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# Plan for Site Characterization in Support of Decommissioning of the Molycorp Inc. Washington, Pa Facility

**Submitted to the U. S. Nuclear Regulatory Commission,**
**Division of Low Level Waste Management and Decommissioning**
**Revised and Resubmitted, August, 1993**

**by**


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**August 5, 1993**

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# 1. Introduction

The Nuclear Regulatory Commission has included the Molycorp plant site at Washington PA among the more than 40 nuclear material sites under the 1990 Site Decommissioning Management Plan (SDMP). As part of its ongoing efforts to comply with the SDMP and to move toward decommissioning and de-licensing of the site, Molycorp and its consultants have developed this Site Characterization Plan (SCP). A primary objective of this plan is to adhere as closely as possible to the recommendations and format described in the NRC Branch Technical Position entitled "Site Characterization for Decommissioning Sites, July, 1992." The organization of this document follows the general outline adopted by the Branch Technical Position (BTP). Because there are sections in the BTP that do not apply to the Molycorp site, the paragraph numbers is this document do not correspond directly to those of the BTP. The Site Characterization Report (SCR), which will be submitted for review to the NRC after the site characterization study has been completed, will also follow the format outlined in the BTP, to the extent that such a format is practical.

## 1.1 Objectives of the Site Characterization

In developing the plan for this site characterization, Molycorp has considered several conceptual plans for decommissioning, the type and extent of existing radiological contamination and the potential for long-term exposure of humans after the decommissioning activities. The main objectives of site characterization proposed here in support of decommissioning are:

(a) To quantify the physical and chemical characteristics of radiological contamination and the extent of contaminant distribution, including rates of migration of Th and its daughter products.

(b) To identify and measure environmental parameters that significantly determine potential human exposure from existing radiological contamination under the condition of unrestricted use. For example, it is necessary to measure the rate of leaching of Th, U and Ra nuclides from the glassy slag formed at high temperatures, which constitutes the contamination of this site, in order to evaluate the potential release of radionuclides to ground water, surface water, and eventually humans deriving their water intake from surface waters.

(c) To support the evaluation of alternative decommissioning actions and detailed planning of a preferred approach for decommissioning, decontamination, and waste disposal. The site characterization plan includes the dose assessment activities needed to evaluate the efficacy of alternate decommissioning plans.

## 1.2 Relevant NRC Guidance

The site contains low level Th wastes in a glassy slag distributed in a spectrum of particle sizes from large pieces several inches across to small particles, both buried in conformity to the NRC Branch Technical Position on "Disposal or Onsite Storage of Thorium or Uranium Wastes from Past Operations" (46 FR 52601) and also stored above ground in a segregated and vegetationally stabilized slag pile. Based on an underground survey (RSA, 1990, see Appendix I) (32 boreholes) the Th waste buried under and adjacent to the eight surface impoundments on the west side of the site meets the option 4 limits at all locations surveyed and on the average, meets option 2 limits. Local hot spots underground generally do not exceed the option 2 limits by more than a factor of 10. A more extensive underground survey covering the rest of the affected areas of the site is described in sections 5.2 and 5.4.

The following documents will be used to assess whether the characterization program proposed will be sufficient to ascertain compliance with the recommendations therein.

(a) Options 1 and 2 of the Branch Technical Position "Disposal or Onsite Storage of Thorium or Uranium Wastes from Past Operations" (46 FR 52601; October 23, 1981).

(b) "Guidelines for Decontamination of Facilities and Equipment Prior to Release for Unrestricted Use or Termination of Licenses for Byproduct, Source or Special Nuclear Material," Policy and Guidance Directive FC 83-23, Division of Industrial and Medical Nuclear Safety, November 4, 1983.

(c) "Termination of Operating Licenses for Nuclear Reactors," Regulatory Guide 1.86, June 1974, Table 1, for surface contamination of reactor facility structures.

(d) The Environmental Protection Agency's (EPA's) "Interim Primary Drinking Water Regulations," 40 CFR part 141 (41 FR 38404; July 9, 1976).

(e) EPA's "Persons Exposed to Transuranium Elements in the Environment" (42 FR 60956, November 30, 1977). This document provides guidelines for acceptable levels of transuranium elements in soil.

### 1.3 Planning for Site Characterization

Personnel from Molycorp, from Radiation Surveillance Associates, Inc. (RSA), and from Vail Engineering, or other qualified hydrogeological contractor, will collaborate to produce the site characterization plan, to conduct the site characterization study, and to the write the site characterization report. Molycorp personnel B. Dankmyer, Resident Manager, G. Dawes, Plant Radiation Safety Officer, and D. Shoemaker, Manager of Molybdenum Operations, will address issues associated with site location, history, current conditions, and future plans. Personnel from RSA, Inc. will carry out radiation studies (M. E. Wrenn, Ph.D., C.H.P., health physics, radiation measurements, dose assessment; W. Delaney, environmental radiation surveys; and L. Bertelli, Ph.D., mathematical modeling for internal and external dose assessment). Vail Engineering

(Ralph Vail), or another qualified hydrogeological contractor, will characterize surface and subsurface hydrology and contaminant transport. Consultants with specialties in meteorology, land use, and demographics will be retained to carry out characterization activities relevant to their disciplines.

This group will assemble and review available information on site history, the physical environment, the type and extent of radiological contamination, and the location of potentially exposed populations.

In the view of Molycorp and its consultants, the purpose of the site characterization study is to furnish information which can serve as a basis for evaluating alternatives for decommissioning. The site characterization report will present the results of the site characterization study. The decommissioning alternatives will be addressed in the decommissioning plan, not in the site characterization report.

The planning for site characterization is greatly simplified at the Molycorp site due to the amount of site characterization data already available. This data is contained in the 1990 report on the impoundment area by RSA, Inc. (See Appendix I), the 1985 report by Oak Ridge Associated Universities, and the historical information dating from the 1971-1973 work by Applied Health Physics to clean up the site and consolidate the thorium slag into the existing pile (See Appendix J). The site characterization study will expand upon this knowledge base by extending the study area to include all potentially affected areas, increase the density of measurements, and provide the basis for dose assessment. Since much is already known about the site, it is unlikely that the study will produce any surprises. A single site characterization study should yield sufficient information needed to design an adequate decommissioning plan.

## 2. General Information

### 2.1 Site Background

The SCR will provide information describing the specific site location, site history and previous investigations relevant to radioactive and hazardous waste activities. Such information will include maps, drawings and aerial photographs. This generic background information will be useful in the process of dose assessment and development of a decommissioning plan.

#### 2.1.1 Site Location and Description.

The following information on site location and description will be provided:

(a) Specific site location, including street address, nearest town, local political jurisdiction (e.g., county, township, borough, district), State, U. S. Geological Survey (USGS) 7 1/2 minute quadrangle, and distances and directions of the site to reference points or coordinates. (Appendix F provides the legal land description of the site.)

(b) General area, dimensions and locations of contaminated areas on and under the site, and any contaminated areas onsite beyond fenced area (additional detail on contamination will be provided from the surveys proposed in section 5).

(c) Site ownership, boundaries and surroundings, including roads, railroads, utility lines, drainage ways, canals, sites of historical significance and other features that could affect the conduct or effectiveness of decommissioning activities. These features will be shown on a map of the site and vicinity.

(d) Topography of the site and its immediate surroundings, including hydrogeologic features such as rivers, dams, wetlands, drinking and supply water intakes, and locations of offsite population centers. Topographic maps will be at a scale of 1:200 with a contour interval of about 5 feet (or other interval that appropriately indicates the relief and grades on and immediately adjacent to the site), along with the portion of the 7 1/2 minute USGS Quadrangle that contains the site and its immediate surroundings.

### 2.1.2 Site History

This section of the SCR will summarize all known significant historical facts and records that may affect the design of decommissioning actions or help explain the nature and extent of site contamination. This information includes existing records of site conditions prior to licensed activities, operation of the facility, records on effluents and onsite disposals and significant incidents of releases or spills. Specifically, this information will include:

(a) Records about onsite activities and past operations involving activities such as generation of FeCb slag, burial of slag on site, and historical efforts aimed at remediation, consolidation and impoundment, and disposal of Th bearing materials. Past operations will be summarized in chronological order along with type of permits and/or approvals that authorized these operations. Estimates of the total activity of radioactive material released or disposed of on the site and its physical and chemical forms will also be included.

(b) Summaries of historical work aimed at characterizing the site and summaries of previous site monitoring programs, including sampling and analytical records of environmental monitoring programs reported for the site or the immediate surroundings.

(c) Records of relevant inspections, surveys, and investigations conducted on-site.

(d) Historic aerial photographs and site location maps showing previous site development and activities (as available).

## 2.2 General Physical Setting

The intent of this section of the SCR is to provide a summary overview of the site characteristics. The SCR will summarize the general physical setting of the site, including general physical characteristics of the site and its proximity to people who potentially could be affected by existing contamination or decommissioning activities.

### 2.2.1 Physical Site Characteristics

The section will summarize the following physical characteristics in general terms:

- Climate (e.g., temperature and precipitation).

- Geologic setting (e.g., unconsolidated deposits and bedrock strata).

- Vegetation (e.g., unvegetated, forested, grassy).

- Soil (e.g., composition, thickness, chemistry).

- Groundwater (e.g., depth, quality, uses and direction and rate of flow).

- Location and description of surface water (e.g., type, flow rates, quality and uses).

### 2.2.2 General Information on Exposed Populations

This section of the SCR will provide a summary description of the general characteristics of potentially exposed populations. These characteristics include:

- General distribution and number of people near the site.

- Current land use(s) adjacent to the site.

- Anticipated future land use(s) on and adjacent to the site.

- Location and characteristics of any subgroups of special concern.

## 2.3 Preliminary Evaluation of Contamination

This section of the SCR will summarize the extent and characteristics of known or suspected site radiological contamination. This summary should be based on analysis of historic operational data, records of slag disposal that may have resulted in site contamination, existing monitoring and survey data and direct observations of the site and its vicinity. This information will be used in:

- Identifying buildings and equipment that require survey for contamination due to historical use in the processing of FeCb slag, or which may have been constructed on top of Th bearing soils;
- Designing radiation surveys for buildings, for equipment, for surface and subsurface soils;
- Designing sampling and testing programs for surface water and groundwater;
- Determining principal radionuclides of concern and relative hazards;
- Identification of applicable cleanup criteria and comparison between known or suspected contamination levels and the criteria; and
- Identification of potential occupational hazards associated with site characterization and decommissioning activities.

**3. Dose Assessment**

Dose assessment is a necessary element in the site decommissioning process for the Molycorp, Washington, PA plant site in order to demonstrate compliance with the clean-up criteria under which the site will be decommissioned. For example, if the site were to be decommissioned under the 1981 NRC BTP Option 2, then dose calculations would be required. (Please note that Option 2 is cited here as an example. Molycorp has not committed itself to any decommissioning alternatives.) The 1981 BTP states that concentrations of total thorium up to 50 pCi/g may be left buried on site as long as certain prescribed conditions are met. Among the prescribed conditions is the requirement that "no member of the public will receive a radiation dose exceeding those discussed under option 1 ... absent intrusion into the burial grounds." And, "In the event that there is an intrusion into the burial ground, no member of the public will likely receive a dose in excess of 170 millirems to a critical organ." The site characterization study, therefore, must produce sufficient data to permit full evaluation of the potential dose to humans for the various decommissioning alternatives that will be examined as a part of the development of the site decommissioning plan.

The site characterization report, which will be submitted for review to the NRC upon completion of the site characterization study, will contain dose assessment analysis aimed at calculating threshold clean-up criteria necessary to keep the potential dose within accepted limits. These calculated clean-up criteria will represent the level to which the site must be cleaned in order to achieve de-licensing (that is, the projected post decommissioning conditions). The report will also contain the results from the site characterization study, which will be aimed at quantifying the concentration and spatial extent of thorium currently present on site (the pre-decommissioning scenario). This quantification of both the pre-decommission conditions and the projected post-decommission thorium concentration on site will allow calculation of the amount of clean-up needed to de-license the site. The results of the site characterization study will be used to identify the source terms and the pathways, and to calculate the dose conversion factors.

The site characterization study will also produce sufficient data to expand analysis to other scenarios. This expanded scenario analysis may be necessary to support the de-commissioning plan that will be developed after the site characterization report is completed.

To conduct the dose assessment, it is necessary to identify and characterize the source terms and the relevant pathways leading to internal and external exposure. The dose assessment in the site characterization report will include calculations using the program RESRAD, which was designed at Argonne National Laboratory to derive site specific guidelines for allowable residual concentrations of radionuclides in soil. The input data for the dose assessment, which will be collected as part of the site characterization study, is outlined in sections 3.1 through 3.3. The RESRAD program is deterministic, not probabilistic, and as such the degree of conservatism in the results is unspecified, but could be very large. Therefore, we will seriously consider using other programs which use the best estimates of parameters and a measure of dispersion about the mean or geometric mean in order to derive probability distribution factors describing expected dose. Indeed, NCRP-50 warns against the pitfalls in using deterministic models such as those employed in RESRAD. The sensitivity analysis in the RESRAD code will be used to assess the effects of uncertainties in the magnitude of certain parameters upon projected doses.

In addition, the MILDOS program will be evaluated for its utility in dose assessment for airborne exposure. This will not preclude our use of other, possibly more sophisticated, models and sensitivity analysis.

### 3.1 Source Terms.

In the case of the Molycorp, Washington, PA facility, the source term for the dose assessment can be defined as the residual concentration of thorium in surface and sub-surface soils. Quantification of the source term requires measurement of several parameters. (See Section 5 for a discussion of the survey and measurement procedures to be used in gathering this data.) The specific parameters to be quantified are:

(a) Residual radionuclides in surface and subsurface soils and water.

(b) Levels of external gamma radiation (both surface and sub-surface).

(c) Concentrations of airborne radioactivity, including resuspendable particulate matter, radon, thoron , and their respective daughter products.

### 3.2 Identification of Pathways.

The site characterization study must include sufficient data to identify the pathways that make significant contributions to the dose to potentially exposed populations. The significance of each pathway is a function of the rate of migration along the pathway. The site specific data necessary to quantify the rates of migration, such as leachability and emanating properties, will be obtained by the survey and measurement procedures discussed in Section 5. Other necessary data are available in the literature. The site specific pathways to be examined as potential exposure routes will include the following.

The most likely to be important are:

(a) External gamma radiation exposure from slag in bulk or finely distributed in soils.

(b) Inhalation of airborne resuspendable particulate matter.

Because of the extreme insolubility of the slag, the following are expected to be less important:

(c) Migration from slag to surface and sub-surface soils, and to groundwater. These migration rates will be determined by leachability studies.

(d) Ingestion of groundwater.

(e) Inhalation of emanation products (daughters of radon and thorium).

(f) Migration from groundwater and soils to vegetable and meat products.

(g) Ingestion of soil containing particles of finely ground slag.

Site specific pathway mechanisms will be characterized either by measurements made on-site, laboratory analysis of samples taken from the site, and/or by use of models and data reported in the literature or developed directly for this site.

## 3.3 Characterization of the Physical Setting and Identification of Potentially Exposed Populations.

To complete dose assessment, a profile must be developed of the physical layout of the plant site and of the possible distributions of the population that may be expected to arise on and around the plant site after de-commissioning is accomplished. A qualified contractor will be engaged to study the demography and land use patterns around the site (see Section 4.5). The radiological impact of these land use and demographic factors upon the pathway analysis will be evaluated.

# 4. Physical Characteristics Of Site

During the site characterization study, the physical characteristics of the site will be documented following, in general, the guidelines presented in the NRC's Branch Technical Position on Site Characterization (July 1992). Vail Engineering, or other qualified hydrology consultant, will carry out the tasks associated with documenting the hydrology and hydrogeology of the site. Documentation of the demography, the geology, the meteorology and climatology, and the land use patterns of the region surrounding the site will be done by a qualified contractor. Map making tasks will be carried out by RSA, Inc., and/or a qualified outside contractor.

### 4.1 Surface Features

This section of the SCR will describe the present topography of the site and immediate vicinity supported by topographic maps of appropriate scale and contour intervals. The maps will also depict significant surface features such as depressions, buildings, roads, wetlands, creeks, landfills, ditches, and drainage systems. Topographic maps will be at 1:200 scale, or at other appropriate scales as required to depict the major surface features of the site relative to decommissioning. The contour interval will be no greater than 5 feet, and the maps will use conventional nomenclature and symbols.

### 4.2 Meteorology and Climatology

The SCR will provide baseline information describing variations in seasonal weather conditions at the site. Such information may be needed to assess the rainfall for the site and to evaluate the transport rates through the airborne and waterborne pathways. The information will also be used to evaluate impacts from long-term releases of radionuclides if any soluble species are found for this site and source. The meteorological and climatological parameters and data which will be reported include:

- Speed, directions, and variability of winds (presented as a wind rose diagram and, if available, the Pasquill atmospheric variability category). Data on the direction and magnitude of wind will be collected from the national weather service stations at the nearest airports to the Washington, Pennsylvania Facility. Data over the last several years will be summarized by a consultant.

- Amount, type, and distribution of annual precipitation.

- Estimates of pan evaporation and evapotranspiration (if available).

- Records of severe weather conditions, such as tornadoes, hurricanes, drought, and flooding, that might affect the stability of the contaminated material before, during, and after decommissioning.

**4.3 Surface Water Hydrology**

The SCR will evaluate surface water at and near the site, and the effects of surface water processes on transport of contaminants. The site characterization program will address both general characteristics of surface water near the site and on-site flow patterns. The information on surface water will include the following:

(a) Characterization of Chartier's Creek, including flow rate, volume, and macrochemistry. Proximity and transport between Chartier's Creek and the site contamination will be discussed.

(b) Historic data on peak discharges and water levels. This data may include, if available, information on stage/discharge relationships, and recurrence intervals of flooding for Chartier's Creek, as well as stages, flow rates, and flow velocities for severe flooding events. This information will be useful to investigate or model the stability of the long lived radioactivity in the slag pile and buried on-site. Such information may be used in the site decommissioning plan to demonstrate that proposals to leave material on-site provide reasonable assurance that waste will remain sufficiently isolated from the human environment for long time periods, on the order of 1000 years.

(c) Locations, areas, and dimensions of wetlands, the 100 year flood plain, and watershed divides on or in the immediate vicinity of the site. Surface erosion and potential contaminant transport associated with such surface processes will be addressed.

(d) Current inventory of surface water uses within approximately 10 kilometers of the site. The SCR will not purport to inventory all water uses within a 10 km radius of the site, but it will provide a representative sampling based on available data.

(e) Estimated potential for contamination of surface water bodies above specified radiological water quality criteria. The potential for significant transport will be evaluated using a model representative of the local hydrogeologic system. Because of the insolubility of the radionuclides in the slag, the potential for significant transport is so minimal that a semi-quantitative analysis of potential surface water transport may suffice.

(f) The potential for transport of thorium bearing slag in surface water by means of erosion and suspended particulates. Section 5.1.5 describes a study to measure the distribution with respect to particle size of thorium bearing slag in soil samples collected onsite. The data collected in the particle size fractionation study can be used in computer simulations of transport by erosion and solubulization. Such computer simulations may indicate that engineered disposal cells are appropriate to ensure long term stability.

## 4.4 Geology

The SCR will sufficiently describe the site geology to support assessment of the long-term stability of the site (since on-site disposal will be assessed), groundwater transport of contaminants, and the selection of background soil and water samples. Geologic site information will be presented in two categories: reconnaissance information on the region surrounding the site, and site specific geologic characteristics.

### 4.4.1 Regional Geology

The site characterization report will include a section on the regional geology that shows the relationship between the local geology of the site and that of the surrounding region. We will examine the FEIS (DOE/EIS-0096-F), entitled "Remedial Actions Site, Canonsburg, PA, for information on regional geology and surface hydrology. If obtainable without the performance of prohibitively costly studies, this section will include:

- A general stratigraphic chart for the area depicting major formations and their thicknesses and characteristics.

- A geologic map depicting the bedrock geology that covers the region around and including the site.

- A geologic cross-section that is keyed to the geologic map and depicts the principle structures and geologic formations beneath the site.

In addition, the summary of regional geology will include the following information:

(a) Geomorphology: information on the physiographic province that contains the site and prominent topographic features within 10-20 km from the site.

(b) Stratigraphy and Lithology: this includes regional stratigraphic units and regional bedrock formations.

(c) Structure and Tectonics: significant geologic structures and their association with any active tectonism. Such features may include faults, folds, joints, cleavage, and major fractures. Information on the current tectonic stability of the region and historical records of seismic activity will be presented if available from the USGS, the state geological survey office, local universities, or other similar sources.

