ± 2.8	58.6 ± 2.4	37.6 ± 4.5

[a]Refer to Figure 13.
[b]Refer to Table 3 for direct radiation levels.
[c]Errors are 2σ based on counting statistics.

TABLE 6

RADIONUCLIDE CONCENTRATIONS IN
BOREHOLE SOIL SAMPLES
MOLYBDENUM CORPORATION OF AMERICA
YORK, PENNSYLVANIA

Borehole No.[a]	Depth (m)	Radionuclide Concentrations (pCi/g)			
		Ra-226	Th-232	Th-228	U-238
H1	Surface	1.91 ± 0.29[b]	3.20 ± 0.54	3.46 ± 0.45	2.62 ± 1.66
	0.15 - 0.30	3.47 ± 0.43	3.07 ± 0.69	3.06 ± 0.64	2.51 ± 2.93
	1.5 - 2.1	1.92 ± 0.34	2.06 ± 0.81	1.71 ± 0.54	1.83 ± 3.77
H2	Surface	1.64 ± 0.39	2.64 ± 0.87	2.14 ± 0.63	2.20 ± 2.47
	1.5 - 2.1	2.38 ± 0.40	1.70 ± 0.63	2.32 ± 0.54	1.95 ± 2.02
H3	Surface	1.60 ± 0.37	3.71 ± 0.65	3.39 ± 0.62	<1.32
	0.30	1.94 ± 0.35	2.35 ± 0.71	2.66 ± 0.71	1.98 ± 2.44
	0.60	2.05 ± 0.77	2.03 ± 0.84	3.36 ± 0.83	<2.17
H4	Surface	1.43 ± 0.33	1.14 ± 0.38	1.48 ± 0.42	<0.93
	0.90	2.54 ± 0.78	2.42 ± 1.22	2.89 ± 0.88	<2.34
H5	Surface	0.85 ± 0.38	1.34 ± 0.47	1.28 ± 0.52	2.02 ± 2.43
	1.5 - 2.1	0.75 ± 0.23	1.47 ± 0.54	1.53 ± 0.45	<1.12
	3.0 - 3.6	1.34 ± 0.36	2.35 ± 0.89	2.45 ± 0.58	<1.36
H6	Surface	0.90 ± 0.30	0.98 ± 0.45	0.61 ± 0.47	<1.26
	0.60	1.01 ± 0.38	2.09 ± 0.75	2.31 ± 0.62	3.06 ± 2.94
H7	Surface	2.64 ± 0.63	16.1 ± 1.2	17.7 ± 1.2	15.0 ± 3.0
	1.5 - 2.1	1.27 ± 0.47	1.34 ± 0.52	1.78 ± 0.69	2.56 ± 1.70

TABLE 6 (Continued)

RADIONUCLIDE CONCENTRATIONS IN
BOREHOLE SOIL SAMPLES
MOLYBDENUM CORPORATION OF AMERICA
YORK, PENNSYLVANIA

Borehole No.	Depth (m)	Radionuclide Concentrations (pCi/g)			
		Ra-226	Th-232	Th-228	U-238
H8	Surface	120 ± 4	1240 ± 10	1310 ± 10	460 ± 19
	0.15	78.2 ± 3.6	950 ± 10	910 ± 10	250 ± 17
	1.5 - 2.1	2.97 ± 1.43	100 ± 5	110 ± 6	10.8 ± 8.8
	3.0 - 3.6	1.14 ± 0.46	3.19 ± 1.11	2.61 ± 0.68	1.72 ± 2.29

[a]Refer to Figure 4.
[b]Errors are 2σ based on counting statistics.