### 4.4.2 Site Specific Geology

The SCR will describe the site specific geologic characteristics in a manner similar to the regional geologic description. The site-specific description, however, will focus on details of site geology and its effect on long-term release and transport of radiological contaminants and stability of residual materials. The following site-specific geologic information will be included in the SCR:

(a) Geomorphology: The object of the study of the geomorphology of the site will be to ascertain the potential for migration of radionuclides by surface erosion into Chartier's Creek, since this is the most likely path of migration for this particular site. To this end, the SCR will include maps and other analysis characterizing such geomorphic features as on-site relief, surface gradient and topography, soil weathering profile and associated surface deposits, and local drainage basins and channels. The description of the fluvial geomorphology of the site will be linked to the hydrologic characterization in Section 4.3.

(b) Stratigraphy and Lithology: The stratigraphic units at the Molycorp, Washington, PA site that are potentially affected by radiologic contamination are (1) fill, consisting of FeMo slag, FeCb slag, and various other materials, in layers between 0 and 10 to 12 feet thick; (2) sediments, clay, and unconsolidated materials going down to about 20 feet in depth; and (3) bedrock, at about 20 feet, as indicated by auger refusal during drilling of boreholes. Because the Th bearing slag on-site is very insoluble and therefore very immobile, it is probable that the potential for radiological impact is limited to these strata. A high density of boreholes (more than 300) will be drilled as part of the radiologic survey of the site (see section 5.2.1). Data from the drilling logs from this drilling program will serve as the basis for detailed descriptions of these potentially impacted strata. Borehole locations and stratigraphic profiles will be presented on geologic maps and cross sections. Drilling logs for all boreholes drilled on-site will be included as an appendix to the SCR , and these logs will include borehole profiles indicating the variation with depth of stratigraphic features. Radiometric logs (as described in RSA, 1990) will be taken in all boreholes, and the various depths characterized as to degree of radioactivity. Samples will be taken for identification of the origin of radioactivity (see section 5.2.3). Various materials will be identified by visual inspection and may include such things as wood, or other buried debris. However, based upon past borings, most of the material will be slag, clay, sand, other soil types, or mixtures of slag/soil.

Lithologic studies on-site will be confined to sampling the bedrock to obtain information on it's mineralogy and other characteristics. Since no other lithologic features are impacted by the site, the bedrock is the only feature that needs to be studied.

(c) Site Structural Features and Geologic Stability. Since the Molycorp, Washington, PA site is relatively small (about 15 acres of active plant area), and the bedrock is known to be level, shallow, and at a fairly uniform depth (about 20 feet) across the site, it is unlikely that major discontinuities or fracture systems that could influence radiologic contaminant transport exist on-site. Agencies such as the USGS and the state seismology office will be consulted to determine if any major faults, fractures, or other discontinuities are known and documented in the section of the Chartier's Creek drainage containing the site. The results of such inquiries will be described in the SCR.

(d) Geologic Stability: estimates of the long term stability of the site. Site stability will be evaluated by estimating the maximum ground motion that can reasonably be anticipated at the site, based on historical records of seismic events, and considering other geologic indications of active processes during the Holocene period that could significantly affect site stability.

## 4.5 Demography and Land Use

### 4.5.1 Demography

The population data for the area surrounding the site that is needed for assessing dose and socioeconomic impacts of radiological contamination includes:

(a) Residence Inventory. Since the Molycorp, Washington, PA plant site is located in an urbanized area, it would be costly and of no practical value to identify the location and number of all residences within a 2 km radius of the plant, as suggested in the NRC Branch Technical Position. Instead, populations in the vicinity of the plant will be documented using such techniques such as maps showing population density isopleths, and aerial photographs. Any sensitive populations within a 2 km radius (e.g., medical institutions and schools) will be identified. The nearest residences will, of course, be identified.

(b) Transient Population: The SCR will document daily and seasonal variations in the baseline population within a radius of 2 km of the site, due to influxes associated with work, education, and other normal human movements.

### 4.5.2 Land Use

This section of the SCR will evaluate the type of land use at the site and in the surrounding vicinity. Land use information will be useful in constructing dose assessment scenarios and limiting off-site exposure during decommissioning. The type of land use will be categorized into one or more of the following types: residential, industrial, agricultural, and special use. For agricultural uses, the SCR will identify the specific uses of the land, for example, grazing, dairy farming, or crop production.

## 4.6 Hydrogeology

### 4.6.1. Introduction

Molycorp's facility is located in Canton Township, Washington County, Commonwealth of Pennsylvania. The active plant area covers approximately 12 acres (650' N-S by 820' E-W). The active plant area is bounded on the west by Chartiers Creek, on the east by B & O Railway lines, on the south by Caldwell Avenue and on the north by another industrial plant. Molycorp also owns several acres of property along the western banks of Chartiers Creek. This area contains no structures and has not been used for industrial purposes by Molycorp. Employee vehicle parking, equipment and miscellaneous storage areas are located in an extension of the plant area to the south of Caldwell Avenue. Chartiers Creek flows in a northerly direction through the plant area at an elevation of approximately 1,010 MSL. The east bank of the creek rises to an elevation of approximately 1,020 MSL. The ground surface in the plant area rises gradually to the east reaching an average elevation along the railroad of 1,040 MSL. There is several hundred feet of residential area development east of the railroad. The ground surface then rises fairly steeply past Interstate 70 to the tops of wooded hills with elevations up to 1,200' MSL, some 1,500 feet east of the railroad. A shallow water aquifer extending to a depth of approximately 20 feet underlies the plant area. Flow in the shallow aquifer is to the west with recharge primarily from the drainage area east of the plant site and discharge to Chartiers

Creek. Depth to the water table varies from less than two feet in the westerly area to nearly ten feet in the eastern part of the plant area.

### 4.6.2 Basis For Preliminary Assessment of Hydrogeology

The primary sources of data used for formulation of the hydrogeological section of the SCP were:

(a) Draft Interim Report - Ground Water Assessment, Molycorp, Inc. Washington, PA prepared by Remcor December 23, 1991. For this study and report, Remcor drilled and logged 17 water wells which were completed in accordance with monitor well construction standards. (Appendix G provides the driller's logs and the details of well construction from the Remcor report.) Split spoon samples of materials drilled were obtained on intervals of five feet or less. Soils were classified by USGS nomenclature based on density, color, grain size, mineralogy, moisture content and other characteristics. Fourteen of the water wells were drilled and completed to bedrock and the remaining three holes were drilled and completed in the fill zone near the surface. Sieve-hydrometer testing was conducted on three representative soil samples and sieve/hydrometer testing, moisture content, liquid-plastic limits, and permeability analysis were made on another three soil samples. Thirty additional soil samples were collected for $^{232}Th$ analysis. Water samples from each of the 17 wells and the four existing monitor wells were collected on July 27 and October 31, 1991 and analyzed for over 30 constituents or parameters. Water levels were recorded for each of the 17 new wells and the four existing wells upon completion of drilling, on subsequent days, at the times water quality samples were obtained and on November 25, 1991. Aquifer testing included rising head slug tests on six wells screened in the clayey sand and gravel zone, two wells completed in the fill zone and one well screened in both units. Slug test data was compiled using AQTESOLV and analytical solutions were based on the Bouwer and Rice (1976) solution. Remcor documented the use of standard and acceptable methods and procedures for all of their sample collection, analysis and quality assurance/control. The locations of the 17 bore holes drilled by Remcor and the four existing monitor wells are shown on Vail Engineering Drawing MCWA-1 included herein.

(b) Radiation Surveillance Associates, Inc. (RSA) Report titled "A Sub-surface Survey for Thorium Content at the Molycorp Plant Site in Washington, PA; Survey period 7-26-90 through 8-24-90; Report Date December 27, 1990" (see Appendix I). This report contained the driller's logs for 32 bore holes drilled for investigation of sub-surface radioactivity at the site. The bore holes were drilled to bedrock or to a depth of approximately 20 feet where bedrock was not encountered. The bore holes were cased with unperforated two inch PVC pipe upon completion of drilling. Depths below ground surface to the water levels inside the casings were recorded at the time when the subsurface NaI probe measurements were made. The report also included the driller's logs and water levels for the existing four monitor wells and another well drilled off-site for determination of ambient conditions. The report did not provide detailed soils analysis or analytical data relative to hydrogeological conditions. The driller's logs were useful in the preliminary hydrogeological assessment for determination of the depth of the fill zone, the continuity and uniformity of the surface of the underlying clayey soils and the depth to bedrock. The bore hole casings were installed to maintain an open hole for the NaI probe survey. In many instances it was difficult to determine if the recorded water level indicated the hydrostatic head in the soil at the bottom of the bore hole or at some higher elevation. In some instances it appeared that the bottom of the casing was plugged before the water level inside the casing rose to the level of the surrounding hydrostatic head. With discretionary use of the data, the RSA water levels were of significant aide in determination of the water table elevations and gradient changes in the vicinity of the impoundments and in other areas.

The location of the RSA bore holes are shown on Vail Engineering Drawing MCWA-1.

(c) Reconnaissance ground water survey made by Vail Engineering during March 1991. During this survey, water levels from both inside the casing and in the open drill hole outside of the casing were determined in ten of the bore holes drilled by RSA. Water levels inside the casings were determined at ten other RSA bore holes and at the four original monitor wells. Draw down recovery well tests were conducted at monitor wells 1, 3 and 4 and a short pump test was conducted at monitor well 2. An inspection was made of a trench being excavated to the north from building 42 for a distance of approximately one hundred feet. The trench was excavated in the fill zone with the northern section to a depth below the ground water table. Observations were made of the dispersion of pockets and seams of slag and other porous materials in the otherwise clayey fill zone and of the nature of the percolation of water from such deposits and seams into the trench which otherwise was not accumulating significant quantities of water. The conductivity of the water was recorded at a number of RSA bore holes, the existing monitor wells, all of the retention impoundments and at several points along Chartiers Creek from several hundred feet upstream to a few hundred feet downstream of the plant site. Samples of water were collected at selected points along Chartiers Creek and from the storm drain outfalls. The samples were delivered to Molycorp for analysis for molybdenum and other constituents. A general appraisal was made of the topography, land use, ground cover, drainage, primary geological features and other physical aspects of the plant site and surrounding area. Additional information was obtained from maps, data and reports contained in Molycorp's files and from personal interviews with Molycorp personnel both during and subsequent to the reconnaissance survey.

(d) Water quality data set forth in the quarterly monitor well reports.

(e) Hydrogeologic, topographic and other plant site data set forth in the Part B Permit Application for a Hazardous Waste Storage Facility as prepared by Molycorp in May 1983.

### 4.6.3 Characteristics Of The Shallow Ground Water Aquifer

A shallow ground water aquifer is present in the soils and fill overlying the bedrock in the plant area. The bedrock (generally logged as claystone) was encountered at depths from 16 to 22 feet below the surface in nearly all of the bore holes and wells. The average depth is 19.3 feet. The top of the bedrock gradually rises to the east nearly parallel with the ground surface through the plant area. The shallow aquifer consists of three principal soil zones. An average of five feet of moderately permeable soils lies fairly uniformly over the bedrock. These soils were generally logged by Remcor as clayey sands and gravel. In Remcor bore hole 9 and in RSA bore holes 25, 29, 30 and 32 a few feet of the material above the bedrock was classified as fairly clean sand and gravel, indicating the possibility of some old drainage channels near the bottom of the shallow aquifer. The semi-permeable soils above the bedrock were reported in all of the Remcor bore holes. The RSA drilling logs generally did not differentiate between the lower clayey sands and gravels and the overlying clay zone. Gray, yellow and brown clays with an average thickness of nearly seven feet lie above the lower more permeable soils. Classification of the clays ranged from sandy clay to dense fat clay. The clay zone was logged in all of the bore holes by both Remcor and RSA. In five Remcor bore holes, the thickness of the clay zone was five feet or less. Review of the logs indicates that this resulted from deeper placement of the fill at these locations. The base of the clay zone lies at a fairly uniform depth above the bedrock and, exclusive of areas of deeper fill, the clay zone has a fairly uniform thickness averaging over eight feet. The fill zone extends from the top of the clay zone to the surface. The logged depth of the fill zone ranges from a few feet to approximately 17 feet with an average and nominal depth on the order of seven feet. The fill zone is composed of very inhomogeneous mixtures of silts, sands, gravels, clays, furnace slag, mill scale and debris. Remcor's bore hole logs and other observations indicate that the fill composition varies from fairly clean slag or mixtures of slag and/or sands and gravels to predominantly clayey and silty soil mixtures. The logs indicate that the fill in the central, western and northern areas of the plant site generally contains higher percentages of slag and mill scale. However, there are significant variations over short distances. There was no slag or mill scale reported in the logs of some of the holes in the easterly and southerly plant area. Early reports indicate that the surface soils were originally classified as silty, sandy, clayey loams. The bore hole logs indicate that such soils have been displaced or substantially mixed with fill materials over at least much of the plant area. The only sieve analysis identified as fill zone material was for a soil sample collected from a depth of 4-6 feet at bore hole M-11. The drilling log indicated "soft, dry to moist, brown to black fill, mainly sand and gravel, slag and mill scale." The laboratory description was "Gray silty sand with gravel (non-plastic fines)". The sieve analysis indicated 100% passing a 3/4" sieve, 38% retained by a #10 sieve and 22% passing a #200 sieve. Outside of the backwater area behind the clay dike, ground water appears to be contained primarily in the lower few feet of the fill zone. In some places it appears that this is perched or semi-perched water. The permeability of the fill zone is highly dependent on the distribution of the slags and sands and gravels within the fill. For mixtures with similar percentages of slag, sand, gravel, clay and silt, the permeability will be much higher where the slags, sand and gravel are contained in relatively unmixed seams and deposits. It is probable that in some areas the fill zone has a very high effective permeability. The location and logged thickness of the soil zones of the shallow water aquifer are shown on the typical cross section through the plant area - Vail Engineering Drawing MCWA-2.

Table 4-1 is a copy of Table 3 from Remcor's report. This table lists the results of three permeability tests on samples of soil collected from the clay zone and other soil geotechnical data. The samples were collected with a Shelby Tube and classified as undisturbed. The average permeability of 2.09 x $10^{-7}$ cm/sec was accepted as a reasonable figure for the clay zone relative to the general analysis of the shallow ground water flow. Table 4-2 is a copy of Table 7 from Remcor's report. This table sets forth the results of rising head slug aquifer tests conducted on nine of the new monitor wells. Slug test data was compiled using AQTESOLV and results obtained with the Bower and Rice (1976) solution. Six of the tests were conducted on wells screened in the clayey sands and gravels overlying the bedrock. The average permeability reported for these six tests was 1.17 x $10^{-4}$ cm/sec. Wells 9S and 18S were screened in the fill zone. Slug tests on these wells indicated permeability values of 2.77 x $10^{-3}$ cm/sec and 3.74 x $10^{-4}$ cm/sec. A review of the driller's logs and other data indicates that the average permeability of the fill zone is probably somewhat higher than these values. During the late 1960's, eight surface impoundments were constructed in the westerly part of the plant area. A few years later a clay dike was constructed along the west side of these impoundments to minimize the flow of leachage from the impoundments to Chartiers Creek. The dike presumably extended from near the ground surface to below the top of the clay zone. Analysis of the water levels indicate that the dike severely restricted the westward discharge of ground water towards Chartiers Creek and raised the ground water levels by several feet in the area east of the impoundments. It appears that the dike acts as a long dam crest or overflow weir which results in somewhat of a backwater ponded condition for several hundred feet to the east. Relatively pervious fill material has been deposited over the top of the dike. Fairly small changes in ground water levels, are therefore needed for discharge of the varying amount of shallow ground water flow. The increased water levels behind the dike has also resulted in higher hydraulic gradients and an increased percentage of the ground water flow that is discharged to the northwest and southwest around the ends of the dike. The approximate location of the dike is indicated on Vail Engineering Drawings MCWA-1 and MCWA-2. The general configuration and approximate contour lines of the unconfined water table are shown on Drawing MCWA-1. The elevation of the water table is somewhat obscure over much of the plant area. Ground water is present in the fill zone over most of the plant area. It appears, however, that in some locations this is perched or semi-perched water. Many of the recorded water well levels appear to reflect the partially confined potentiometric head near the bottom of the aquifer. During a reconnaissance survey made in March 1991, the water levels in the RSA bore holes in the impoundment area indicated a significant vertical hydraulic gradient. At that time, the average shallow water surface in the impoundment area was at 1018.74 while the average hydrostatic head of the deeper water, as indicated by the water inside the bore hole casing, was 1017.65. At some locations, the difference was nearly two feet. The RSA casings were not purposely sealed off in the bore holes indicating that even higher vertical gradients may be present. In most of the holes drilled by Remcor in 1991, the casing was sealed off to below the fill zone and the intake screen set in the bottom of the hole. In many of these holes the water level was below the fill zone. Remcor, however, indicated that water was present in the fill zone in many of these holes. The intake screen in Remcor's well M-15, located in the north easterly part of the plant area, was set just above the claystone. The water level in this well was at elevation 1027.17 on September 20, 1991. In Remcor's well 15S completed in the fill zone a few feet from well 15, the water level was at elevation 1030.77 on the same date (a difference of 3.6 feet). Water table contours shown on Drawing MCWA-1 were based in part on water levels recorded in the RSA bore holes. The depth within the aquifer, at which these water levels reflected the hydrostatic head, was often not determinable.

The configuration of the water table as shown on Drawings MCWA-1 and MCWA- 2 clearly indicates that the clay dike constructed along the west end of the impoundments, significantly restricts the discharge of ground water to the west from the impoundment area. The ground water level in the upper part of the aquifer abruptly drops about five feet from the east to the west sides of the dike. Calculations indicate that flow through the dike and lateral flow in the clay zone beneath the dike would amount to only a few gallons of water per day. Shallow ground water is generally present at a depth of from one to two feet below the surface in the impoundment area east of the dike. It appears that the top of the dike acts as an overflow weir and that the water level upstream of the dike is at whatever level is necessary to discharge the ground water flow through the pervious fill material deposited on top of the dike.

Over much of the plant area the potentiometric head in the moderately permeable soil zone above the claystone, appears to be several feet below that of the unconfined water level near the surface. There must, therefore, be some leakage from the fill zone through the clay zone to the more permeable soils below. This would be discharged underneath the dike westward to Chartiers Creek.

Elevations of the water level in the various monitor wells and bore holes are shown on Drawing MCWA-1. The water table contours on this drawing are often at variance with the indicated well water elevations for several reasons. The water table contours indicate the generalized elevation of the unconfined (unperched) ground water surface in March 1991. Most of the indicated well water elevations were recorded at various other times. Many of the well water elevations reflect the hydrostatic head beneath or within the clay zone. Uncomfortably low water levels were recorded in Remcor's well M-11 and some of the RSA bore holes. The low level in M-11 may be due to infiltration into a nearby storm drain. Some of the low RSA water levels could also reflect leakage to the storm drain or may be in error due to plugged casings or water levels which had not fully recovered. The gradient of the unconfined water table is nearly flat in the backwater area behind the clay dike. In other areas of the plant site, the gradient is generally on the order of 2 - 3%. There are indications that the gradient may steepen along the eastern part of the plant area. An analysis has not been made of the potentiometric gradient in the partially confined soils in the lower part of the aquifer.

### 4.6.4 Quantity And Rate Of Ground Water Flow

The shallow ground water discharged through the plant area results primarily from infiltration of precipitation over the area east of the plant site that probably has extents and configuration similar to that of the surface drainage area. It is estimated that this drainage basin is from 30 to 50 acres in area. Annual precipitation and typical infiltrating values indicate an average shallow aquifer ground water discharge through the plant area from 15 to 40 gpm. It appears that from 5 to 10 gpm of this flow may infiltrate into or otherwise be intercepted and discharged directly to Chartiers Creek by the plants storm drainage system. On March 13, 1991 water samples were collected from Chartiers Creek from several hundred feet upstream to a few hundred feet downstream of the plant area. At this time the flow in Chartiers Creek was estimated at 30 cfs (13,500 gpm). Analysis of the water samples indicated molybdenum concentrations of below the detection limit upstream and 0.06 mg/l down stream. The discharge from the south storm drain was estimated 7 gpm and from the north storm drain at 10 gpm. The molybdenum concentration was 10.5 mg/l in the south storm drain and 4.0 mg/l in the north storm drain. The monitor well data indicated an average molybdenum concentration of 60 mg/l in the shallow ground water being discharged to Chartiers Creek. Algebraic extrapolation using these values indicates that the shallow ground water flow at that time was on the order of 12 gallons/minute. Remcor's soil analysis and aquifer tests indicated average permeability values of 1.17 x $10^{-4}$ cm/sec for the clayey sands and gravels above bedrock, 2.09 cm/sec for the clay zone and 2.77 x $10^{-3}$ for the permeability of the fill material at well 9S. The nominal width of the flow path through the main plant area is 650 feet. The average ground water gradient is approximately .03. The average thickness of the clayey sands and gravels is 5 feet and the clay zone is 8 feet. The average saturated thickness of the fill zone is estimated at two feet. Computation based on these values indicates a ground water flow of 0.17 gpm in the clayey sands and gravels, .002 gpm in the clay zone (assuming a horizontal permeability of 5X the laboratory value) and 1.6 gpm in the fill zone. The driller's logs indicate that a significant percentage of the fill zone is composed of deposits of fairly clean slag and other porous material. Such indicates that the average permeability in the fill zone may be an order of magnitude or more higher than the permeability at well 9S. If so, the flow in the fill zone would be commensurate with that estimated by drainage area infiltration and increases in constituent concentrations in Chartiers Creek. The analysis also indicates that 95% to 99% of the ground water flow is conducted in the fill zone.

Analysis of the monitor well data indicates that significant changes in water quality in well M-1 up gradient of the impoundment areas are generally reflected by similar changes in the water quality in the down gradient wells at the same reporting time.

This indicates that the ground water flow travel time between well M-1 and the other wells is somewhat less than three months. Average ground water flow velocities in this area would, therefore, be on the order of three to four feet per day. Analysis of the aquifer indicates that the ground water flow is conducted primarily in the fill zone in the upper part of the aquifer. Permeability in portions of the fill zone may exceed 3 x $10^{-2}$ cm/sec. With this permeability and a hydraulic gradient on the order of .03, the computed ground water flow rate would be approximately 10 feet/day. This is consistent with the velocity indicated by the fairly short time in which up gradient water quality change is reflected by the down gradient wells. Significantly lower permeabilities in the clay and clayey sand and gravel zones were indicated by the laboratory and aquifer tests conducted by Remcor. The derived values indicate average flow rates of from 10 to 20 feet per year in the clayey sands and gravels. Flow velocities along the more pervious flow paths could be on the order of a few feet per day. The permeability values indicate that there is no significant horizontal flow in the clay zone. Vertical hydraulic gradients in the clay zone may approach unity in some locations. Even at a unity gradient the vertical flow velocity would produce a theoretical flow rate of only a few feet per year for the highest clay zone permeability found by Remcor. The data indicates that, on the average, it takes several years for the ground water to percolate from the fill zone through the clay zone to the lower clayey sand and gravel zone. Diffusion may result in much more rapid dispersion of fill zone constituents to the lower zone.

### 4.6.5 Chartiers Creek

USGS advised that there were no stream gauging stations on Chartiers Creek in the vicinity of Washington, Pennsylvania and that probably there were only a few other records of flow measurements in the area. Flow estimates made on a few occasions and other observations indicate that the flow in Chartiers Creek past Molycorp's plant site is in excess of 30 cfs most of the time. In March 1991, the conductivity of Chartiers Creek was measured at 470 mS/cm indicating a good quality of water. At a flow of 30 cfs, the dilution ratio relative to the 20 gpm of ground water flow would be approximately 700:1. Increases in concentrations of the waters in Chartiers Creek would be very small or undetectable as a result of the ground water discharge from the plant area.

### 4.6.6 Radioactivity Of Ground And Surface Waters

The preliminary hydrogeological assessment indicates that ground water movement probably does not result in any significant mobilization, transport, distribution or concentration of radionuclide activity at Molycorp's facility. The emphasis of the initial part of the final site characterization study, relative to hydrogeology, will be to substantiate the above premise or to quantify the degree to which ground water transport, etc. are significant factors. Such studies will provide verification of the leachability properties of the host material and adequate determination of the radioactivity levels in the ground water. The SCR study will also include quantification of the stream flow in Chartiers Creek and an analysis of the impact of the discharge of ground waters to the creek under minimum and other stream flow conditions. Water samples in Chartiers Creek are collected on a semi annual basis from upstream, opposite and downstream of the thorium slag storage pile in the area south of Caldwell Avenue. The samples are analyzed by radio-chemical methods by International Technology Corporation. The laboratory analysis did not indicate any significant activity or increase in activity in the water of Chartiers Creek. (See summary below.) No records of direct measurement of radioactivity in the ground water were found. Molycorp has advised that leachability tests have indicated that the thorium bearing slag is not soluble. Subsurface gamma radiation was measured at 0.5 foot increments by RSA in 32 bore holes drilled in 1990. In general, elevated radiation activity was detected in only the fill zone. In a few bore holes there was slightly elevated activity recorded at some depth below the top of the clay zone. It is believed that these isolated elevated readings were the result of slag or other active materials which had sloughed off the sides of the bore hole in the fill zone and fallen to a deeper depth. The preliminary hydrogeological assessment indicates that throughout most of the plant area, ground water flow is from the fill zone in nearly a vertical flow path through the clay zone to the more permeable underlying soils. Absence of elevated activity in the clay and lower soil zones indicates that the percolating water does not contain elevated activity within the range detectable by the NaI probe used for the down hole survey. RSA believes that activity in the ground water, on the order of 5 pCi/g above background, would have been observable. Examination of the RSA gamma logs do not show increased activity at the top of the clay zone. This indicates that there is little or no adsorption or filtering out of active particulate material where the ground water enters the clay zone.

### 4.6.7 Ground Water Quality

The quality of the shallow ground water entering the plant area is fair as indicated by the analysis of the water in Remcor's well M-8. This well is located in the northeast corner of the plant area up gradient of sources of constituent increases stemming from Molycorp's operations. Molycorp maintains four monitor wells from which water samples have been collected and analyzed quarterly since 1982. Three of the monitor wells are located along the east bank of Chartiers Creek and the fourth well was installed to indicate the ambient quality of the ground water up gradient of the impoundment area. The location of the four monitor wells and well M-8 are shown on drawing MCWA-1.

Table 4-3 is a tabulation of the water quality analysis for the four monitor wells and well M-8. Figures 4-6 through 4.9 provide graphs of the trending of the significant constituents in the monitor wells.

The water quality analysis indicates there are moderate increases over much of the plant area in chlorides, iron, magnesium, manganese, molybdenum, sodium and sulfates. At some individual wells the increases in one or more constituents is substantial.

In consideration of the small amount of ground water flow for dilution, the magnitude of the increased concentrations is not inordinate for an industrial plant of this nature. The specific sources of the increased concentrations have not been determined. However, they appear to be spread out over much of the plant area. The probable sources are leachage of fill materials, previous spillage and leakage of process waters and chemicals and leakage from the surface impoundments which are being eliminated. The analysis of monitor well water does not indicate the discharge from the plant area of significant quantities of any hazardous waste constituents and that the quantity of molybdenum, sulfates, etc., is such that the impact on Chartiers Creek is probably near or below the detection limit for the usual analytical methods. Analysis of the graphs and other data indicate a declining trend in the concentrations in the ground water being discharged from the plant area. It is anticipated that this declining trend will continue.

### 4.6.8 Ground Water Use

It is doubtful that there is any location at the plant site above bedrock where a well could be pumped for any length of time at a rate of one gallon per minute. It appears, therefore, that there is no potential use of the ground water for domestic, industrial, agricultural or other purpose.

### 4.6.9 Study Plan - Goals, Rational and Methodology

NRC comments in its letter dated February 25, 1993 indicate the NRC desires that the plan for the site characterization study stipulate specific numbers and locations for sample collection, analysis to be performed and quantification and detailed procedures relative to other predetermined study activities.

Experience indicates that a substantial amount of latitude should be allowed in the collection of field data, the type and number of field and laboratory test and analysis and the time and effort for interpretation and presentation. As the investigations and study work progresses, it generally is found that some components become more or less important and warrant increased or decreased emphasis; that more or less data may be required to adequately characterize a particular element; that the initial study method does not produce consistent and reliable results; and that new elements needing consideration arise or proposed elements are found to be irrelevant. Molycorp has advised its technical consultants that the collection and analysis of data and the analytical effort should be as extensive and detailed as necessary to insure a fully competent and satisfactory site characterization report relative to the requirements for decommissioning and general environmental considerations. Collection and presentation of excess or irrelevant data tends to diminish the amount of effort affordable to the more significant elements and obscure the salient portions of the report. Vail Engineering probably will not conduct the field work and analysis for the final site characterization study and report. In such case, the technical firm employed may, after review and analysis of the preliminary assessment and other factors, revise and amend the following goals, objectives and study outline to conform with that firms interpretation of the data, study requirements and methodology. Any proposed significant change will be submitted for review and comment by NRC and PADER.

### 4.6.10 Outline of Study Plan

(G) Goals and Objectives; (R) Rational; (SP) Study Plan

**1. Quantification of Present Hydrogeologic Parameters**

(G) Quantification of the present mobilization, transport, distribution, attenuation and concentration of radionuclide activity in the ground waters and determination of future potential for such.

(R) The magnitude of the amount of mobilization and transport of radionuclide activity (and the potential for such) is a significant factor in the determination of the extent and intensity of the analysis of the hydrological properties of the aquifer and the related physical properties of the soils necessary for adequate site characterization. The magnitude of the potential for mobilization and transport of radionuclide activity by the ground water is also a major factor in the determination of the method and extent of the activity required for satisfactory decommissioning of the plant site.

(SP) Water samples will be collected from:

| | |
|---|---|
| Well M-8 | Ambient up gradient ground water quality |
| Well M-18S | Water in fill zone-central plant area |
| Well M-9 | Water in lower part of aquifer-south plant area |
| Well M-9S | Water in fill zone-south plant area |
| Well M-4 | Well of poorest quality |
| Well M-12 | Down gradient of maximum indicated soil activity and high dissolved metals |
| New Well | Completed in fill zone near Well M-5, area of probable maximum activity. |

Samples will be analyzed for activity by the radiochemistry method. Additional samples will be collected and analyzed if the results are not conclusive.

The scope and results of the leachability tests on the thorium bearing slag will be reviewed. Additional testing will be conducted if the adequacy of the present data is questionable. In particular, assurance will be made that leachability tests have been conducted using fine grained slag materials and that tests have been conducted with leaching liquids which extend over the potential pH range of the ground waters. (See section 5.1.4 for details of the planned leachability studies.)

**2. Flow Regime of Chartiers Creek**

(G) Establish the flow regime of Chartiers Creek at the plant site including determination of minimum and average flows and flow rates which are exceeded 90%, 80% and 50% of the time and 10, 50 and 100 year and PMP flood flows. Develop a flow rate vs. gage height curve or chart at a favorable location in the plant vicinity.

(R) Quantitative flow data is essential for assessment of the environmental impact of the discharge of ground water and storm drainage flows to Chartiers Creek. Increases in Chartiers Creek in the concentrations of some of the elevated ground water constituents, will provide an indication of the total amount of discharge of such constituents. The precision of such quantifications is dependent, in part, on the accuracy of the determination of the Chartiers Creek flow rate. A fair determination of the total ground water flow may be possible by algebraic extrapolation based on the concentration of certain constituents in the ground water and the flow and increase in the concentration of such constituents in Chartiers Creek.

(SP) The area of the drainage basin of Chartiers Creek above the mill site and the pertinent topographic, geologic and climatic characteristics will be taken from existing maps and records. Correlation of such data with that of similar other basins in the region, where long term stream flow data is available, should result in a reasonable approximation of the flow regime of Chartiers Creek. The analysis will also give weighted consideration to the ratio of the drainage area to the total drainage area of the nearest downstream gauging station on Chartiers Creek. The flow in Chartiers Creek will be gauged by USGS standard methods at times of low flow, moderately low flow and near average flow. The gauging should be performed at a point where the stream reach is reasonably straight and uniform and at a section where the channel is stable and geometrically simple. A plot of the flow rates relative to gage height will provide for estimation of the stream flow at other gage heights.

### 3. Hydraulic Properties Of The Fill Zone

(G) Adequate characterization of the hydraulic properties of the fill zone of the shallow aquifer with specific reference to properties related to quantity of flow, travel rate, and attributes affecting mobilization, transport and distribution of radionuclide activity and hazardous waste constituents.

(R) The preliminary hydrogeological assessment indicates that well over 90% of the ground water flow and transportation of hazardous waste constituents is in the fill zone. The thorium bearing materials are primarily contained within this zone. In proportion to its importance and inhomogeneity, there presently is insufficient and considerably less specific data for characterization of the properties of the fill zone than there is for the clay and underlying clayey sand and gravel zones. (i.e. number of sieve analysis, aquifer tests etc.). Conversely, if further study substantiates that there is not a significant amount of radionuclide activity or transport in the clay and clayey sand and gravel zones, then the existing data base may provide for adequate characterization of these zones. Additional basis for this premise are that there is very little ground water flow in these zones, these zones are fairly homogeneous, these zones are generally at sufficient depths below the surface that there is little likelihood of significant future penetration into or disturbance or distribution of the soils.

(SP) Provide a soils technician or equivalent during drilling operations to provide a general log of all bore holes with particular emphasis on the nature of the fill materials and the elevation of the bottom of the fill zone.

Complete approximately 80% of the new bore holes with perforated casing extending from the upper part of the clay zone into the fill zone. Establish elevations of the bore hole water level measuring points. Record water levels in all bore holes the day after completion, after three days and at 14 days and 28 days. Record water levels in all Remcor wells and the four original monitor wells at the same time. Plot the data for refinement of the water table configuration and mapping of the bottom and saturated thickness of the fill zone. Excavate four 15 foot long trenches to the top of the clay zone and map the nature and distribution of the fill materials in the trench side walls and note the sources and estimated quantities of seepage. Tentative locations for the trenches are 50 feet southeast of well M-6. 40 feet east of impoundment 2, 15 feet south of well M-7 and 25 feet east of well M-16. Allow the water level in the trenches to rise until the level stabilizes and then pump the water from the trench at a rate which maintains a constant depth of approximately 40% of original. Make a record of the pumpage rates and water levels in the trenches and utilize nearby bore holes as observation wells for obtainment of draw-down data at a distance. Conduct the pumping test until water levels stabilize or definitive draw down curves can be developed. Analyze the data for computation of average effective permeability and flow rates.

**4. Ground Water Flow**

(G) Quantification of the total shallow aquifer ground water flow through the plant area and determination of the percentage of flow in the fill zone.

(R) Computation of the total amount of discharge of waste constituents and radioactivity is dependent on both the concentration and flow. The total amount of discharge is needed to assess the environmental impact on Chartiers Creek and may provide data relative to the long term diminution of leachable constituents from the plant soils. Total flow is also a major component in the calculation of flow rates or velocity.

(SP) Obtain an estimated average concentration of favorable trace element constituents in the ground water being discharged to Chartiers Creek by averaging the concentrations of water samples collected from the bore holes and monitor wells located along Chartiers Creek and those along the western part of the north property line. The averaging should be flow weighted to the extent that the data provides a reasonable basis for estimating the probable relative rate of flow pertinent to the individual wells, i.e., saturated thickness of fill zone, ground water gradient, determined or estimated permeability, and distance between sampling points. Determine the increase in Chartiers Creek in the concentration of the selected trace elements by analysis of water samples collected from upstream and downstream of the plant site. Elements which appear to have a good potential for a determination of the increase in concentration in the creek are magnesium, manganese and molybdenum. Increases in the concentrations will be quite small (0.01 to 0.1 mg/l because of the dilution ratio of Chartiers Creek flow to ground water flow (on the order of 700:1). In order to obtain sufficiently precise results, ICP spectrograph or atomic absorption with graphite furnace methods of analysis will be required. Determination of the increased concentration of sulfate by ion chromographic analysis may also provide reasonably precise values.

Analysis for three or more elements should be made. The samples should be collected during low flow periods and on two different occasions. The total quantity of the constituents discharged to Chartiers Creek will be computed from the increased concentration and the flow in Chartiers Creek. It appears that a reasonably good estimate of the total ground water flow can be made by algebraic extrapolation using the flow and increased concentration in the creek and the estimated average concentrations in the ground water being discharged to the creek. It may be possible to obtain a reasonable estimate of the quantity of ground water accretions to Chartiers Creek along shorter reaches of the stream by analysis of water samples at intermediate points correlated with the average concentrations of elements indicated by the bore holes and wells along the particular reach. Such is not proposed unless there is evidence of significant radioactive or waste discharge along specific reaches or preferred flow paths.

The reasonableness of the determination of total ground water flow from increased concentrations in Chartiers Creek will be checked by estimating the ground water flow based on the drainage basin characteristics and precipitation parameters. The probable extent of the drainage basin tributary to the plant site will be determined in conjunction with the geological appraisal of the site surroundings. Topography, vegetation, characteristics of the regolith and underlying soils and other pertinent factors will be mapped for the drainage basin. Average precipitation amounts and distribution will be obtained from published data. Infiltration and ground water run-off will be computed on the basis of values determined by other ground water flow studies and/or data in similar topographic areas in the region. In consideration of the inhomogeneity of the fill zone, it is unlikely that the average permeability can be deduced from well tests with sufficient precision for reliable computation of the total ground water flow. It appears more likely that it will be possible to make a reasonable estimate of the average permeability of the fill zone from the amount of ground water flow indicated by the methods outlined above.

The clay zone and underlying clayey sand and gravel zone appear to be fairly homogeneous. Determination of ground water flow in these zones will be computed using the previously derived hydraulic parameters, thickness and observed gradients of these zones. Such should provide reasonably accurate quantification in consideration of the apparent low amount of flow and relative unimportance of these zones.

**5. Preferred Flow Paths**

(G) Determination of the presence of preferred flow paths.

(R) The contours of the preliminary water table map (MCWA-1) suggest that there may be an area of unusually high permeability and ground water flow extending from the vicinity of well M-1 toward the northwest corner of the plant area. If so, such should be analyzed relative to its effect on the transport of radioactive or hazardous waste transport from the plant site.

(SP) Particular emphasis will be placed on the characterization of the fill zone material, hydraulic gradients and other parameters of this and other areas where the possibility of a preferential flow path or zone is indicated.

**6. Storm Drainage System**

(G) Assessment of the effect of the storm drainage system on the ground water levels and flow patterns.

(R) There are indications that a significant portion of the ground water flow may be intercepted by or infiltrating into the storm drainage system.

(SP) During a dry weather period, a survey will be made to locate and quantify the discharge of all water to the storm drainage system and such shall be compared with the drainage system discharge. Some plant site maps indicate the presence of some manholes in the system. If located the flow will be measured at such locations to determine the quantity of infiltration along separate portions of the line.

**7. Drainage Channels**

(G) Locate and define characteristics of paleo drainage channels or other unconformities in the soil zone lying above the bedrock.

(R) The drilling logs indicated fairly clean deposits of sands and/or gravels at the bottom of a few of the bore holes. If such deposits are extensive they may have a significant effect on the ground water flow.

(SP) Logs of the bore holes will be examined for evidence of extensive or continuous deposits of relatively high permeable soils in the zone above the bedrock. If such are indicated; additional test wells will be installed and completed for discreet aquifer tests at these locations. The aquifer test method will be dependent on the indicated yield of the well and may consist of slug tests or pumping tests.

Consideration will be given to conducting packer type tests USBR Method E-19 or equivalent.

## 8. Soil Characteristics

(G) Quantification of pertinent soil characteristics.

(R) Input data is required for determination of flow rates and velocities and computer modeling of the aquifer. The necessary extent and precision of the parameters is highly dependent on the determination of the extent that the ground water is mobilizing and transporting radioactivity, wastes or other constituents in concentrations which may have an adverse environmental effect.

(SP) Soils and other materials in the fill zone will be classified by several categories or types and the percentages of each type will be estimated for sections of the plant area. Determination of the vertical distribution of the types and percentages of the fill materials may also be warranted. Discreet hand sampling will be conducted in the fill zone for obtainment of representative, uncomposited samples of typical materials for analysis.

Sieve analysis will be made for each type of material. Other laboratory tests and analysis will be conducted as normal for the particular type of material. Laboratory permeability tests will probably not be conducted on clayey soils because of the small percentage of flow that is conducted in such materials.

The clay zone and clayey sand and gravel zone conduct very little ground water flow, are at a significant depth below the surface, and do not contain radioactive fill. In consideration thereof, the existing data and analysis is generally sufficient for adequate characterization of the soils and hydraulic properties of these zones.

Diffusion may be a significant factor in the disbursement of constituents in the ground water in the clay and lower zones. Diffusion and dispersivity coefficients based on typical values determined for similar soils should, however, be adequate for these zones. Diffusion probably is not a significant factor in the fill zone and assumed values will be used unless further analysis indicate otherwise.