TABLE 7

RADIONUCLIDE CONCENTRATIONS IN SURFACE AND SUBSURFACE SOIL
FROM LOCATIONS IDENTIFIED BY THE WALKOVER SCAN OUTSIDE THE SITE PERIMETER
MOLYBDENUM CORPORATION OF AMERICA
YORK, PENNSYLVANIA

Location[a]	Depth (m)	Radionuclide Concentrations (pCi/g)[b]			
		Ra-226	Th-232	Th-228	U-238
1	Surface	4.47 ± 0.57[c]	2.64 ± 0.78	2.20 ± 0.90	4.59 ± 3.56
	0.15 - 0.30	3.34 ± 1.20	11.4 ± 1.3	12.8 ± 1.2	4.56 ± 3.92
	0.30 - 0.45	4.63 ± 0.60	2.37 ± 0.34	3.14 ± 0.74	<2.02
2	Surface	88.1 ± 1.9	0.96 ± 1.41	4.02 ± 1.40	<4.02
	0.15 - 0.30	1.38 ± 0.25	1.65 ± 0.62	1.57 ± 0.50	1.94 ± 1.94
3	Surface	23.1 ± 2.2	320 ± 10	350 ± 10	110 ± 10
	0.15 - 0.30	6.54 ± 0.98	63.5 ± 3.2	74.8 ± 3.0	8.24 ± 1.00
4	Surface	2.48 ± 0.85	67.7 ± 2.8	66.7 ± 2.8	50.5 ± 6.0
	0.15 - 0.30	1.50 ± 0.62	33.6 ± 1.7	31.6 ± 1.6	29.2 ± 4.2
	0.30 - 0.45	1.65 ± 0.42	17.0 ± 12.0	16.7 ± 1.2	7.09 ± 3.60
5	Surface	0.78 ± 0.30	2.80 ± 0.53	2.85 ± 0.61	<1.15
	0.15 - 0.20	4.60 ± 0.53	2.28 ± 0.59	1.50 ± 0.56	37.3 ± 4.5
6	Surface	4.69 ± 0.86	103 ± 3	97.7 ± 2.6	13.4 ± 5.9
	0.15 - 0.30	1.90 ± 0.42	23.0 ± 1.2	24.2 ± 1.2	16.6 ± 2.8
	0.30 - 0.45	1.36 ± 0.26	3.27 ± 0.63	3.62 ± 0.66	1.38 ± 3.12
7	Surface	4.27 ± 1.08	90.6 ± 3.7	80.3 ± 3.4	6.27 ± 11.04
	0.15 - 0.30	3.04 ± 0.57	7.84 ± 1.17	9.06 ± 1.02	2.64 ± 3.21
	0.30 - 0.45	3.48 ± 0.70	4.44 ± 0.99	5.62 ± 1.00	1.76 ± 6.87
	0.45 - 0.60	3.48 ± 0.52	7.87 ± 1.09	7.40 ± 1.00	4.36 ± 3.68

TABLE 7 (Continued)

RADIONUCLIDE CONCENTRATIONS IN SURFACE AND SUBSURFACE SOIL
FROM LOCATIONS IDENTIFIED BY THE WALKOVER SCAN OUTSIDE THE SITE PERIMETER
MOLYBDENUM CORPORATION OF AMERICA
YORK, PENNSYLVANIA