Most of any radionuclide activity and possibly a significant portion of the hazardous waste constituents in the ground water would emanate from leaching of the materials in the fill zone. The source of such constituents extends over much of the plant area. This together with the fairly thin saturated thickness of the fill zone makes it probable that the precise determination of dispersivity coefficients are not critical to the hydrogeological analysis. It is doubtful if a realistic determination of dispersivity coefficients could be made by laboratory testing of the highly inhomogeneous fill materials. So far no clearly discernible plumes of constituent concentrations have been evident. In the absence of such and if the verification of dispersivity characteristics appears to be of significance, then consideration will be given to developing a triangular shaped network of closely spaced observation wells with the apex at the ground water up gradient point. A suitable tracer solution such as salt water would be injected at the apex well and concentrations of the trace solution recorded at time intervals in the down gradient wells. Preliminary analysis indicates that wells spaced at ten foot intervals down gradient and five foot intervals laterally should result in adequate determination of the ground water flow rate and dispersion of constituents in the fill zone within a reasonable period of time (10 - 30 days).

The preliminary analysis indicates that dissolved molybdenum has been adsorbed in the clay zone. This may also be true for some other metals. Otherwise adsorption does not appear to be a significant factor. Since only a small percentage of the ground water flow is through the clay zone, use of assumed values for absorption appears to be sufficient. If subsequent data and analysis indicates that absorption is a significant factor, additional soil testing and analysis will be made as appropriate.

**9. Vadose Zone**

(G) Characterization of the vadose zone. In particular, determination of infiltration rates and leachability of the soils and fill materials above the water table.

(R) A significant portion of any radioactivity in the ground water may emanate from leaching in the vadose zone.

(SP) Conduct TCLP tests on at least four representative samples of the fill material. The samples will contain, or be milled to, a fine granular size before testing. Analysis of the leachate will be made for at least radioactivity, molybdenum, sulphate, magnesium, manganese, and selenium. Maximum infiltration rates will be estimated from measurements of the subsidence of water vs. time in shallow surface pools of water.

## 10. Hydro-Potentiometric Water Levels

(G) Depiction of the hydro-potentiometric water levels and gradients in the lower part of the shallow aquifer.

(R) Relative to the flow in the fill zone, the ground water flow in the lower part of the shallow aquifer appears to be of little significance. Determination of the hydrostatic levels and gradients in the lower aquifer is necessary for the verification of such a premise and for full analysis and understanding of the plant site hydrogeology.

(SP) It appears that at least three additional wells completed in the lower part of the aquifer will be necessary for adequate depiction of the gradients in the lower part of the aquifer. Tentative new well locations are east of the administration building, north of Building 29 and west of surface impoundment 4.

## 11. Deposits Of Hazardous Waste Materials

(G) Survey for deposits of hazardous waste materials or concentrations in the ground water.

(R) In the past, there may have been isolated incidents of spillage or leakage of concentrated acid and possibly other chemicals which may have resulted in localized deposits of hazardous waste materials. Additional investigations appear to be warranted for verification of such.

(SP) The conductivity of the water at all new bore holes will be determined upon completion of drilling operations. If specific conductance of over 10,000 umhos/cm is detected then additional water samples and analysis will be made. If hazardous waste concentrations are found in significant levels, additional drilling and testing will be conducted to determine the extent of the contamination.

## 12. Bedrock Formation

(G) Verification of the character and hydraulic properties of the bedrock formation.

(R) The preliminary assessment is that the formation underlying the shallow aquifer has a very low permeability and that there has been little if any intrusion of hazardous waste constituents or radioactivity into this formation. Additional investigations appear to be desirable for verification of such.

(SP) Drill by air-rotary or equivalent method, a bore hole to a depth of approximately five feet below the top of the bedrock. Set and cement seal an unperforated six inch casing to the bottom of the hole. Drill a five inch hole to a depth of approximately ten feet below the bottom of the casing. Obtain soil samples for laboratory verification of the formation classification, mineralogy and gradation of materials. Record the water level in the hole at appropriate intervals until such stabilizes. Obtain and analyze samples of the accumulated water. Conduct an aquifer test by determining the rate at which water must be added to maintain the water level near the top of the casing. The proposed location of the deep well is in the northwest corner of the plant area midway between wells M-5 and M-6 because this is the location most likely to indicate any seepage of water from the shallow aquifer into the bedrock formation.

**13. Ground Water Quality.**

(G) Verification of trending of ground water quality.

(R) The projected ground water quality will determine what remedial action, if any, is required for plant decommissioning. There is evidence that the ground water quality has been improving. At the present concentrations of constituents, it is probable that the ground water discharge does not have a significant impact on Chartiers

Creek. Further investigations are desirable to verify continuance of the improving trend in the ground water quality and that radioactivity is within acceptable levels.

(SP) The sampling of the four existing monitor wells is and will be continued on a quarterly basis. The results of the laboratory analysis will be tabulated as a part of the site characterization study. In addition, water samples will be collected at the beginning and at the end of the SCR study period, from all of Remcor's wells M-5 through M-18 and from at least four additional bore holes located in the northwest part of the plant area. The four additional bore holes will be completed so that the water samples are collected from the fill zone. The northwest area has been selected for additional sampling because the highest concentrations of most constituents appear to be present in this area. All of the above water samples will be analyzed for the same constituents as being performed for the regular monitor well reporting. In addition, sampling and analysis for radioactivity will be conducted as set forth in Study Plan item No. 1 and conductivity will be determined at all new bore holes.

**14. Regional Hydrogeology**

(G) Determination of regional hydrogeology.

(R) The characteristics of the regional hydrogeology need to be determined for analysis of the possible effects on the shallow aquifer of deep ground water or artesian flow.

(SP) The characteristics of the regional hydrogeology will be conducted in conjunction with the study of regional geology and will be based primarily on field observations and published technical data and reports.

## 15. Computer Modeling

(G) Depiction of the shallow aquifer flow and solute transport of constituents by computer modeling.

(R) Computer modeling will provide for testing of the reasonableness of the values developed and assumed for the aquifer flow and dispersion characteristics and for the timely evaluation of possible latitude of flow and transport using different combinations of probable, maximum and minimum input values. Computer modeling will also provide for rapid depiction of solute distribution in the future and/or as affected by the proposed decommissioning activity.

(SP) After collection, tabulation and plotting of field data, a study will be made to define the objectives and required capabilities and other attributes of the computer program. Presently available programs will be reviewed for a determination of their adequacy and suitability. If none of the presently available programs has all of the required capabilities and attributes, current catalogs of computer programs will be reviewed. Favorable appearing programs will be investigated for verification of capabilities and other attributes. One or more programs will be selected based on an evaluation of pertinent factors and considerations. The computer program analysis will be conducted using a number of combinations of input values and data to determine the probable latitude of flow and solute transport potential.

## 16. Breaching of Clay Dike

(G) Depiction of the configuration of and flow directions and magnitudes within the shallow aquifer with the clay dike breached. Actual, physical breaching of the dike would only be done with the understanding and written concurrence of the Pennsylvania Department of Environmental Resources.

(R) The clay dike has created an unnaturally high water table in the western part of the plant area. It appears to be desirable to breach the dike for a number of reasons. Lowering of the water table will facilitate excavation of materials which may be required for decommissioning of the plant site or for future construction, will increase the stability of the upper soils, will decrease the potential for leaching of undesirable constituents from the soils in the saturated portion of the fill zone and will provide for a more rapid and uniform purging of the ground water.

(SP) It is anticipated that the computer modeling program will adequately depict the configuration of and flow and soluble transport within the shallow aquifer with the dike breached.

### 4.6.11 Hydrogeology

Previous studies have established the general characteristics of the shallow ground water regime in the plant area, i.e., the direction of the ground water flow is from the east across the plant area with discharge to Chartier's Creek along the westerly boundary of the plant site. The water table generally lies from a few feet to about ten feet below the ground surface. The contaminated soils associated with past plant operations are primarily contained within the surface soils, the fairly thin vadose zone and the upper few feet of the shallow water aquifer. Ground water transport of contaminants is probably limited to the shallow water aquifer which extends from the water table elevation to the top of bedrock, which generally lies at a depth of less than twenty feet. Original natural soils of the shallow water aquifer are fairly low permeability silt and clay loams of alluvial origin. In some areas, the upper several feet of the soil has been altered by distribution of cinders, slag and other fill materials during plant development and operation. The average shallow ground water flow through the plant area is on the order of forty gallons per minute.

The SCR will be based on such additional field investigations and soils analysis as are necessary to describe and quantify in detail the ground water regime and transport mechanisms pertinent to mobilization and attenuation of contaminants resulting from past plant operations.

### 4.6.12 Identification and Characterization of Hydrogeologic Units

Each soil unit from the surface to and including the upper strata of the underlying bedrock formation shall be identified and described with specific data relative to flow characteristics and lateral and vertical extents. Particular emphasis shall be given to analysis of the upper portion of the shallow water aquifer where the natural soils have been altered by deposition of fill materials and other debris.

**4.6.12.1 Soil Characterization.** Determinations of the primary soil characteristics shall be made for each pertinent soil unit and the SCR shall include the general physical and pertinent hydrological properties of the soils relative to mass transport characteristics, soil reaction characteristics, soil contaminant properties and soil engineering characteristics. If the leaching studies show that the radionuclides are readily leachable, then $K_d$'s will be measured for Th and Ra.

**4.6.12.2 Vadose Zone Characterization.** The vadose zone in the plant area is relatively thin. It is of significant importance, however, because it and the surface soils contain the bulk of the radioactive contaminants. The vadose zone will be analyzed and described relative to infiltration rates and other characteristics affecting the potential for mobilization, transport and attenuation of contaminants.

**4.6.12.3 Saturated Zone Characterization.** The shallow water aquifer shall be described in detail and particular emphasis will be made of the hydrological properties of the shallow water aquifer down gradient from the contaminant sources. During the subsurface survey described in Section 5.2.2 of this plan, water level measurements will be made and water samples collected at many of the boreholes. A determination of the pH and conductivity will be made for each water sample and additional analysis made of the water chemistry of selected samples. The soil samples and logs of each borehole will be inspected relative to hydraulic properties. The data obtained will provide considerable detail on the water table configuration and the distribution and flow travel paths of non-radioactive contaminants. A well will be drilled and completed in the shallow water aquifer upgradient of the plant area for determination of ambient water quality. A well will be drilled and completed in the upper portion of the bedrock formation underlying the shallow water aquifer in the northwestern part of the plant area. The well shall be tightly sealed to cut off flow from the overlying formation. If the well produces sufficient water; it will be used to determine the hydraulic characteristics of the bedrock aquifer and the pressure and direction of vertical hydraulic gradients. Water analysis will be made to determine if there is leakage of contaminates into the lower aquifer from the overlying ground water. Investigation of the bedrock aquifer will be extended if evidence is found that contamination is present in the lower formation.

Prior investigations indicate that the majority of the shallow ground water flow may be conducted by the irregular and non-continuous cinder and slag deposits in the upper part of the shallow aquifer. This condition results in an aquifer that has hydrological characteristics that, in many aspects, are more similar to fracture following flow paths of rock formations than that of homogeneous porous soils. Well pump tests under such conditions are generally of little value in the determination of general aquifer transmissivity and average formation and discrete flow path water velocities. The final determination of total shallow ground water flow and effective travel times will probably be based on an analysis of the probable amount of infiltration from the area tributary to the ground water flow through the plant area and from analysis of the increase of selected chemical constituents in the water of Chartier's Creek as it flows by the plant area.

Historical data from the monitor wells will be analyzed relative to known events in the plant area which may have resulted in noticeable chemical changes in the ground water and which could indicate the average ground water velocity along discreet flow paths.

Additional soils and water quality analysis will be made as necessary to describe and document in the SCR, the saturated zone characteristics of the shallow water aquifer for the pertinent parameters set forth in the guide lines.

### 4.6.13 Groundwater Flow and Transport Models.

Computational models may not provide an effective method for representation of the flow and transport of contaminants in the shallow water aquifer because of such site specific conditions as the short flow path (less than 1,000 feet from possible contaminant source to discharge to Chartier's Creek), small amount of ground water flow, fairly narrow, thin, and confined extent of the affected aquifer, the probable conductance of most of the shallow ground water along irregular fill deposits, the widely dispersed and highly variable contaminant sources.

Determination of the flow and transport models to be used for the SCR, if any, will be made after evaluation of the other data prepared for the report. Depiction of the conceptual characteristics of the aquifer together with manually developed mathematical abstractions for site specific conditions may result in a more realistic representation of the ground water flow system and contaminant transport.

### 4.6.14 Hydrogeologic Characterization Methods and Monitoring Practices and Procedures

This section will include a description of all hydrogeologic site characterization activities, methods, and monitoring installations sufficient to demonstrate that the site characterization methods and devices provided data that are representative of site conditions. The SCR will describe the monitoring practices, procedures, and quality assurance programs used to collect water quality and hydraulic data. Monitoring well descriptions will include location, elevation, screened intervals, depth, construction and completion details, and the hydrologic units monitored.

# CONDUCTANCE COMPARISON

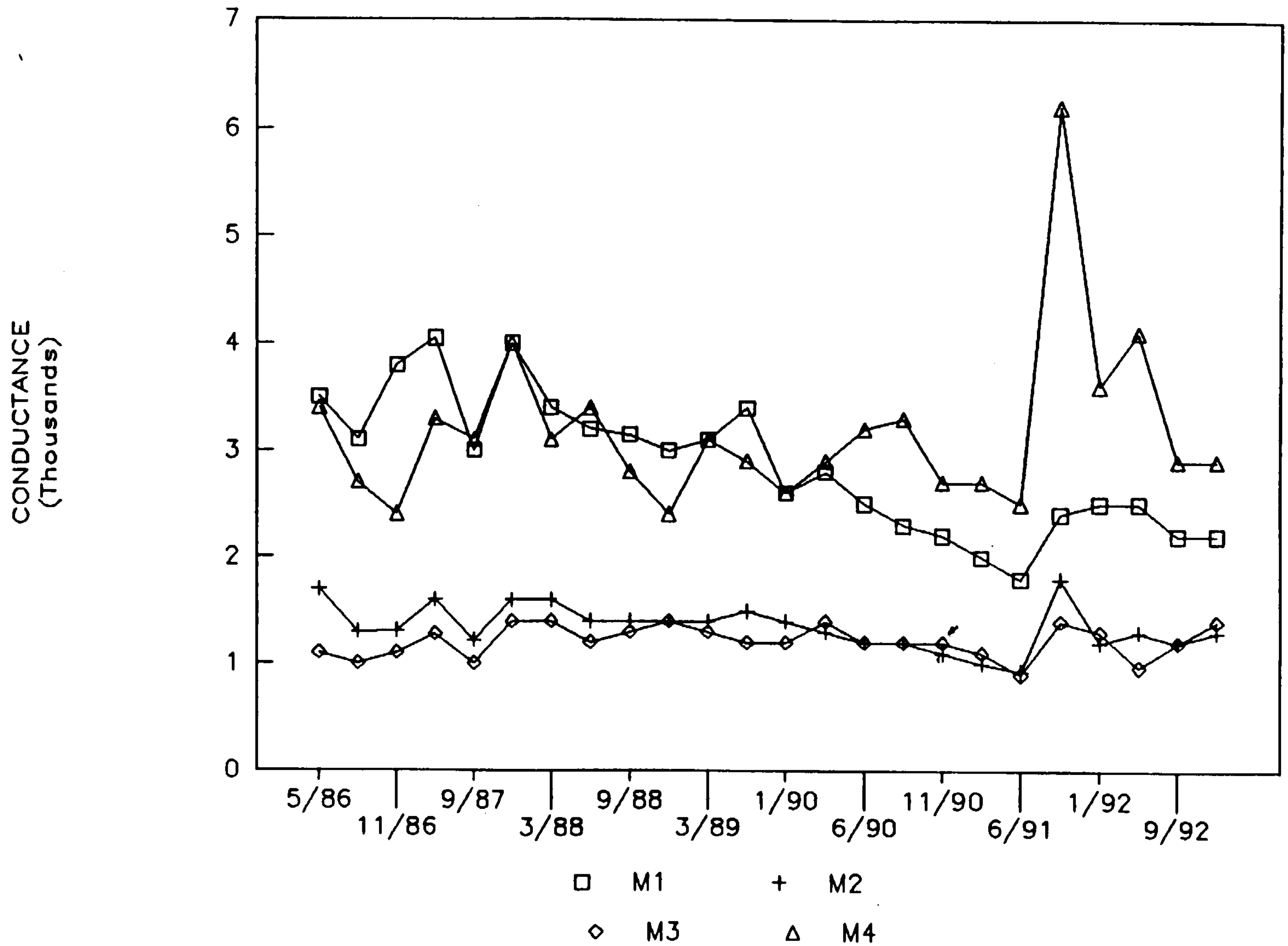


Figure 4-1: Conductance Comparison

# pH COMPARISON

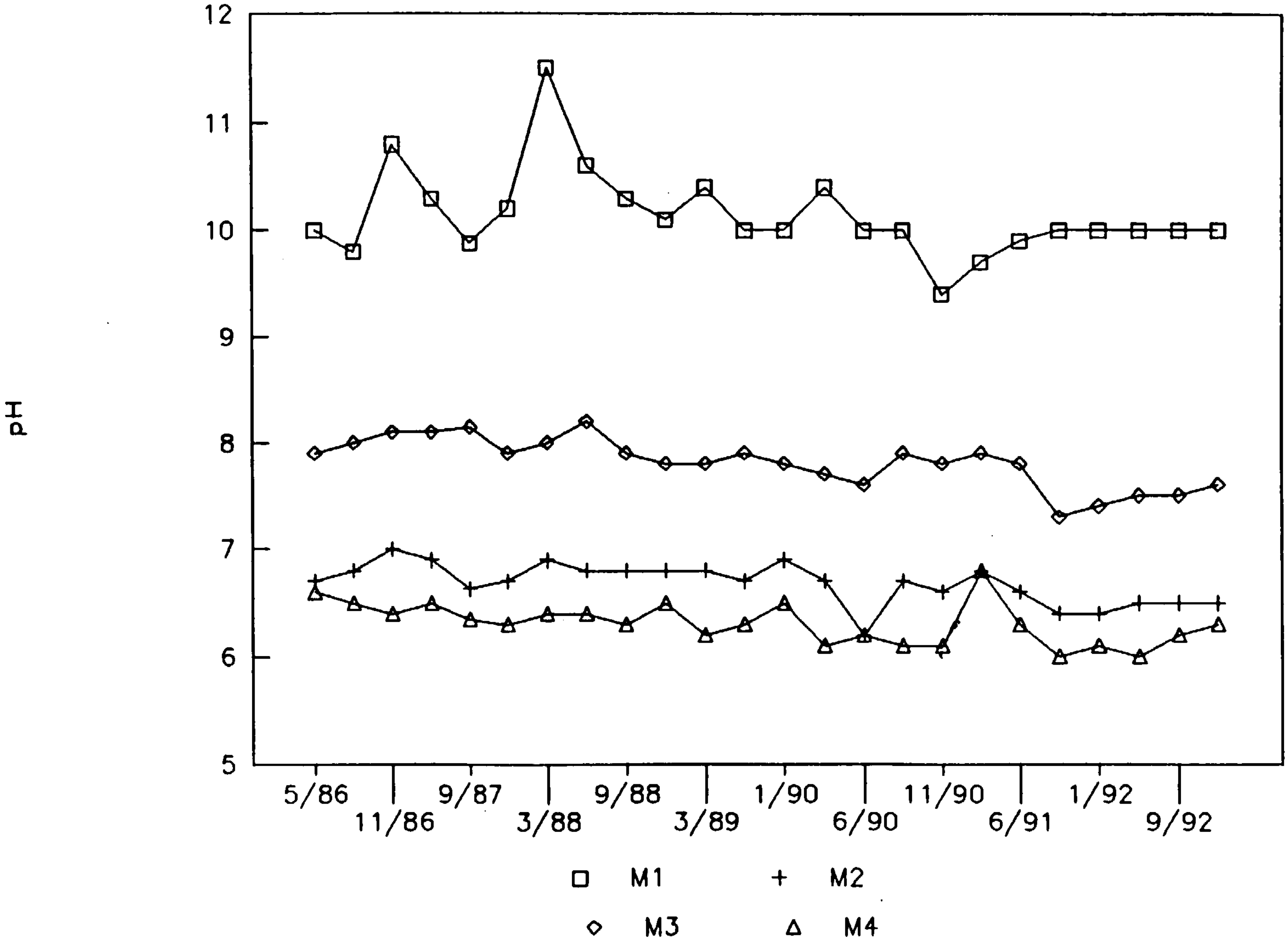


Figure 4-2: pH Comparison

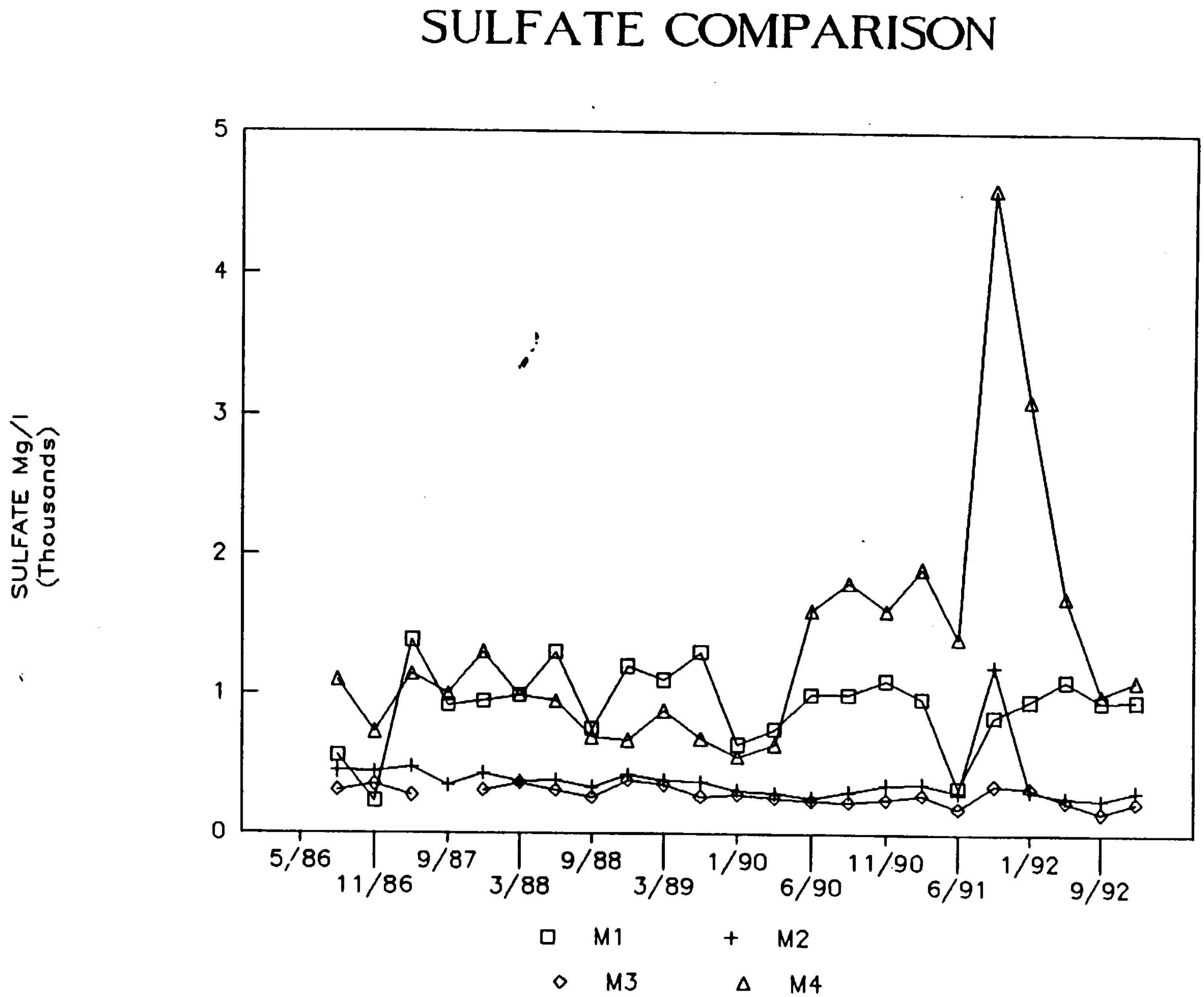


Figure 4-3: Sulfate Comparison

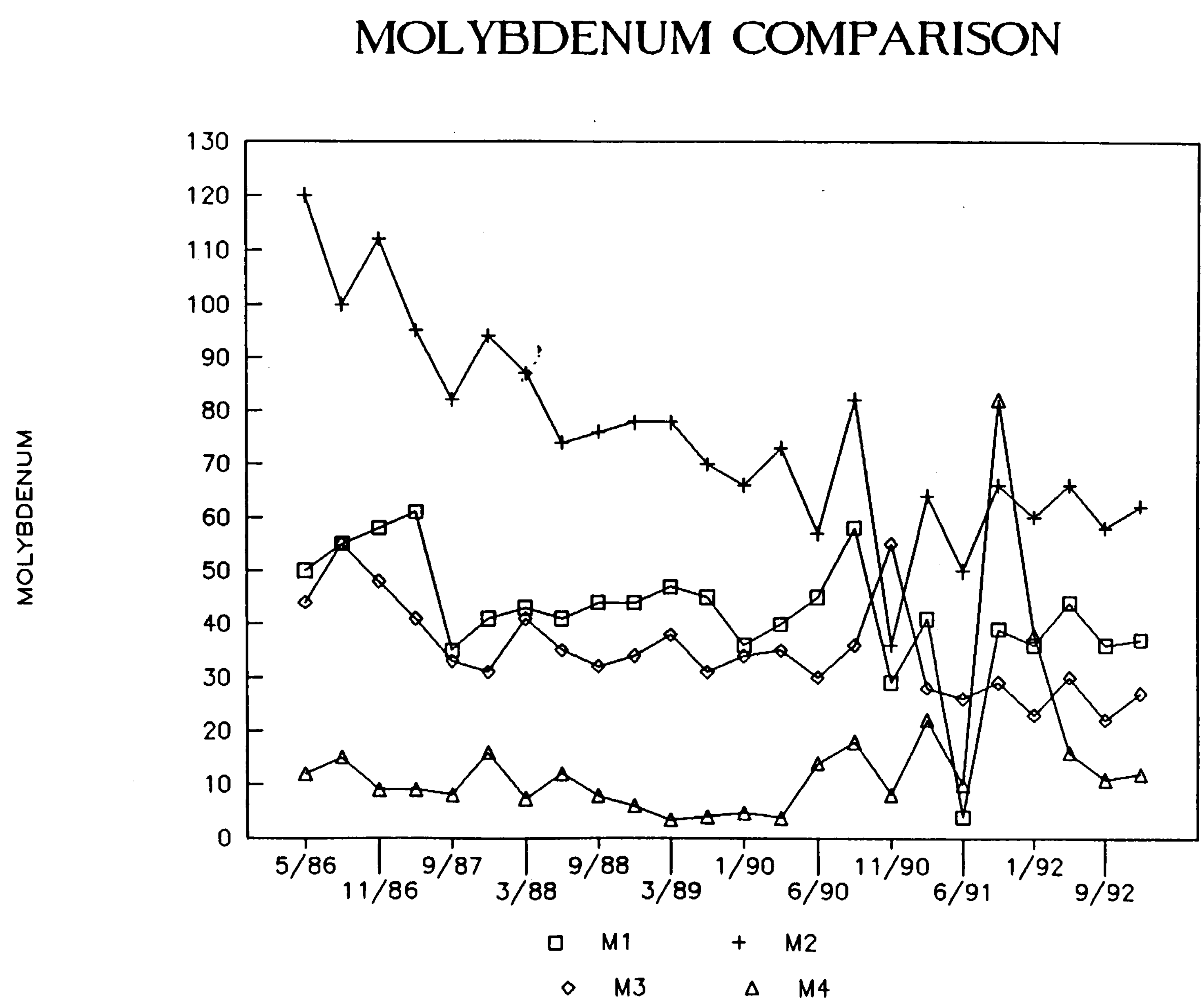


Figure 4-4: Molybdenum Comparison

# MAGNESIUM COMPARISON

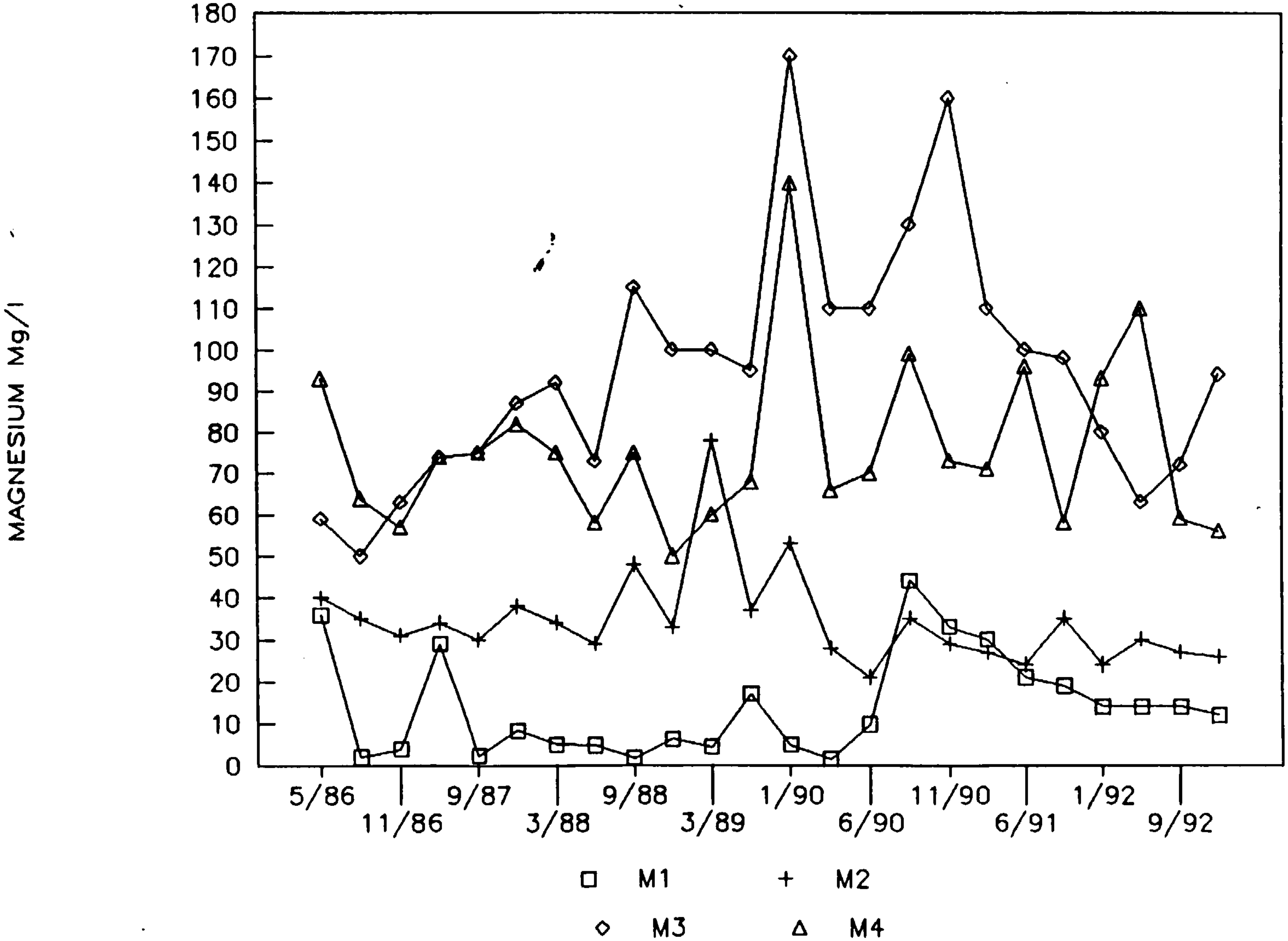


Figure 4-5: Magnesium Comparison

# WELL MI

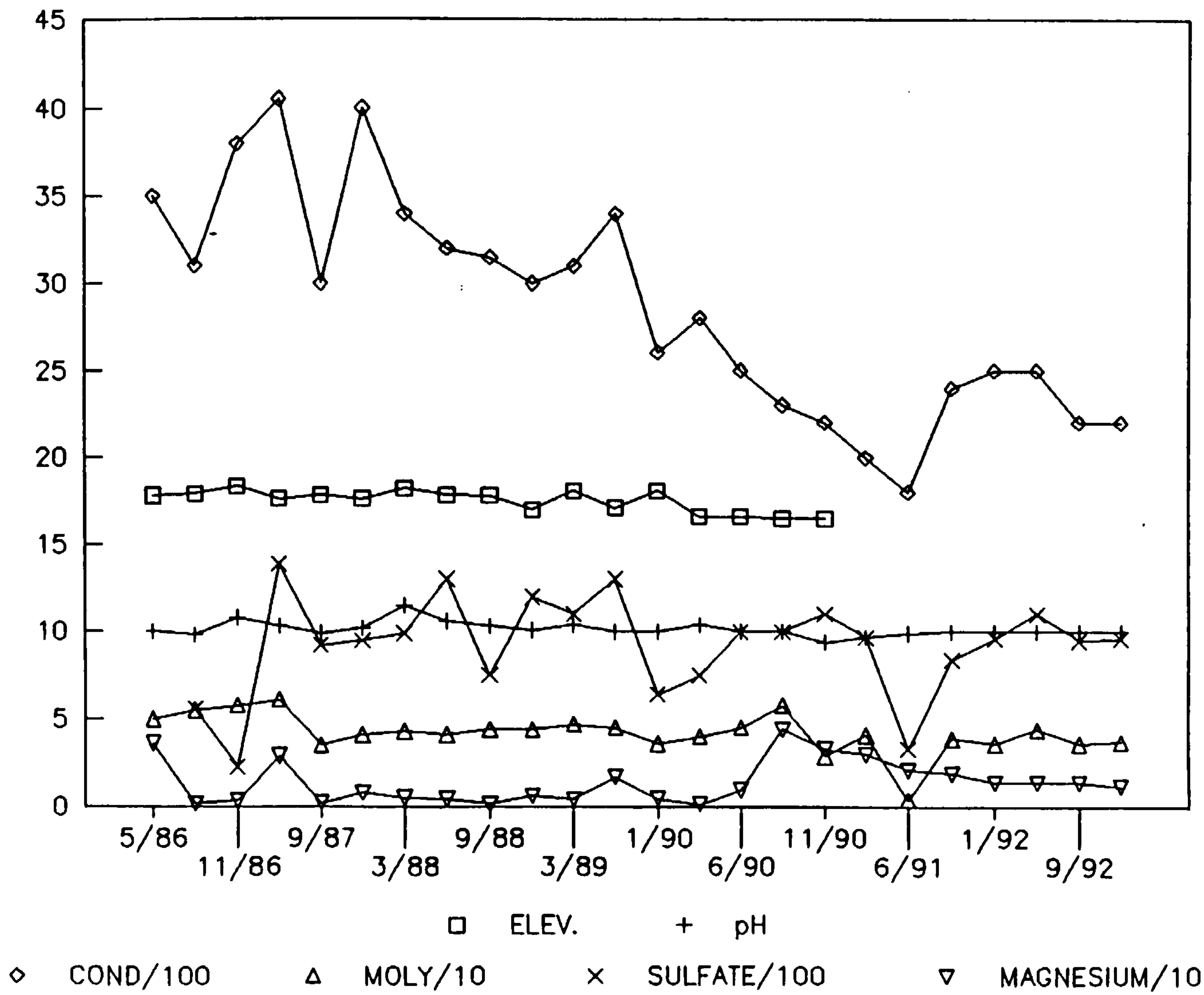


Figure 4-6: Well M1

# WELL M2

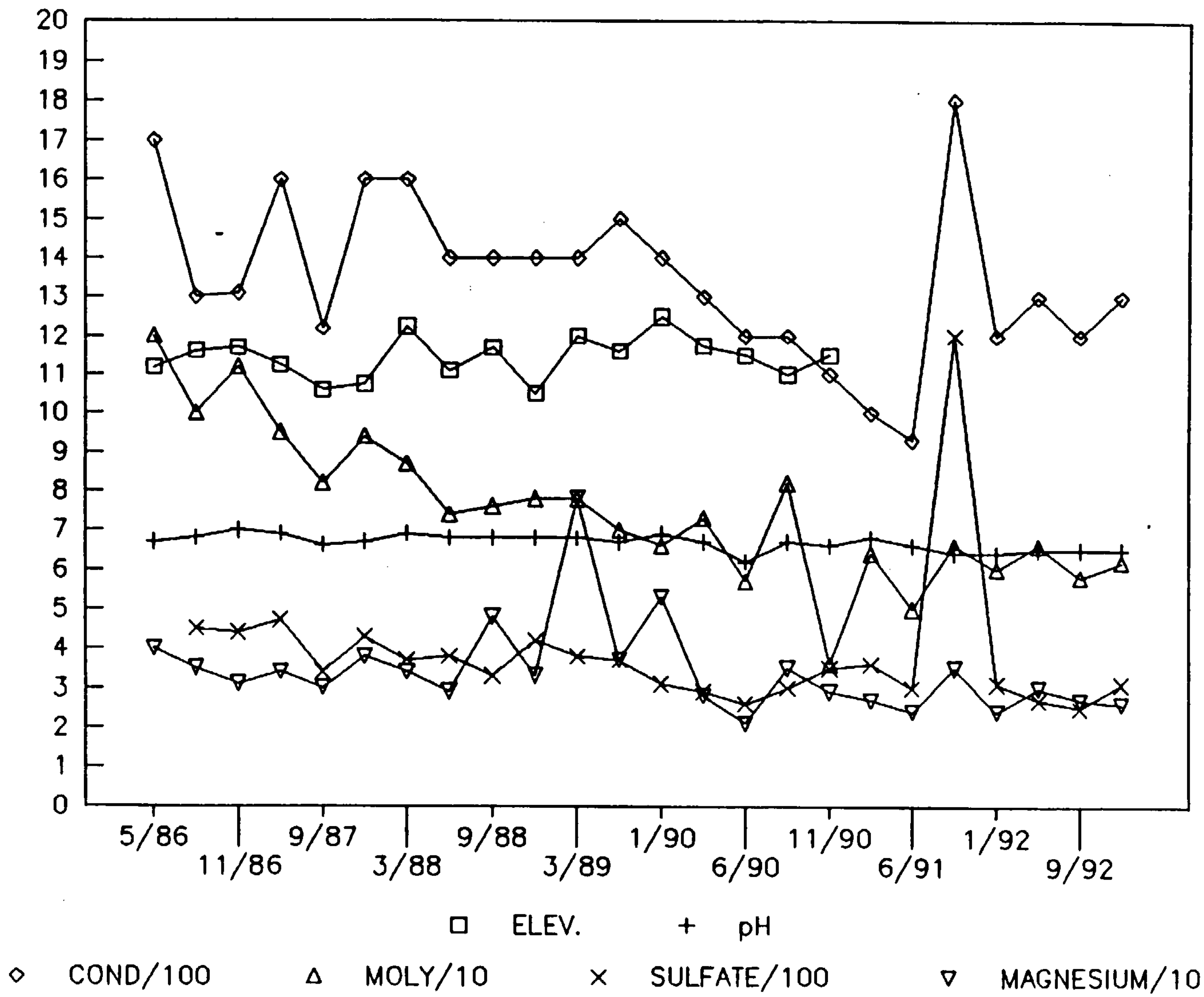


**Figure 4-7: Well M2**

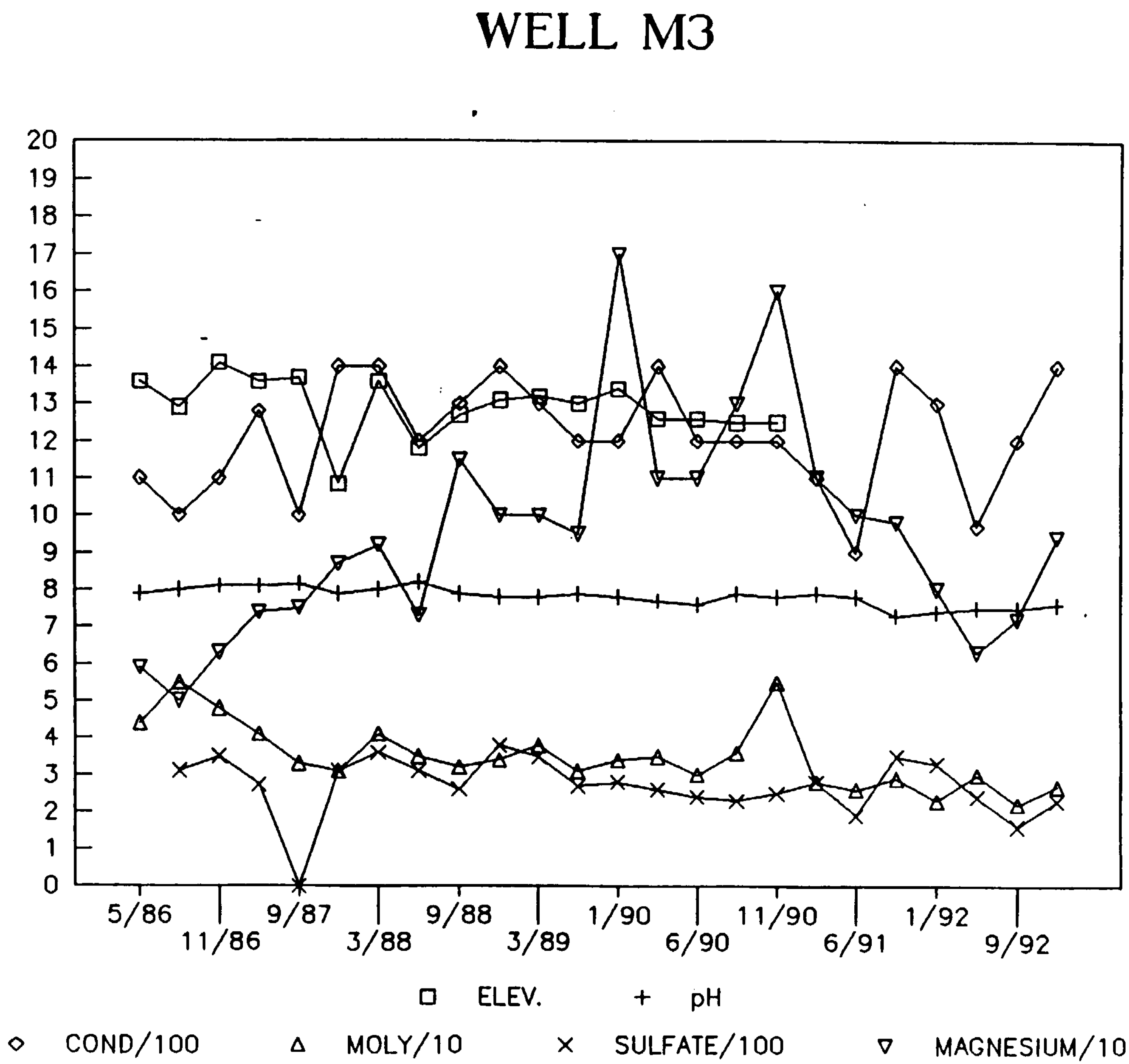


Figure 4-8: Well M3

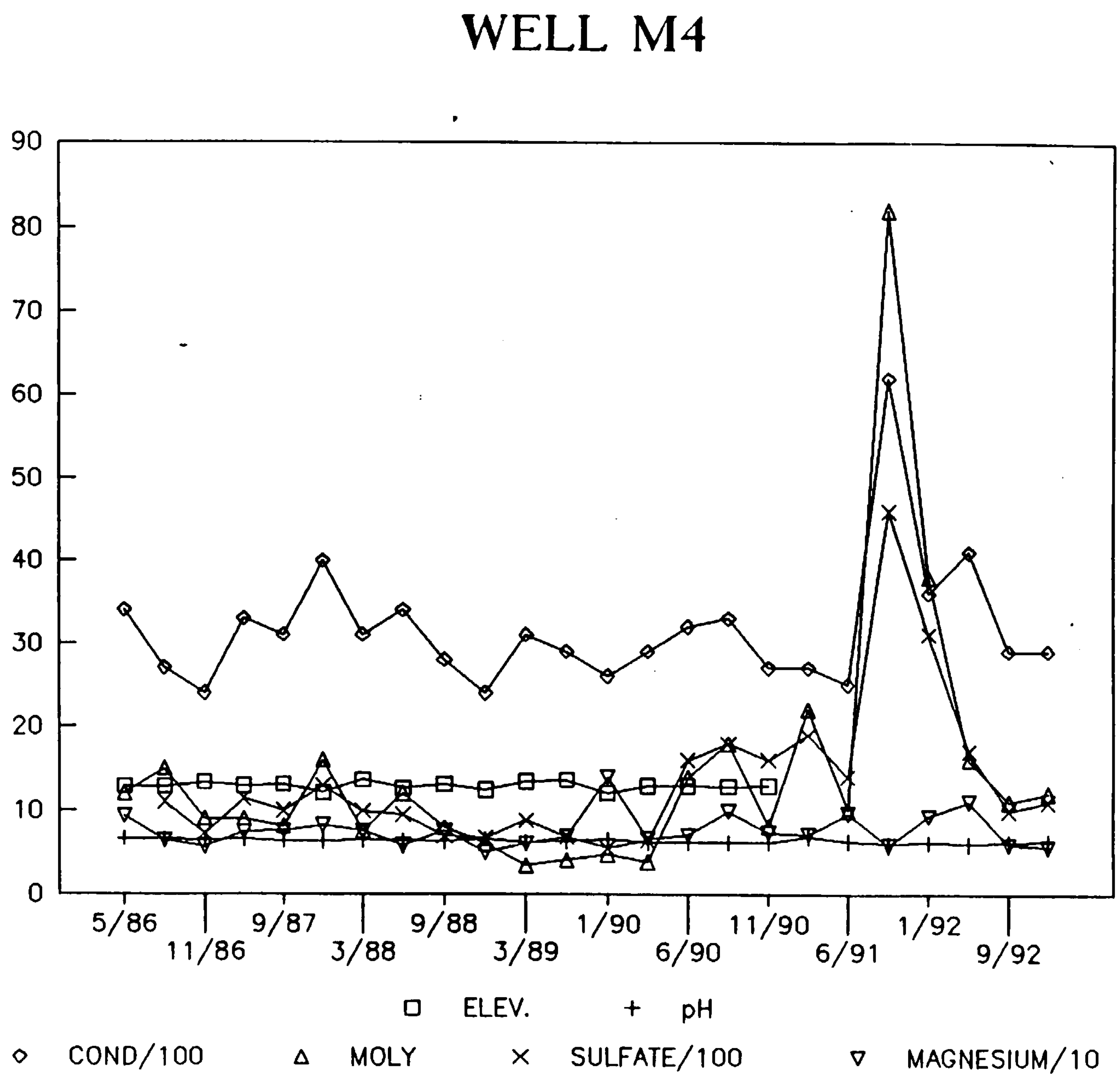


Figure 4-9: Well M4

TABLE 3
SOIL GEOTECHNICAL DATA
MOLYCORP, INC.
WASHINGTON, PENNSYLVANIA

PROJECT: GROUND WATER ASSESSMENT AND RECOVERY SYSTEM DESIGN
PROJ. NO.: 91276
DATE: 12/20/91

| SAMPLE NUMBER | MONITORING WELL | SAMPLE DEPTH (ft-bgs)(a) | LABORATORY SAMPLE DESCRIPTION | USCS (b) SYMBOL | PERCENTAGE | | | LIMITS | | WATER CONTENT (%) | PERMEABILITY (cm/sec) |
|---|---|---|---|---|---|---|---|---|---|---|---|
| | | | | | GRAVEL | SAND | SILT & CLAY | LIQUID (%) | PLASTIC (%) | | |
| MW-M5-G3 | M-5 | 15.5 TO 16.5 | Brown Clayey Sand with Gravel | SC | 34 | 46 | 20 | 34 | 21 | 13.7 | NA |
| MW-M13-G4 | M-13 | 10.0 TO 11.5 | Brown Fat Clay | CH | 0 | 8 | 82 | 52 | 22 | 24.9 | NA |
| MW-M11-G5 | M-11 | 16 to 16.5 | Gray Silty Sand with Gravel | SM | 38 | 40 | 22 | NA (c) | NA | 22.0 | NA |
| ST-1 | M-6 | 14.5 TO 16.5 | Gray Sandy Lean Clay | CL | 2 | 31 | 67 | 36 | 21 | 41.7 | 5.8 X 10^-7 |
| ST-2 | M-8 | 6.5 TO 8.5 | Brown Fat Clay | CH | 0 | 11 | 89 | 59 | 23 | 27.6 | 1.5 X 10^-8 |
| ST-3 | M-11 | 9.5 TO 11.5 | Gray Fat Clay with Sand | CH | 3 | 18 | 79 | 90 | 38 | 43.0 | 3.2 X 10^-8 |

NOTES:

(a) "ft - bgs" indicates depth in feet below ground surface
(b) "USCS" indicates Unified Soil Classification System
(c) "NA" indicates paramter not determined

Table 4-1: Copy of Table 3 from Remcor Report

TABLE 7
AQUIFER CHARACTERSTIC DATA SUMMARY
MOLYCORP, INC.
WASHINGTON, PENNSYLVANIA

PROJECT: GROUND WATER ASSESSMENT AND RECOVERY SYSTEM DESIGN
PROJ. NO.: 91276
DATE: 12/20/91

| MONITORING WELL | UNIT SCREENED | SCREEN LENGTH (ft) | STATIC (ft) | SATURATED THICKNESS (ft) | Yo (ft) | K (cm/sec) |
|---|---|---|---|---|---|---|
| M-5 | C | 10 | 8.36 | 12.6 | 0.80 | 5.70E-05 |
| M-6 | C | 10 | 8.63 | 12.5 | 1.24 | 5.32E-05 |
| M-9S | F | 7 | 2.95 | 7.8 | 1.85 | 2.77E-03 |
| M-9 | C | 5 | 4.29 | 14.2 | 1.46 | 6.82E-05 |
| M-11 | C | 10 | 11.34 | 4.5 | 0.37 | 1.68E-05 |
| M-12 | C | 10 | 6.92 | 13.0 | 1.26 | 4.16E-04 |
| M-14 | F/C | 10 | 4.75 | 12.3 | 1.48 | 6.40E-04 |
| M-18S | F | 5 | 7.78 | 3.2 | 0.25 | 3.74E-04 |
| M-18 | C | 7 | 7.98 | 13.1 | 1.40 | 9.08E-05 |

NOTES:

"C" – indicates unit screened is silty or clayey sand with gravel
"F" – indicates unit screened is fill
Radius of each test well is 0.083 ft
Radius of each borehole is 0.33 ft
"Yo" – indicates the drawdown at time t=0
"K" – indicates hydraulic conductivity calculated using analytical solutions for slug tests after Bouwer and Rice, 1976

Table 4-2: Copy of Table 7 from Remcor Report

WATER QUALITY ANALYSIS

| | MW-1 12-10-92 | MW-2 12-10-92 | MW-3 12-10-92 | MW-4 12-10-92 | MW-8 10-31-91 |
|---|---|---|---|---|---|
| Specific Cond. | 2200 | 1300 | 1400 | 2900 | 950 |
| pH | 10 | 6.5 | 7.6 | 6.3 | 7.1 |
| Total Organic Carbon | 15 | 8.5 | 15.5 | 22 | 7.7 |
| Total Organic Halogen | 0.89 | 0.033 | 0.057 | 0.914 | NA |
| Total Dissolved Solids | | | | | |
| Aluminum mg/l | 0.6 | 0.7 | 0.6 | 0.6 | 0.8 |
| Cadmium | ND | 0.006 | ND | ND | NA |
| Chloride | 130 | 4.8 | 13 | 200 | 100 |
| Chromium | ND | ND | ND | ND | NA |
| Cobalt | ND | ND | ND | ND | NA |
| Copper | ND | 0.04 | ND | ND | NA |
| Iron | 0.4 | 12 | 2 | 170 | 2.3 |
| Lead | ND | ND | 0.004 | ND | NA |
| Magnesium | 12 | 26 | 94 | 56 | 25 |
| Manganese | ND | 14 | 2.2 | 28 | 0.48 |
| Molydenum | 37 | 62 | 27 | 12 | 0.42 |
| Nichel | ND | ND | ND | ND | NA |
| Phenot | ND | ND | ND | ND | NA |
| Sodium | 190 | 29 | 26 | 180 | 27 |
| Sulfate | 960 | 310 | 230 | 1100 | 81 |

* ND = Not Detected
NA = Not Analized

Table 4-3: Water Quality Analysis

## 5. Extent and Concentration of Contamination

The characterization of the extent and concentration of radiological contamination at the Molycorp, Washington, PA plant site falls into three broad categories of tasks.

(1) Analysis of physical, chemical, and radiological characteristics of FeCb slag. Section 5.1 contains the portion of the site characterization plan that provides for this category of analysis.

(2) Documentation of the physical extent of Th bearing FeCb slag distribution, of radioactivity in surface and subsurface soils, and in buildings and equipment. Sections 5.2, 5.4, and 5.6 describe the plan for documenting the physical distribution of radioactivity and radiations from FeCb slag on site.

(3) Analysis of the concentration and rate of dispersal of contamination from thorium and its daughter products derived from FeCb slag in air, and in surface and subsurface water. Sections 5.3, 5.5, and 5.7 provide the plan for characterizing current concentrations of radionuclides in airborne and waterborne pathways.

## 5.1 Characterization of Source

The sampling and analysis program described in this section of the site characterization plan will document the physical and chemical properties of Th bearing FeCb slag which contains smaller amounts of uranium and its daughter products, which is the only known radiological contaminant present at this site.

A great deal is already known about the site. For example, the inventory and concentration of $^{232}$Th has already been measured in the above ground slag pile on the southern section of the site. Based upon the Applied Health Physics report (May 22, 1975, see Appendix K) and their analyses of activity by gamma spectrometry, the mean concentration of $^{232}$Th is 1250 pCi/g and the total inventory is 12.7 Ci. The slag is present in a stabilized configuration in a pile covered with vegetation and with a volume of 249,000 cubic feet and a density of about 90 pounds per cubic foot.

Gamma exposure rates have already been measured over much of the surface of the site (ORAU Report, June 1985) and on the surface and subsurface in the areas around the surface impoundments (RSA Report, Dec. 1990, see Appendix I).

### 5.1.1 Chemical Composition of Slag

The process employed at the Molycorp plant that formed the FeCb slag involved a highly exothermic reaction that produced FeCb from ore imported from Araxa, Brazil. The Araxa ore contained natural Th as an unwanted trace constituent. The ore was reduced to metallic form in the reaction and shipped as product for use as an alloy in the production of specialty steel. The trace Th remained in the slag, which, as an unwanted by-product of the reaction, was retained on-site.

**5.1.1.1 Ingredients.** The Site Characterization Report will describe the ingredients and reagents used in the reaction that formed the FeCb slag and it will describe the normal amounts and proportions used.

**5.1.1.2 Chemical reaction.** The SCR will contain a description of the chemistry of the reaction that formed the slag.

**5.1.1.3 Determination of Chemical Composition of Slag.** A chemical analysis will be performed on six samples of FeCb slag, obtained using the sampling procedures outlined in section 5.1.2.4, and the results will be reported in the SCR. The samples to be analyzed will consist of uncrushed pieces of FeCb slag. This will ensure that the sample contains only slag, and no soil or other constituent that is not normally found in the slag itself. The samples will be collected by random selection from the slag pile, since this is the only known location of uncrushed FeCb slag.

### 5.1.2 Radiochemical Composition of Slag

Laboratory analyses will be performed to determine the radiochemical and isotopic composition of both the Araxa ore and the FeCb slag.