Location	Depth (m)	Radionuclide Concentrations (pCi/g)			
		Ra-226	Th-232	Th-228	U-238
8	Surface	4.01 ± 0.70	7.84 ± 1.50	8.08 ± 1.15	6.60 ± 5.00
	0.15 - 0.30	8.74 ± 0.97	16.4 ± 2.0	16.8 ± 1.8	9.55 ± 6.31
	0.45 - 0.60	13.4 ± 1.1	32.2 ± 2.0	39.4 ± 2.2	2.78 ± 4.11
	0.60 - 0.75	6.00 ± 0.69	11.6 ± 1.8	12.0 ± 1.5	6.71 ± 6.17
	0.75 - 0.90	10.5 ± 0.9	25.2 ± 1.9	30.2 ± 1.8	10.2 ± 7.5
9	Surface	3.61 ± 0.82	39.2 ± 1.8	41.9 ± 1.8	32.5 ± 4.0
	0.15 - 0.30	1.88 ± 0.38	6.95 ± 1.30	8.03 ± 1.14	3.64 ± 4.70
	0.30 - 0.45	1.64 ± 0.46	5.14 ± 1.12	6.68 ± 0.86	5.91 ± 1.99
10	Surface	3.96 ± 0.83	57.5 ± 2.8	58.6 ± 2.4	37.6 ± 4.5
	0.15 - 0.30	1.68 ± 0.43	9.23 ± 1.22	9.40 ± 1.15	4.00 ± 2.30
	0.30 - 0.45	1.36 ± 0.33	4.69 ± 0.68	4.58 ± 0.60	2.43 ± 2.01
	0.45 - 0.60	0.37 ± 0.34	3.23 ± 0.74	2.80 ± 1.48	2.17 ± 2.44

[a]Refer to Figure 13.
[b]Refer to Table 3 for direct radiation levels.
[c]Errors are 2σ based on counting statistics.

TABLE 8

RADIONUCLIDE CONCENTRATIONS IN WATER SAMPLES
MOLYBDENUM CORPORATION OF AMERICA
YORK, PENNSYLVANIA

Sample No.[a]	Description	Radionuclide Concentrations (pCi/l or x 10^{-9} µCi/ml) Gross Alpha	Gross Beta
W1	Surface	4.29 ± 1.07[b]	8.40 ± 1.32
W2	Surface	7.86 ± 2.98	18.7 ± 3.4
W3	Clarifier Tank	<28.4[c]	<29.2[c]
W4	Neutralizing Tank	<27.4[c]	70.5 ± 43.4[c]
W5	Sanitary Sewer	<27.6[c]	98.5 ± 44.8[c]
W6	Groundwater Discharge	1.99 ± 1.83	6.99 ± 2.59
W7	Surface	<1.24	2.74 ± 2.11
W8	Surface	2.35 ± 1.37	12.5 ± 1.8
W9	Surface	0.62 ± 0.63	2.59 ± 0.89
W10	Subsurface (Borehole H5)	<2.22	<2.81
W11	Subsurface (Borehole H6)	2.51 ± 2.82	6.04 ± 3.12
W12	Subsurface (Borehole H7)	3.46 ± 1.52	9.50 ± 1.74
W13	Well	7.89 ± 1.93	41.6 ± 2.7
W14	Well	2.11 ± 1.94	4.03 ± 2.08
W15	Well	<0.75	3.43 ± 1.27
W16	Well	11.8 ± 6.0[c]	5.08 ± 5.26[c]
W17	Well	6.69 ± 2.54	8.09 ± 2.37

[a]Refer to Figures 6 - 8.
[b]Errors are 2σ based on counting statistics.
[c]Large amounts of dissolved solids resulted in relatively poor detection sensitivities and high errors for gross alpha and beta analysis.

TABLE 9

RESULTS OF ALPHA SPECTROSCOPY ANALYSES ON WATER SAMPLES
MOLYBDENUM CORPORATION OF AMERICA
YORK, PENNSYLVANIA

Sample No.[a]	Description	Radionuclide Concentrations (pCi/l or x 10^{-9} μCi/ml)					
		Ra-226	Ra-228	Th-232	Th-228	U-234	U-238
W3	Clarifier Tank	0.16 ± 0.06[b]	0.70 ± 0.43	0.25 ± 0.22	0.25 ± 0.22	12.8 ± 0.7	13.5 ± 0.7
W4	Neutralizing Tank	0.09 ± 0.04	2.08 ± 0.66	<0.07	<0.07	13.4 ± 0.8	13.4 ± 0.8
W5	Sanitary Sewer	0.15 ± 0.05	0.79 ± 0.47	0.04 ± 0.05	0.04 ± 0.05	24.0 ± 1.2	24.4 ± 1.2
W16	Well	<0.05	1.04 ± 0.65	0.36 ± 0.21	0.36 ± 0.21	11.1 ± 0.8	11.8 ± 0.8

[a]Refer to Figures 7 and 8.
[b]Errors are 2σ based on counting statistics.