**5.1.2.1 Radioelements in Cb Ore.** The radiochemical composition and the relative abundance of naturally occurring radionuclides in Cb ore will be reported from the literature (if available).

**5.1.2.2 Testing of an Historical Ore Sample.** If a representative unprocessed ore sample dating to the time of FeCb production at the Molycorp plant site can be found, the relative abundance of radioactive isotopes will be measured, in the manner described in Paragraph 5.1.2.5.

**5.1.2.3 Measurements of Radionuclides in Slag.** In order to assess the radiological impact of residual FeCb slag remaining on the Molycorp site, it will be necessary to measure the degree of equilibrium in the uranium and thorium series radionuclides, and the ratio of U to Th, in the slag. The analysis will be performed on aliquots from the six samples identified in section 5.1.2.4, "Sampling of Slag."

Radioactive equilibrium in slag will be determined by dissolution, radiochemical separation, followed by alpha spectrometric analysis for thorium isotopes. This will also provide an analysis for $^{230}Th$ which is a uranium series radionuclide. A preliminary analysis of Th isotopes in one slag sample is shown in Figure 5-1. It can be seen that $^{232}Th$ and $^{228}Th$ are in equilibrium and that the relative activity of $^{230}Th$ from the uranium series is about 10% of the $^{232}Th$ activity.

Gamma spectrometry may be performed on the samples to provide further confirmation of conclusions regarding radioactive equilibrium.

**5.1.2.4 Sampling of Slag.** Three samples of FeCb slag will be taken from the slag pile, one at each end and one at the center, and three will be chosen from other areas of the site. Two of the three samples taken from the slag pile will be of crushed slag (probably mixed with soil or other fill material), and one will be of discrete pieces of slag collected from the pile. Likewise, two of the three samples taken elsewhere on site will be will be of crushed slag (probably mixed with soil or other fill material), and one will be of discrete pieces of slag collected from the pile. In other words, four of the samples will be of crushed slag and two will be of discrete pieces that are not mixed with a host matrix material. In the case of the crushed slag samples, efforts will be made to find samples of relatively elevated activity in order to maximize analytical resolution. Crushed slag may be sieved and activity as a function of particle size determined by gamma spectrometry or radiochemistry.

Aliquots from the six samples will be analyzed radiochemically and/or by gamma spectrometry (see section 5.1.2.3); for leaching of Uranium isotopes, Thorium isotopes, $^{226}$Ra, and $^{228}$Ra (see section 5.1.4); and for emanating power of $^{222}$Rn and $^{220}$Rn(see section 5.1.3). Note that 20 samples from the slag pile have already been analyzed for Th by gamma spectrometry, giving a mean of 11.4 ± 0.6 mg of thorium per gram of sample. The mean is known to be 10%, and the coefficient of variation is about 22% (Applied Health Physics Report, 1975, see

Appendix K). This indicates that the FeCb slag present on site is sufficiently homogeneous in its Th content that a large sampling program is not warranted.

The choice of six for the number of samples to be analyzed is in conformity with the recommendations of NUREG/CR-5849. We quote the pertinent statements from section 8.2 of NUREG/CR-5849, entitled "Measurement Uncertainty" (page 8.4):

> The total uncertainty associated with a particular type of measurement can be determined empirically by performing repeat (6 to 10 recommended) measurements of several selected locations and determining the average and standard deviation of the data. This will provide an estimate of the upper bound on the magnitude of systematic uncertainties.

We note that the repeat sampling will, indeed, place a limit on the upper bound of random uncertainties (that is, the precision of the measurements). It will not place a limit on systematic uncertainties (the accuracy of the measurements). It is normally difficult to quantify systematic uncertainties by statistical means.

**5.1.2.5 Analysis.** In the analysis technique to be employed for FeCb slag and ore samples, the material will be first completely dissolved in HF and $HNO_3$ and then $^{234,238}U$ and $^{232,230,228}Th$ will be analyzed by radiochemical analysis and alpha spectrometry. $^{226}Ra$ will be analyzed by the $^{222}Ra$ emanation technique and $^{228}Ra$ by radiochemical separation and low level beta counting or by ingrowth of $^{228}Th$ and alpha spectrometric analysis.

These analyses may be supplemented by or replaced by laboratory analyses of samples for $^{214}Bi$ and $^{228}Ac$ by high resolution gamma spectrometry using GeLi detectors, or NaI gamma spectrometry.

### 5.1.3 Emanating Properties of Slag

The emanating properties of aliquots taken from each of the six samples identified in section 5.1.2.4, "Sampling of Slag," will be measured in order to characterize the rates of release of radon ($^{222}Rn$) and thoron ($^{220}Rn$).

**5.1.3.1 Measurements.** The following analysis of emanating properties will be performed for each of the six aliquots: Two equal portions of the sample will be taken. One will be left in bulk form, and the other will be ground to -100 mesh. Each will be placed in a sealed container for one month, and the ingrowth and release of $^{220}Rn$ and $^{222}Rn$ to air trapped in the container will be measured over time by gross alpha counting in Lucas Flasks.

**5.1.3.2 Results.** The emanating power of the samples will then be inferred from these results, combined with the results of radiochemical measurements of $^{226}Ra$ and $^{228}Th$ in the same samples, both for bulk and pulverized slag.

### 5.1.4 Leachability of Slag

Aliquots from each of the six FeCb slag samples identified in section 5.1.2.4, "Sampling of Slag," will be analyzed for leachability of Uranium isotopes, Thorium isotopes, $^{226}Ra$, and $^{228}Ra$.

One leachability study will be conducted using either ground water taken from wells #2 through #6, or water prepared in the lab to simulate water from these wells. The simulated well water will be used if the actual well water is found to contain trace contaminants of the substances being measured for leachability because such contamination would affect the outcome of the leachability tests. Wells #2 through #6 are located along the western boundary of the site, between the impoundment area and Chartier's Creek. The protocols for the leachability studies will be based upon the EPA TCLP parameters and the American Nuclear Society Standard for measurement of the leachability of solidified low-level radioactive wastes (ANSI standard ANSI/ANS-16.1-1986). The results will be used to model release rates to ground water for slag buried in bulk. At least one other leachability study will be performed, using one of the following leaching solutions: humic acids, distilled water, or simulated lung fluid. Simulated lung fluid will be used in this second leachability study if in vivo leaching rates for inhaled insoluble material proves to be a significant pathway for dose assessment. Otherwise, humic acid or distilled water will be used to help model ground water transport rates.

### 5.1.5 Particle Size Fractionation of Slag Samples.

A minimum of six to ten soil samples will be collected onsite for the purpose of measuring the distribution of thorium bearing slag with respect to particle size. Two of these samples will be collected from the slag pile; four will be collected at surface locations onsite demonstrating elevated levels of gamma radiation; and four will be taken by split spoon sampling in onsite boreholes at a depth where NaI borehole logging indicates elevated gamma radiation.

The thorium content of the unfractionated samples will be measured using gamma spectrometry (NaI or GeLi). Each sample will then be fractionated by a wet and/or dry sieving technique and the thorium content will once again be measured by gamma spectrometry. Commonly used meshed sizes for such fractionation studies of this type are: #4 (4.75 mm), #50 (0.30mm), #100 (0.15 mm), and #200 (0.075).

### 5.1.6 Physical Properties of Slag.

The site characterization report will contain a description of the macroscopic physical properties of the FeCb slag, including color, density, appearance, friability, and brittleness.

## 5.2 Design of Survey for External Radiation and Contamination

Because natural Th is the major radioactive contaminant on-site at the Molycorp facility, and since bulk contamination by natural Th at levels exceeding the NRC Option 1 guidance of 5 pCi/g is readily detectable by measurements of external gamma, the external radiation from surface and subsurface soils at the site can be completely characterized by gamma measurements. Therefore, on-site measurements of external radiation will be confined to gamma.

### 5.2.1 Surface Gamma Survey

Due to the significant amount of external gamma data already available for the Molycorp site, it is now possible to identify, at least in a general way, the known affected areas on site. (See Figure 5-2) The known affected areas are (1) the impoundment area extending from the west side of Buildings 36 and 42 to Chartier's Creek, on the west side of the site; (2) the storage yard in the northwest corner of the site; (3) the fenced area south of Caldwell Avenue (where the slag impoundment is located); and (4) spotty contamination along the north fenceline. Due to historical usage patterns, there is a potential for contamination under or adjacent to the Building 38 and the process buildings west of Building 34, where the FeCb slag was produced. The remainder of the property is not presently known to be affected.

The designation of areas of the property as affected in the above paragraph is based on our present knowledge of the site. It does not represent the final statement as to which areas are affected and which areas are not affected. Such final designation must be deferred until after the site characterization study is completed. The tentative designation given above is based on surface surveys, historical operating data, and limited sub-surface measurements (confined to the area of the surface impoundments). This is the only data that is presently available. In areas for which sub-surface data is not presently available, the preliminary designation described in the above paragraph, and shown in Figure 5-2, is based on surface readings and on historical knowledge of the site. This does not imply that surface measurements can be used to detect the presence of subsurface radioactive material. This plan contains a program to adequately characterize the subsurface radionuclide content of all areas shown in Figure 5-2, including the areas shown as affected and those not shown as affected. (See section 5.2.2 for a description of the plan for sub-surface monitoring.) Figure 5-2 is meant only to reflect our current understanding of the site. The site characterization report will contain a revised division of the site into affected and unaffected areas, and this revised designation will be based on both surface and sub-surface monitoring of the entire site.

An external gamma survey of the impoundment area was completed as part of the 1990 RSA survey at the site. As part of the site characterization study, this survey will be extended to cover all known affected or potentially affected areas. The survey will be made on a 20 foot grid system and will employ the procedures described in the 1990 RSA report (see Appendix I). The grid system will coincide with the Cartesian co-ordinate system imposed on the site during the 1990 RSA survey. (English units were chosen instead of metric units for the grid, because the site is laid out in English units, making it easier and less costly to work in English system units.)

The survey will be conducted with scintillometers that have been cross calibrated against a pressurized ionization chamber. The values indicated by the scintillometers will be multiplied by the calibration constant obtained from the PIC, to yield true gamma. The true gamma values will be entered onto site maps. (See the 1990 RSA report, Appendix I, for a detailed description of the calibration and survey techniques that will be employed.) The survey will also adhere to the guidance in NUREG/CR-5849 on conducting open land surveys, recognizing, of course, that the document is directed toward final site surveys, so that its recommendation are not always applicable to site characterization surveys. The final site survey will be addressed in the decommissioning plan.

The results of the external gamma survey is useful both for quantifying the external gamma rates and the concentrations of Th in surface soils. For example, 5 pCi/g of $^{232}$Th (in equilibrium with its daughters) distributed uniformly in soil will produce an exposure rate 3 feet above the surface of 14 μR/hr. Therefore, for example, a surface gamma exposure rate below 23 μR/hr (14 μR/hr + natural gamma background of about 6 to 9 μR/hr in the vicinity of the Molycorp site) will indicate that the average concentration of $^{232}$Th in surface soils within a radius of about 10 meters of the measurement are below the NRC Option 1 clean-up criteria.

In addition, field measurements may be made using a high resolution intrinsic Ge detector and multichannel analyzer, such as the ORTEC NOMAD system. This equipment permits the identification of the natural emitters present and the results can be interpreted in terms of the concentration of the $^{232}Th$ series in equilibrium in the soil. A sensitivity of 1 pCi/g average for contaminated soil can be obtained with reasonable counting times with a sufficiently large detector.

A "scanning survey," of the type described in NUREG/CR-5849, section 6.5.2 (page 6.7), using scintillometers, will be made of the areas presently classified as unaffected. That section of NUREG/CR-5849 states that, in scanning surveys, "Locations of direct radiation, discernible above the ambient level, are marked on facility maps and identified for further measurements and/or sampling." It does not recommend that measurements be recorded in areas where the direct radiation is not discernible above background levels. Section 6.4.2 of that document states that the minimum discernible increase in count rate for such a scanning survey is 2 to 3 times the ambient count rate. Since the background gamma exposure rate is 6 to 9 μR/hr in the vicinity of the plant, 20 μR/hr corresponds approximately to the minimum discernible increase in count rate. With the high sensitivity scintillometers to be used in the study, increases of 50% above background are readily measured. This survey will employ a similar density of measurements than that used for affected areas, and gamma readings below 20 uR/hr will be recorded with a similar frequency to the affected areas. If any elevated readings are detected above 20 μR/hr, a local surface survey will be conducted with an intensity of effort equuivalent to that in the affected area survey.

### 5.2.2 Subsurface Survey

The 1990 RSA survey of the site included subsurface measurements in 36 boreholes located in the impoundment area and in the yard in the northwest corner of the property. For the site characterization study, approximately 350 additional boreholes will be drilled to bedrock (i.e., auger refusal) and logged at six inch intervals using a NaI probe to measure the intensity of the subsurface gamma field. The NaI readings (counts per minute) will be used to calculate the exposure rate in the borehole and the average concentration of natural Th in the surrounding material. Profiles of the variation with depth of Th concentrations in each hole will be graphed. The procedures for drilling and logging the boreholes and for graphing the borehole profiles will be based upon the procedures given in the 1990 RSA report (see Appendix I). The procedures from the 1990 report will be updated to include additional correction factors (for example, the correction factor for the geometry at the top of borehole), and other refinements in the NaI gamma logging technique (RSA, 1992, see Appendix J).

The locations of the boreholes will be chosen to achieve the following goals:

(1) Extend coverage to include all affected areas on site.

(2) Increase the density of boreholes over that employed in the 1990 RSA survey.

(3) Locate the edges of contamination. To achieve this goal, the borehole coverage will overlap and extend into unaffected areas at boundaries between known affected and unaffected areas.

(4) Provide quantitative data to assess average downhole $^{232}Th$ activity vs. depth which can be used for the dose assessment, particularly for external exposure.

The data obtained by the drilling program will be useful for inventory of the amount and distribution of subsurface radioactivity, to better delineate affected and unaffected areas, and to provide information for a dose assessment.

The rationale for the estimated number of additional boreholes (approximately 350) is based on the information in the following table:

| | | Number of Boreholes Needed for 100% Coverage of Survey Unit at Given Density | |
|---|---|---|---|
| Survey unit | Area of unit ($m^2$) | 23 m grid (density in RSA 1990 study) | 10 m grid density |
| Unit 1: Area surveyed in 1990 (impoundments) | 15,700 | 30 boreholes | 157 boreholes |
| Unit 2: Yard South of Caldwell Ave (slag pile) | 18,300 | 35 boreholes | 183 boreholes |
| Unit 3: Plant area north of Caldwell Ave. not surveyed in 1990, less area covered by buildings | 20,500 | 39 boreholes | 205 boreholes |

For the purposes of the Site Characterization Study, the plant will be divided into three survey units.

Survey unit 1 is the area covered by the 1990 RSA survey. The unit covers the region of eight surface impoundments and the storage yard in the NW corner of the plant site.

Survey unit 2 is the fenced yard south of Caldwell Avenue containing the slag pile.

Survey unit 3 is the area of the plant north of Caldwell Avenue that was not included in the 1990 survey.

The procedure for selecting borehole locations will be as follows: (1) Each survey unit will be covered with boreholes at approximately density of coverage employed in the RSA 1990 survey. This density of coverage is already available for unit 1 from the 1990 study. (2) Based on the data collected, each survey unit will be subdivided into affected and unaffected areas. These areas will be considered as separate survey units so that no unit contains both affected and unaffected areas. Additional drilling will be carried out in affected areas to achieve a density of coverage equal to that of a 10 m grid. The 10 m grid density was chosen to conform with the recommendations of NUREG/CR-5849.

Based upon the RSA 1990 survey, unit 1 is considered to be an affected area in it's entirety. Unit 1 will therefore have a borehole coverage density equivalent to that of a 10 m grid. It is our estimation, based upon historical evidence, that about half of unit 2 will be an affected area. Likewise, again based on historical evidence, we estimate that only a small portion of unit 3 will be classified as affected. Our estimate of the number of boreholes drilled to bedrock is therefore as follows:

| | |
|---|---|
| Unit 1: 100% coverage at density of 10 m grid | 157 holes |
| Unit 2: 50% coverage at density of 10 m grid | 92 holes |
| Unit 2: 50% coverage at density used in 1990 | 18 holes |
| Unit 3: 100% coverage at density used in 1990 | 39 holes |
| Holes allocated for additional drilling to locate the edges of contamination | 50 holes |
| **Total estimate of number of boreholes** | **356 holes** |

The total number of boreholes shown above is an estimate. A sufficient number of boreholes will be drilled in order to cover all affected areas at the density of a 10 m grid, in conformity with the recommendations of NUREG/CR-5849.

The NRC in a memorandum dated Oct. 29, 1992 has accepted the utility of the downhole technique but requires more information in order to judge whether they will accept the quantitative interpretation in terms of average concentration of $^{232}Th$ at various depths. Molycorp and it's consultants will continue to develop and refine the downhole logging technique. A report will be filed with the NRC prior to the submission of the decommissioning plan, documenting the utility of the downhole calibration and interpretation of count rate as representing an average content of $^{232}Th$. Gamma spectrometric data from the analysis of downhole samples will be presented in that report. The utility of downhole measurements for quantitative dose assessment purposes will be addressed. The extent of the underground monitoring program which will be undertaken during decommissioning for the purpose of demonstrating compliance will depend upon whether or not, subsequent to the site characterization study, the NRC will accept a quantitative interpretation of average $^{232}Th$ concentration from the gamma log data.

The locations of all boreholes will be surveyed and depicted on site maps drawn to scale. In addition, the locations will be reported in terms of the Cartesian co-ordinate system imposed on the site for the external gamma surface survey described in section 5.2.1.

### 5.2.3 Soil Analysis

About 200 soil samples will be taken from cores obtained by split spoon sampling during the drilling of boreholes. Of the approximately 300 to

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## MCWA-1: WELL LOCATIONS AND WATER TABLE CONTOURS

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**D-1**

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## MCWA-2

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350 boreholes to be drilled onsite, 20% will be cored. The boreholes to be cored will be selected by use of a random number generator. Samples from 25% of the boreholes that are cored will be analyzed for thorium content by ICP, XRF, or gamma spectrometry. The remainder of the cores will be retained and will be available in the event that further soil sample analyses are indicated. The boreholes are approximately 20 feet deep, and the split spoon samples are 1.5 feet in length, which implies 13.3 samples per borehole. 300 boreholes x 20%(boreholes cored) x 25%(cores analyzed) x 13.3 (samples per borehole) = 200 samples. If more than 300 boreholes are drilled, the number of samples analyzed will be increased comensurately.

Each sample will be screened and each fraction ground in a hammermill until homogeneous and an aliquot of each fraction will be analyzed by ICP. This method measures Th by mass and is readily capable of measuring 1 pCi/g of $^{232}$Th (i.e., about 9 ppm). These samples may also or alternatively be analyzed by gamma and/or alpha spectrometry. The total sample contributes to external gamma exposure whereas only the smaller particle size fraction can be resuspended by wind and other disturbances and contribute to possible inhalation.

An additional 200 soil samples will be collected from the surface at random locations throughout all affected areas. The purpose of the surface soil samples is to provide an independent data set that will be compared statistically to the results from the scintillometer survey for gamma radiation. The soil sample locations will be selected as follows: (1) The locations of all surface gamma readings taken in affected areas will be compiled into a single data set. (2) 200 locations will be drawn randomly, using a random number generator. (3) Soil samples will be collected from each of the 200 locations for analysis. The samples will be collected according to standard methods.

When the results from the surface soil sampling become available, the data set from the 200 soil samples will be compared statistically to the mean surface soil concentrations inferred from the gamma scintillometer measurements. Tests will be performed on both the soil sample data and the gamma data for normality, kurtosis, and skew. Then the averages of the two data sets will be compared using Student's t test and/or ANOVA. We expect that significant statistical differences will be found between the data sets, because the data are not drawn from the same parent populations. The data sets will represent the results of different analytical techniques performed on very different sample sizes. The purpose of the statistical analysis is to help quantify and explain the differences between the techniques. The two data sets are also not necessarily expected to be normally distributed. This is because the process by which the thorium was distributed throughout the site was not necessarily random. Additionally, a partial clean-up of the site has occurred, significantly affecting the distribution throughout the site. The soil samples will help us to understand how the contamination is distributed onsite. This is important information, because some of the statistical techniques recommended in NUREG/CR 5849 for demonstration of compliance are not statistically valid for data that is not normally distributed. If the distributions are not normal, then appropriate statistical tests will be used for the comparisons. For example, if the soil characteristics are log normally distributed, then the log transform of the results will be normally distributed and the tests can be performed on the log transforms.

About 40 additional samples will be taken down boreholes and measured by the methods described in section 5.1 as a confirmation of the gamma survey results in the affected areas. These samples will be taken from three boreholes that will be specifically drilled and cored, using split spoon sampling techniques, in order to collect the samples. Each of these three boreholes will be drilled at a distance of five feet from another borehole that has been previously logged using an NaI probe and found to contain elevated regions of gamma radiation. Therefore, each of these cores will come from regions of elevated thorium content in the soil. 13.333 samples per borehole x 3 boreholes = 40 samples.

Because of the inhomogeneous distribution of bulk and ground slag on and under the site, it is expected that the surface soil samples will not produce a one to one correspondence with the results of gamma measurements made at the same location (see RSA, 1992). The results from measurements of soil samples, by their very nature, are averages over small volumes whereas gamma measurements in free air result from the average emission rate of gamma rays over much larger volumes of soil. However the gamma ray exposure rates are much less sensitive to variations in homogeneity of the source distribution than are soil samples. At a site such as the Molycorp facility, where contamination is very spotty, highly variable, and not well mixed, one must expect a lot of "scatter" when comparing the results from a single sample to gamma measurements. The characterization of the site used to justify the decommissioning plan will rely heavily on gamma data, since that data is the result of direct measurement of much larger quantities of material than is possible from the use of soil sampling alone. The average produced by a gamma measurement is also a better indicator of exposure or dose than is that from a single soil sample. In addition the critical path for exposure from this site is most probably external gamma exposure.

## 5.3 Surface Water and Sediments

### 5.3.1 Chartier's Creek Water Samples

The site characterization study will include upstream and downstream grab sampling. The upstream location will be in an area unaffected by site activities to establish background surface water quality. Samples will be taken from the stream bank in a well mixed zone. The downstream location will be north of the north property line in order to assess possible impact from all contributing areas of the plant site. If practical, the downstream location will be on the east bank, since the affected areas are all east of Chartier's Creek. Water levels will be recorded at the time samples are taken. Flow rates and volumes will be sufficiently characterized at both sampling locations to establish the relationship between water level and the volume and flow rate of the creek. Samples will be taken monthly for 6 months.

Samples with volumes of one liter or larger will be filtered and non-filterable and filterable fractions will be analyzed for $^{228,230,232}Th$, $^{228}Ra$, and $^{226}Ra$. This information will provide a measure of effective rate of input of radionuclides from the ground water percolating through the site and into Chartier's Creek, and may be used in the dose assessment in lieu of or in addition to results from materials leaching studies.

### 5.3.2 Chartier's Creek Sediments.

One round of sediment sampling will be conducted at both the upstream and downstream locations. The samples will be analyzed using ICP, XRF, or gamma spectrometry for Th. If the results exceed 10 ppm, the samples will also be analyzed by alpha or gamma spectrometry. In addition, the site characterization study will include a scan of creek banks and exposed sediments for elevated gamma, using a scintillometer. If readings are found in excess of 20 μR/hr, local soil samples will be collected and analyzed for Th using the ICP or XRF; if samples are found to exceed 40 ppm, they will be analyzed also by alpha spectrometry for Th isotopes.

### 5.3.3 Runoff from Affected Areas into Chartier's Creek

The topography of the affected areas will be studied to determine if any runoff from the affected areas discharges directly into Chartier's Creek. In that event that such discharges are present, one round of water sampling will be conducted during a discharge event. One sample will be collected at the outfall point, one immediately upstream, and one immediately downstream. The samples will be analyzed in the manner described in section 5.3.1

### 5.4 Soils in Vadose Zones

The vertical borehole study described in section 5.2.2 will include soils in the vadose zone. The depth at which any increase above background occurs will be available from the radiation logs of the boreholes. Studies have already been conducted that establish the relative gamma attenuation between saturated and non-saturated soils (see the 1990 RSA report, Appendix I). The gamma count rates from the vadose zone will be corrected to account for non-saturated conditions. Since the water table is very near the surface at this site, the vadose zone is very narrow.

Soil samples from two boreholes are currently being analyzed for $^{232}$Th in order to verify the calibration established from first principles relating concentration of Th in the soil to counts per minute measured with the NaI probe in the boreholes. Based on these results, more direct analyses of soil may or may not be needed. If needed, about 20 more soil samples will be taken from borehole cores with Th content in the range of 1 to 50 pCi/g and analyzed for $^{232}$Th. This should assist in providing an appropriate calibration factor relating $^{232}$Th content to gamma cpm, at concentrations of $^{232}$Th producing gamma exposure comparable to background exposure rates.

Three boreholes in non-FeCb slag and 6 boreholes in adjacent soils not contaminated by site operations will be logged using the NaI probe in order to establish the background count rate due to gamma exposure from naturally occurring radionuclides in native soils and in other fill material used on site. Core soil samples will be taken at 18 inch intervals from each of these 9 boreholes. The radioisotopic content of the samples from these background boreholes will be measured by radiochemical or gamma spectrometric analysis.

## 5.5 Analysis of Groundwater for Radioactivity

Twenty-one wells have been drilled from which groundwater samples can and have been taken. These wells consist of the 17 wells drilled in 1991 by Remcor, and the four existing monitor wells located along the west fenceline. (See section 4.6.2 for a more detailed description of these wells. Appendix G provides the driller's logs and the details of construction of the wells.)

The $^{232}Th$ contained in slag buried on site is believed to be in an insoluble form, unavailable for leaching. $^{228}Th$ is similarly unavailable but, if any $^{228}Ra$ is present, the $^{228}Th$ daughter should be detectable. Historical information from the site on gross alpha, Th and other radionuclides previously measured in well water will be reviewed. About 20 samples of water from wells W2 through W6 will be analyzed using highly sensitivity techniques for $^{232,230,228}Th$, $^{238,234}U$, and $^{226}Ra$ and $^{228}Ra$, with detection limits for the U and Th isotopes of about 0.02 pCi/sample, for 1 liter sample sizes.