TABLE 10

RADIONUCLIDE CONCENTRATIONS IN SEDIMENT SAMPLES
MOLYBDENUM CORPORATION OF AMERICA
YORK, PENNSYLVANIA

Location[a]	Radionuclide Concentrations (pCi/g)			
	Ra-226	Th-232	Th-228	U-238
S1	10.8 ± 1.1[b]	160 ± 3	170 ± 4	50.1 ± 5.8
S2	6.31 ± 0.99	81.0 ± 2.9	56.2 ± 2.5	30.7 ± 5.7
S3	8.06 ± 1.37	160 ± 4	170 ± 5	71.0 ± 8.4
S4	14.6 ± 1.4	190 ± 4	150 ± 4	140 ± 10
S5	1.37 ± 0.33	1.31 ± 0.61	1.55 ± 0.35	<1.06
S6	1.54 ± 0.36	2.22 ± 0.68	2.29 ± 0.49	<1.37
S7	1.01 ± 0.30	3.00 ± 0.57	3.28 ± 0.51	1.65 ± 1.96
S8	0.96 ± 0.21	1.42 ± 0.41	1.03 ± 0.37	1.13 ± 2.04
S9	0.55 ± 0.17	0.51 ± 0.21	0.42 ± 0.20	<0.55

[a]Refer to Figures 5 and 6.
[b]Errors are 2σ based on counting statistics.

TABLE 11
VELOCITY PROFILES IN EXHAUST DUCTS
MOLYBDENUM CORPORATION OF AMERICA
YORK, PENNSYLVANIA

Building	Duct Diameter (cm)	Measurement Location (cm from duct wall)	Velocity (m/min)
Tank	25	A - 0.81	488
		B - 2.67	427
		C - 4.93	595
		D - 8.20	762
		Centerline - 12.7	869
		E - 17.2	899
		F - 20.5	915
		G - 22.7	915
		H - 24.6	869
REC	30	A - 0.97	305
		B - 3.20	335
		C - 5.92	381
		D - 9.86	427
		Centerline - 15.2	427
		E - 20.6	442
		F - 24.6	457
		G - 27.2	457
		H - 29.5	442

TABLE 12

STACK SAMPLING FLOW RATES AND VOLUMES
MOLYBDENUM CORPORATION OF AMERICA
YORK, PENNSYLVANIA

Building	Sampling Location (cm from duct wall)	Date	Velocity at Sampling Point (m/min)	Sampling Rate (l/min)	Sampling Time (min)	Sampling Volume (liters)
Tank	12.7	6/7-8/85	869	14.7	1427	20977
	12.7	6/8-9/85	869	14.7	1358	19963
	12.7	6/9-10/85	869	14.7	1422	20903
	12.7	6/10-11/85	869	14.7	1375	20213
	12.7	6/11/85	869	14.7	417	6130
REC	15.2	6/7-8/85	427	21.1	1582	33380
	15.2	6/8-9/85	427	21.1	1343	28337
	15.2	6/9-10/85	427	21.1	1386	29245
	15.2	6/10-11/85	427	21.1	-[a]	-
	15.2	6/11/85	427	18.2	460	8372

[a]Dash indicates a system failure.

TABLE 13

RESULTS OF STACK MONITORING - TANK BUILDING
MOLYBDENUM CORPORATION OF AMERICA
YORK, PENNSYLVANIA

Date	Radionuclide Concentrations (μCi/ml)	
	Gross Alpha	Gross Beta
6/7-8/85	$4.38 \pm 1.76 \times 10^{-14}$[a]	$2.22 \pm 0.40 \times 10^{-13}$
6/8-9/85	$<7.50 \times 10^{-15}$	$1.39 \pm 0.34 \times 10^{-13}$
6/9-10/85	$<7.60 \times 10^{-15}$	$<1.48 \times 10^{-14}$
6/10-11/85	$6.87 \pm 2.86 \times 10^{-14}$	$6.43 \pm 2.37 \times 10^{-14}$
6/11/85	$3.12 \pm 0.64 \times 10^{-13}$	$2.87 \pm 1.08 \times 10^{-13}$

[a]Errors are 2σ based on counting statistics.

TABLE 14

RESULTS OF STACK MONITORING - REC BUILDING
MOLYBDENUM CORPORATION OF AMERICA
YORK, PENNSYLVANIA

Date	Analysis by	Radionuclide Concentrations (μCi/ml) Gross Alpha	Gross Beta
6/7-8/85	ORAU	$3.80 \pm 5.00 \times 10^{-15}$[a]	$4.10 \pm 1.67 \times 10^{-14}$
6/8-9/85	ORAU	$<1.05 \times 10^{-14}$	$9.98 \pm 3.38 \times 10^{-14}$
6/9-10/85	ORAU	$<1.02 \times 10^{-14}$	$<5.10 \times 10^{-15}$
6/10-11/85	ORAU	-[b]	-
6/11/85	ORAU	$3.46 \pm 2.86 \times 10^{-14}$	$<3.58 \times 10^{-14}$

[a]Errors are 2σ based on counting statistics.
[b]No analysis performed due to system failure.

REFERENCES

1. Standards of Performance for New Stationary Sources, Title 40, Code of Federal Regulations, 1977.

APPENDIX A

MAJOR SAMPLING AND ANALYTICAL EQUIPMENT

APPENDIX A

Major Sampling and Analytical Equipment

The display or description of a specific product is not to be construed as an endorsement of that product or its manufacturer by the authors or their employer.

A. Direct Radiation Measurements

Eberline PRM-6
Portable Ratemeter
(Eberline, Sante Fe, NM)

Victoreen NaI Gamma Scintillation Probe
Model 489-55
(Victoreen, Inc., Cleveland, OH)

Reuter-Stokes Pressurized Ionization Chamber
Model RSS-111
(Reuter-Stokes, Cleveland, OH)

B. Air Sampling

Stack sampling nozzles
(NuTech Corp., Durham, NC)

Rotameters, 0-30 lpm
(Union Carbide Corp., Linde Air Products Div.,
Birmingham, AL)

Gast Vacuum Pumps
115v/60Hz
Cat. #P8400
(American Scientific Products, Stone Mountain, GA)

Velometer - all purpose set
Type 6000 a.p.
(Alnor Instrument Co., Niles, IL)

"Precision" Wet Test Meter
Used to calibrate rotameters
(Precision Scientific Co., Chicago, IL)

Additional supplies
Plastic tubing, connectors, impinger glassware

C. Laboratory Analysis

Automatic low-background Alpha-Beta Counter
Model LB5110-2080
(Tennelec, Inc., Oak Ridge, TN)

Ge(Li) Detectors (2)
Model LGCC2220SD, 23% efficiency
(Princeton Gamma-Tech, Princeton, NJ)

Used in conjunction with:
Lead Shield, SPG-16
(Applied Physical Technology, Smyrna, GA)

High Purity Germanium Detector
Model GMX-23195-S, 23% efficiency
(EG&G ORTEC, Oak Ridge, TN)

Used in conjunction with:
Lead Shield, G-16
(Gamma Products Inc., Palos Hills, IL)

ND-66/ND-680 System
(Nuclear Data, Inc., Schaumburg, IL)

Alpha Spectrometry System
Tennelec Electronics, EG&G ORTEC
Surface barrier detectors
(Tennelec, Inc., EG&G, Oak Ridge, TN)

Radon Emanation System
Counter Timer, Model 2071
Single Channel Analyzer, Model 2031
High Voltage Power Supply, Model 3102
(Canberra Industries, Meriden, CT)

Tennelec Linear Amplifier
Model TC 202BLR
(Tennelec, Inc., Oak Ridge, TN)

Ludlum Scintillation Detector
and Source Holder, Model PR-3120
(Ludlum Measurements Sweetwater, TX)

Radon Bubblers and Lucas Cells
(Rocky Mountain Scientific Glass Blowing, Co., Aurora, CO)

APPENDIX B

MEASUREMENT AND ANALYTICAL PROCEDURES

APPENDIX B

Measurement and Analytical Procedures

Gamma Scintillation Measurement

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

Borehole Logging

Borehole gamma radiation measurements were performed using a Victoreen Model 489-55 gamma scintillation probe connected to a Ludlum Model 2200 portable scaler. The scintillation probe was shielded by a 1.25 cm thick lead shield with four 2.5 cm x 7 mm holes evenly spaced around the region of the scintillation crystal. The probe was lowered into each hole using a tripod holder with a small winch. Measurements were performed at 30 cm intervals in all holes. The logging data were used to identify regions of possible residues and guide the selection of subsurface soil sampling locations.

Soil and Sediment Sample Analysis

Gamma Spectrometry

Soil and sediment samples were dried, mixed, and a portion placed in a 0.5 l Marinelli beaker. The quantity placed in each beaker was chosen to reproduce the calibrated counting geometry and ranged from 600 to 800 g of soil. Net soil weights were determined and the samples counted using intrinsic germanium and Ge(Li) detectors coupled to a Nuclear Data Model ND-680 pulse height analyzer system. Background and Compton stripping, peak search, peak identification, and concentration calculations were performed

using the computer capabilities inherent in the analyzer system. Energy peaks used for determination of radionuclides of concern were:

Ra-226 - 0.609 MeV from Bi-214 (secular equilibrium assumed)
Th-232 - 0.911 MeV from Ac-228 (secular equilibrium assumed)
Th-228 - 0.583 MeV from Tl-208 (secular equilibrium assumed)
U-238 - 0.094 MeV from Th-234 (secular equilibrium assumed)

Water Sample Analysis

Water samples were rough-filtered through Whatman No. 2 filter paper. Remaining suspended solids were removed by subsequent filtration through 0.45 µm membrane filters. The filtrate was acidified by addition of 10 ml of concentrated nitric acid. A known volume of each sample was evaporated to dryness and counted for gross alpha and gross beta using a Tennelec Model LB-5110 low-background proportional counter.

Analysis for Ra-226 and Ra-228 was performed using the standard technique EPA 600/4-80-032.

Uranium and thorium isotopic analyses were performed by taking aliquots of liquid, then acidifying and evaporating to dryness. The residue was dissolved by pyrosulfate fusion and precipitated with barium sulfate. The barium sulfate precipitate was redissolved and the uranium and thorium separated by liquid - liquid extraction. The uranium and thorium were then precipitated with a cerium fluoride carrier and counted using surface barrier detectors (ORTEC), alpha spectrometers (Tennelec), and an ND-66 Multichannel Analyzer (Nuclear Data).

Air Sample Analysis

Aliquots of liquid from impinger solutions were evaporated to dryness and counted for gross alpha and beta levels using an automatic low-background proportional counter, Tennelec Model LB-5110. Results of the gross analyses were related to the total sample activity using ratios of analyzed volume to total sample volume.

Errors and Detection Limits

The uncertainties associated with the analytical data, presented in the tables of this report, represent the 95% (2σ) confidence levels based only on counting statistics. Other sources of error associated with the sampling and analyses introduce an additional uncertainty of ± 6 to 10% in the results.

Calibration and Quality Assurance

Laboratory and field survey procedures are documented in manuals developed specifically for the Oak Ridge Associated Universities Radiological Site Assessment Program.

With the exception of the measurements conducted with portable gamma scintillation survey meters, instruments were calibrated with NBS-traceable standards. The calibration procedures for the portable gamma instruments are performed by comparison with an NBS calibrated pressurized ionization chamber.

Quality control procedures on all instruments included daily background and check-source measurements to confirm equipment operation within acceptable statistical fluctuations. The ORAU laboratory participates in the EPA and EML Quality Assurance Program.

APPENDIX C

SUMMARY OF RADIATION PROTECTION GUIDELINES

APPENDIX C

SUMMARY OF RADIATION PROTECTION GUIDELINES

1. Direct Radiation Levels (Maximum Limits for Unrestricted Use)

Radiation Criteria (mrem/time above background)
2 mrem/hr or 100 mrem/7 consecutive days[a]

2. Soil Guidelines (Maximum Limits for Unrestricted Use)

Radionuclide	Soil Criteria (pCi/g above background)
Ra-226	5, 15*[b]
Th-232 plus Th-228	10[c]
U-Natural (processed)	35[c]

*The allowable level for Ra-226 is 5 pCi/g, averaged over the first 15 cm of soil below the surface; 15 pCi/g when averaged over 15 cm thick soil layers more than 15 cm below the surface.

3. Water Guidelines

Radionuclide	Water Criteria[a] (μCi/ml above background)	
	Onsite	Offsite
Ra-226	4×10^{-7}	3×10^{-8}
Ra-228	8×10^{-7}	3×10^{-8}
Th-232	5×10^{-5}	2×10^{-6}
Th-228	2×10^{-4}	7×10^{-6}
U-234	9×10^{-4}	3×10^{-5}
U-238	1×10^{-3}	4×10^{-5}

4. Air Guidelines

Radionuclide	Air Criteria[a] (μCi/ml above background)	
	Onsite	Offsite
Ra-226	3×10^{-11}	3×10^{-12}
Ra-228	7×10^{-11}	2×10^{-12}
Th-232	3×10^{-11}	1×10^{-12}
Th-228	9×10^{-12}	3×10^{-13}
U-234	6×10^{-10}	2×10^{-11}
U-238	7×10^{-11}	3×10^{-12}

[a]Title 10, Code of Federal Regulations, Part 20, Standards for Protection Against Radiation, 1985.

[b]Title 40, Code of Federal Regulations, Part 192, Environmental Standards for Uranium and Thorium Mill Tailings at Licensed Commercial Processing Sites, 1983.

[c]Branch Technical Position on "Disposal or Onsite Storage of Thorium and Uranium Wastes from Past Operations", Nuclear Regulatory Commission, 1981.

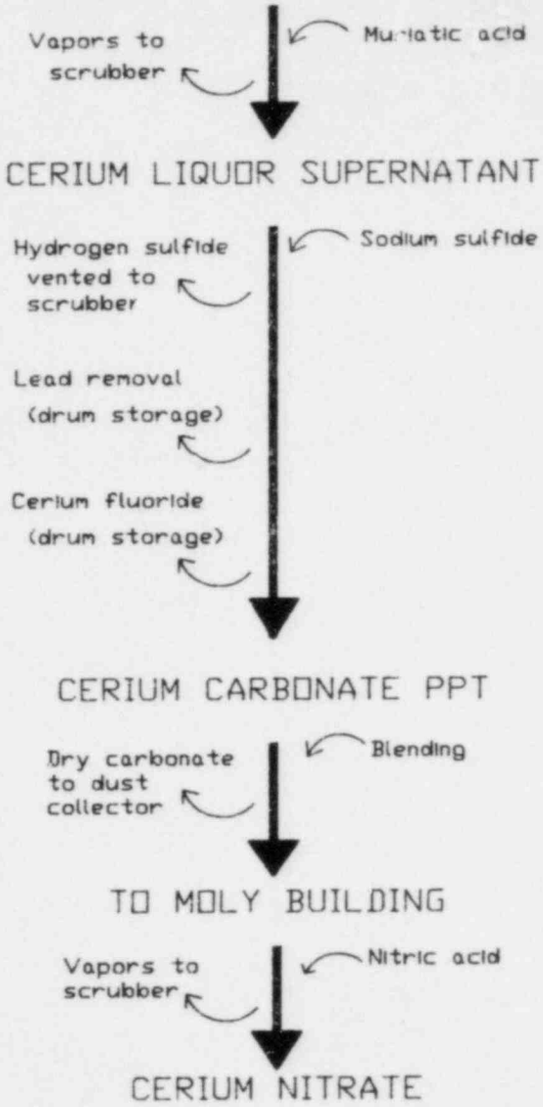
APPENDIX D

FLOW DIAGRAMS OF PROCESS OPERATIONS

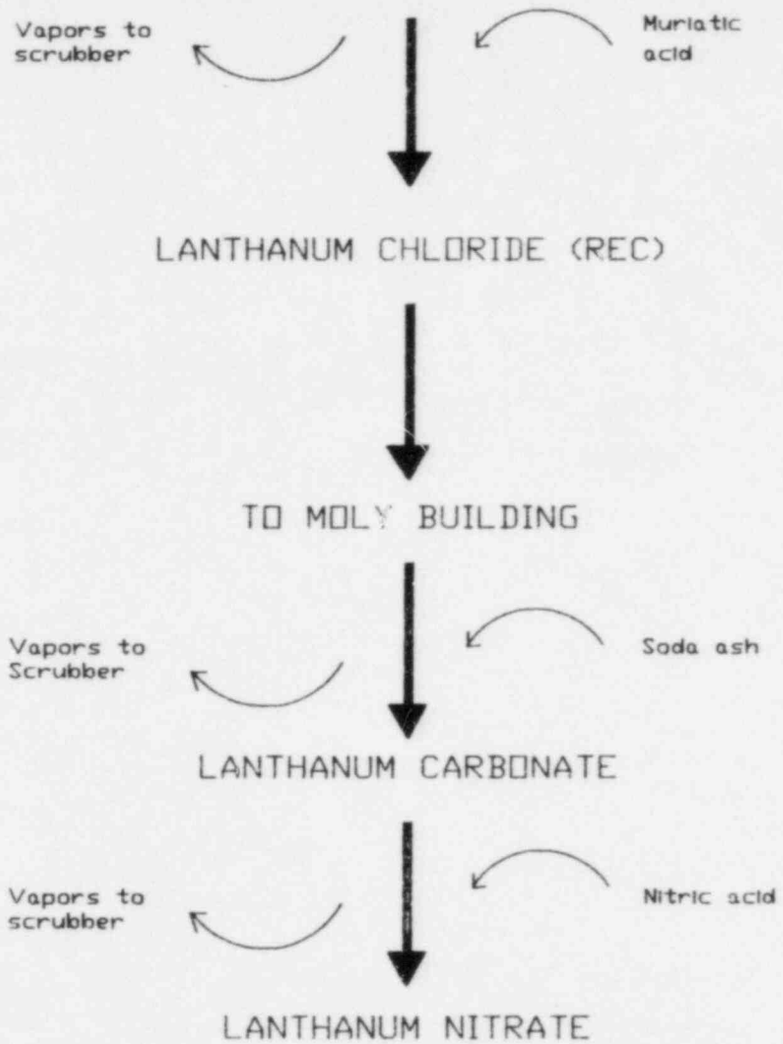
APPENDIX D

Flow Diagrams of Process Operations

CERIUM CONCENTRATE (Source Material) - TANK BUILDING



LANTHANUM HYDRATE - REC BUILDING



BASTNASITE ORE - REC BUILDING