## 5.6 Buildings and Equipment

### 5.6.1 Structures and Fixed Equipment

All structures that have historically been used for the FeCb plant process or as storage areas for FeCb slag and Cb ore will be mapped on a CAD program. A scintillometer survey, with a density of approximately 1 reading per 100 $ft^2$ floor space will be made of each building. For buildings with areas of elevated gamma readings, walls, floors, and surfaces of fixed machinery will be scanned with alpha survey meters and maps and diagrams will be made showing the extent of contamination. Swipes moistened with alcohol will be taken and measured for gross alpha to determine the amount of removable activity. A sufficient number of measurements will be made to decide whether individual building and equipment will require decontamination as per the standards in Reg. Guide 1.86. See Figure 5-3 for a map depicting potentially contaminated buildings.

### 5.6.2 Vehicles and Mobile Equipment

For mobile equipment that has been historically used in a manner that might lead to contamination, surfaces will be scanned with a large area probe such as a gas proportional counter. Alcohol swipes will be taken and measured for gross alpha to determine the amount of removable activity.

### 5.6.3 Measurement of Th Under Existing Structures.

Bore holes will be drilled to permit NaI measurement of gamma radiation underneath buildings for which historical usage patterns suggest a potential for Th contamination of soils. The drilling program will involve penetration through floors, slant drilling or other drilling methods that will be developed in consultation with a drilling contractor. The holes will be logged and profiles of the variation with depth of Th concentration will be graphed, using the procedures employed for all other boreholes drilled on-site. 20% of the holes drilled will be cored. Any of the cored holes exhibiting elevated activities will have the cores analyzed for Th.

## 5.7 Air Sampling

### 5.7.1 Air samples

Four air sampling locations will be established: one off-site and predominantly upwind of the affected areas, one off-site and downwind, one downwind at the site boundary, and one on-site near the impoundments. Each sampler will collect at least 30 $m^3$ of air per week (approximately 10,000 $ft^3$). The location on the downwind boundary will be adjacent to Chartier's Creek. The samples will be collected with generally accepted sampling equipment and procedures. This will permit the detection in air of 1% of the current 10CFR20 limits for Th in air.

### 5.7.2 Analysis

The filters from the air sampling program will be analyzed for Th isotopes by alpha spectrometry with a detection limit of 0.03 pCi/sample for $^{232}$Th .

### 5.7.3 Concentration of Thorium

Airborne Th originating from on-site sources can be distinguished from that originating off-site because any concentration of Th from the site will have a different $^{230}$Th/$^{232}$Th ratio than that from the natural local environment. See Figure 5-1, which shows that the $^{230}$Th/$^{232}$Th ratio from slag is 0.1 whereas in normal soils adjacent to the plant, this ratio is 1:1. Based on the 1985 ORAU report which measured U and Th series in soil samples by gamma spectrometry the average ratio of $^{232}$Th/$^{226}$Ra in 55 soil samples which exceeded a concentration of 10 pCi/g was 0.22. Therefore, any substantial additions of windblown Th isotopes from the site will be inferable from the Th isotope ratio measured in the air samples. The $^{232}$Th/$^{230}$Th ratio measured in background soils was close to one.

### 5.7.4 Background

The background concentration of airborne Th will be measured at the upwind sampling location. However there can be significant variation in the background levels depending primarily upon the amount of dust in the atmosphere and its origin. Soil derived aerosol should exhibit an airborne $^{232}Th/^{230}Th$ ratio of about 1, and any significant addition to background derived from the site can be inferred by examining the disturbance in this ratio from one. The mass of aerosol collected will be weighed.

### 5.7.5 Sampling Intervals

Weekly air samples will be collected, producing 104 samples over the first 6 months. After the first month however, samples may be composited for monthly averages. It is unlikely, however, that a year's worth of data will be available for inclusion in the SCR.

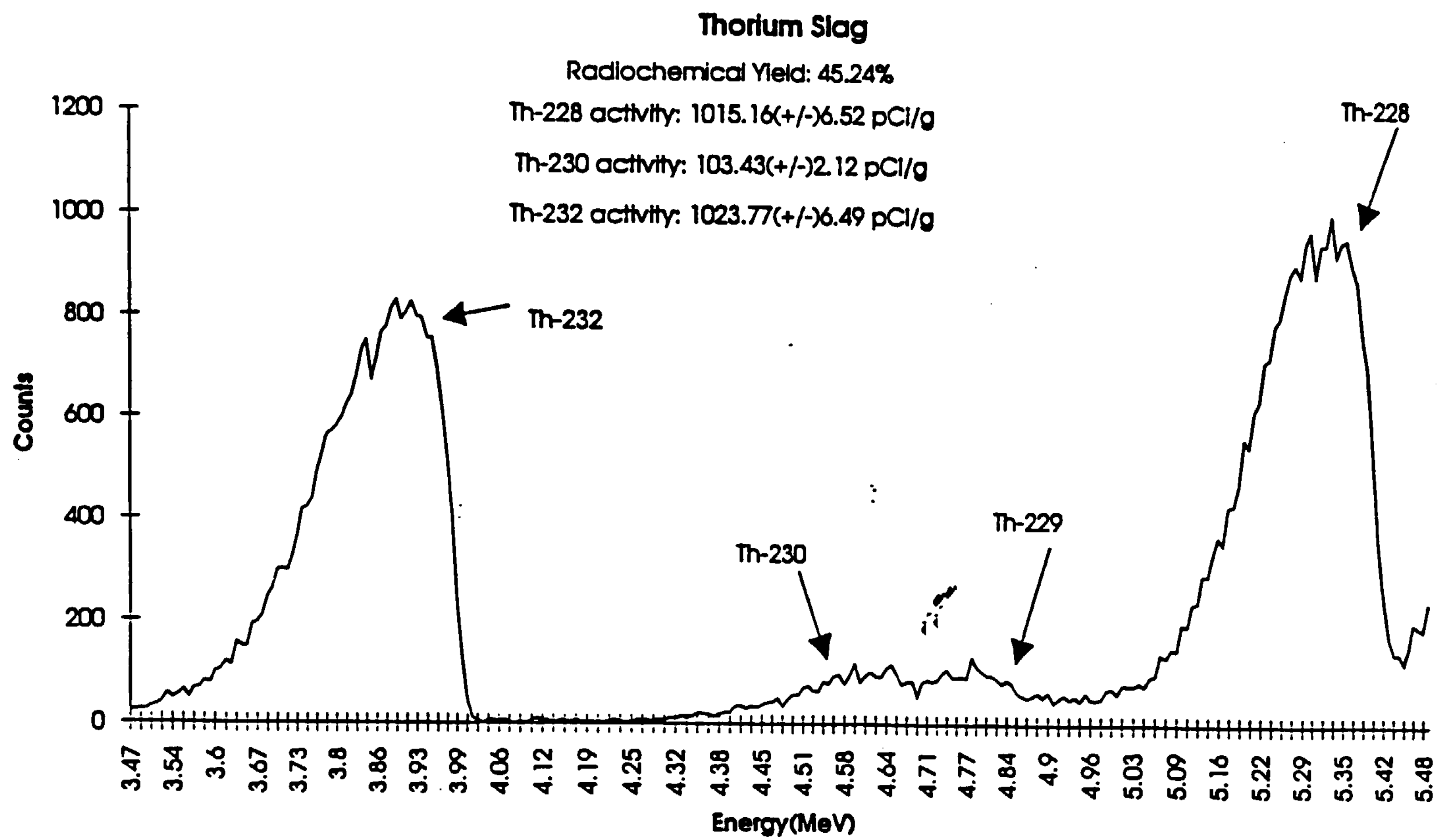


Figure 5-1

RSA, 11/5/92

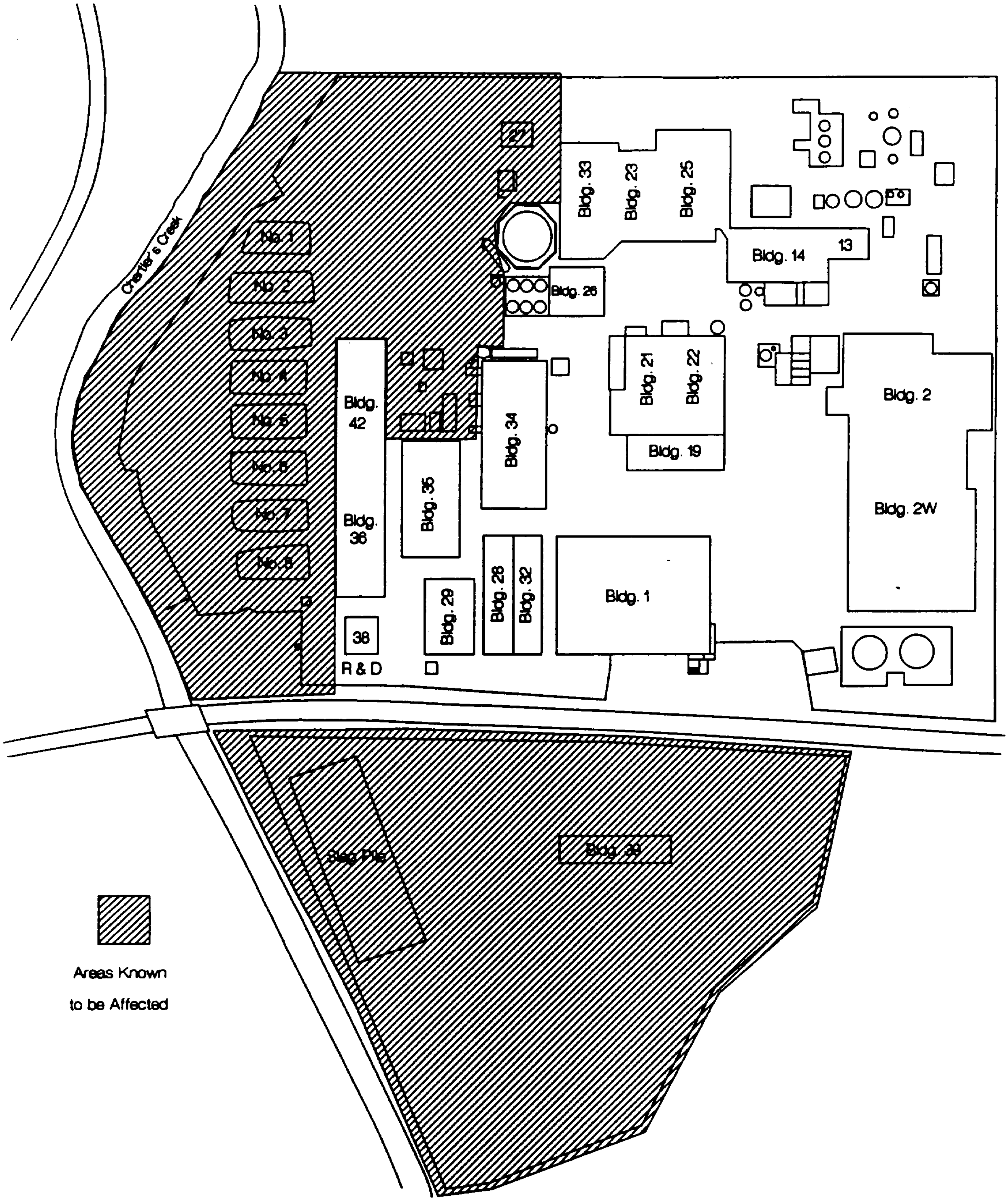


Figure 5-2: Areas at the Molycorp, Washington Pa Plant Site Currently Classified as Affected Areas

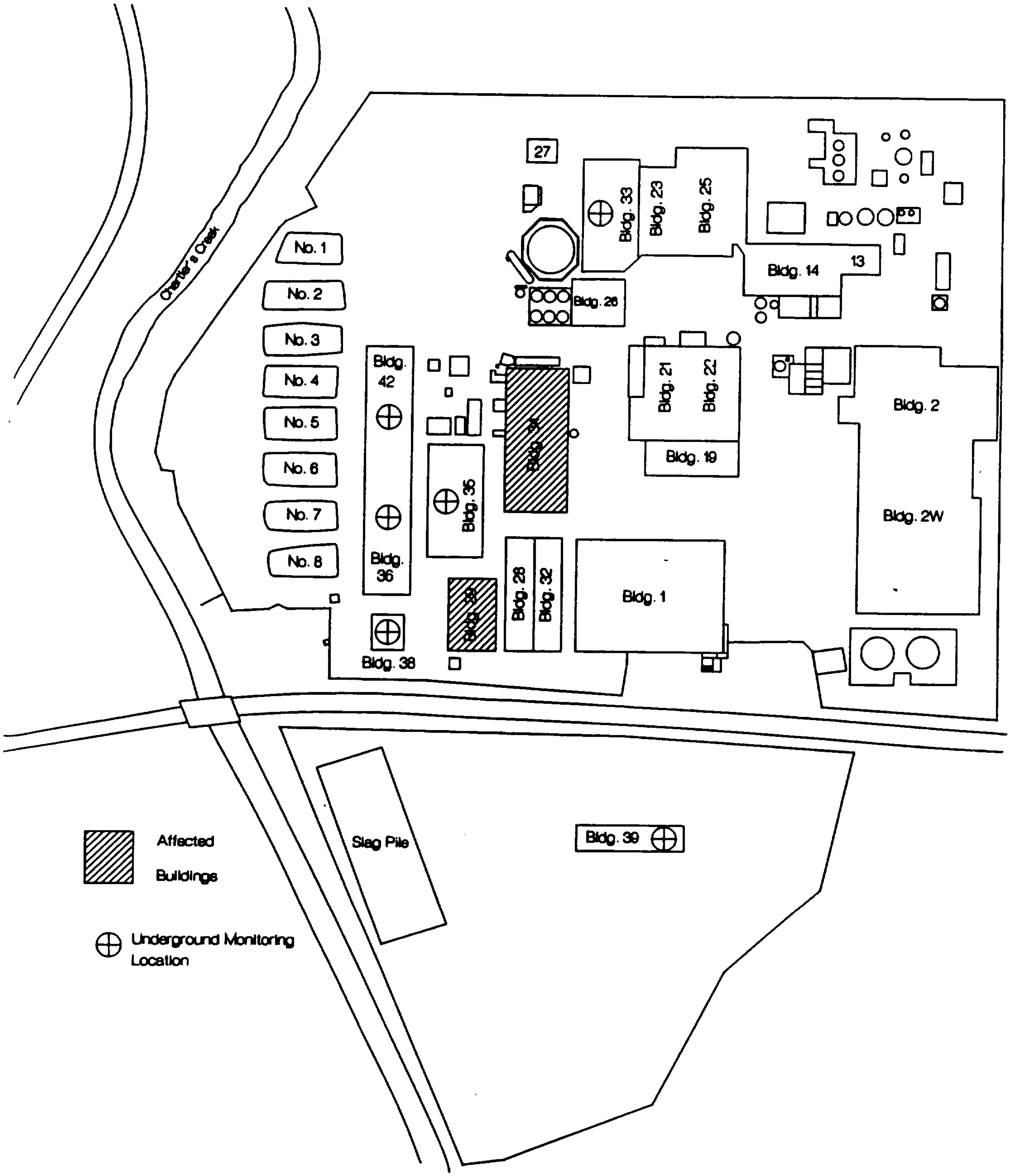


Figure 5-3: Buildings at Molycorp, Washington Pa Plant Site which, Due to Historic Usage Patterns, May Be Classified as "Affected Buildings"

# Appendix A: Capabilities of the RESRAD program

The objective of this text is: (a) to provide a brief explanation about the necessary program inputs in order to match with the available data and to provide information on the necessity of new data acquisition. (b) to describe the outputs in order to allow the evaluation of the impacts due to the several pathways (individually and summed) and to provide possible site-specific remedial actions.

**The RESRAD program deals with:**

1) Concentration in soil
2) Concentrations of airborne radon decay products
3) Levels of external gamma radiation
4) Levels of radioactivity from surface contamination
5) Concentrations of radionuclides in air and water

**Controlling Principles:**

1) Annual radiation dose received by a member of critical group (realistic but conservative, for 50 years, not exceeding 100 mrem/y)
2) Doses should follow the ALARA principle

**Pathway analysis:**

1) Source analysis: (source terms: the rate at which residual radioactivity is released into the environment)
2) Environmental Transport Analysis:(identify environmental pathways by which radionuclides can migrate from the source to a human exposure location and determining the rate of migration)
3) Dose/exposure analysis: (dose conversion factors)
4) Scenario analysis: addresses problems of determining the quantity of radionuclides or radiation to which an individual is exposed.

**Input data:**

The input data needed by RESRAD are accessible in a series of input forms, which are briefly described as follows:

1) TITLE, USED DATA FILES, AND CONTAMINATED ZONE PARAMETERS:

a) AREA OF CONTAMINATED ZONE ($m^2$): Contains the locations of all soil samples with radionuclide concentrations that are clearly above background (if they exceed the background by at least two standard deviations) and are separated from the locations of other above-background soil samples by a distance of at least 100 m.
b) THICKNESS OF CONTAMINATED ZONE (m): the distance between the uppermost and lowermost soil samples with radionuclide concentrations that are clearly above background.
c) LENGTH PARALLEL TO AQUIFER FLOW (m): the distance between two parallel lines perpendicular to the direction of aquifer flow, one at the upgradient edge of the contaminated zone and the other at the downgradient edge. d) BASIC RADIATION DOSE LIMIT (mrem/year): the annual radiation dose limit used to derive all site-specific soil guidelines.
e) TIMES FOR CALCULATIONS (years): the times following the radiological survey for which the single radionuclide soil guidelines and mixture sums will be calculated. (Guidelines require that the mixture sum be less than one at all times).

2) INITIAL CONCENTRATIONS OF PRINCIPAL RADIONUCLIDES:

These important definitions were directly extracted from the RESRAD manual, since they are helpful in guiding the acquisition of data which will be used in the program:

"A principal radionuclide is defined as a radionuclide with a half-life longer than one year. An associated radionuclide is a decay product with a half-life of one year or less. The radionuclides "associated" with a principal radionuclide consist of all decay products down to, but not including, the next principal radionuclide in the chain. It is assumed that all associated radionuclides are in secular equilibrium with their principal radionuclide in the contaminated zone and also at the location of human exposure."

"If the contaminated zone is treated as an inhomogeneous contaminated zone, then the contaminated zone may be divided into subzones within each of which the peak concentration does not exceed the average concentration by a factor larger than three. The mixture sums for these subzones are then calculated as if each subzone were an isolated, homogeneous contaminated zone. The total of the mixture sums for subzones within a $100\text{-m}^2$ area must be less than 1 for any $100\text{-m}^2$ area within the contaminated zone. The current version of RESRAD will calculate the mixture sum only for a single homogeneous zone or subzone. For an inhomogeneous contaminated zone, the subzone contributions must be summed separately according to the procedures described in the Section 3.3 of the manual".

All radionuclides for which guidelines can be derived are listed and the corresponding nonzero concentrations in pCi/g can be entered.

3) COVER AND CONTAMINATED ZONE HYDROLOGICAL DATA:

More comprehensive definitions about the following parameters are given in the Appendix E of the manual.

a) COVER DEPTH (m): the distance from ground surface to the location of the uppermost soil sample with radionuclide concentrations that are clearly above background.

b) DENSITY OF COVER MATERIAL ($g/cm^3$): the bulk density of dry soil.

c) COVER EROSION RATE (m/year): rate at which soil is removed by erosion

d) DENSITY OF CONTAMINATED ZONE ($g/cm^3$): same as b)

e) CONTAMINATED ZONE EROSION RATE (m/year): same as c)

f) CONTAMINATED ZONE TOTAL POROSITY: g) CONTAMINATED ZONE EFFECTIVE POROSITY:

h) CONTAMINATED ZONE HYDRAULIC CONDUCTIVITY (m/year):

i) CONTAMINATED ZONE b PARAMETER:

j) EVAPOTRANSPIRATION COEFFICIENT:

k) PRECIPITATION (m/year):

l) IRRIGATION (m/year):

m) IRRIGATION MODE (0 FOR OVERHEAD; 1 FOR DITCH):

n) RUNOFF COEFFICIENT:

o) WATERSHED AREA FOR NEARBY STREAM OR POND ($m^2$):

Default values for items b) to o) are provided in the program to allow preliminary estimates. Typical parameter values for various soil materials are presented in the Appendix E of the RESRAD manual.

4) SATURATED ZONE HYDROLOGICAL DATA:

Definitions about the following parameters are given in the Appendix E of the manual.

a)DENSITY OF SATURATED ZONE (g/cm$^3$):

b) SATURATED ZONE TOTAL POROSITY:

c) SATURATED ZONE EFFECTIVE POROSITY:

d) SATURATED ZONE HYDRAULIC CONDUCTIVITY (m/year):

e) SATURATED ZONE HYDRAULIC GRADIENT:

f) SATURATED ZONE b PARAMETER: (only if h) > 0)

g) DISTANCE FROM SURFACE TO WATER TABLE (m): = Cover Depth + Contaminated Zone Thickness + Thicknesses of the unsaturated zone strata below the contaminated zone.

h) WATER TABLE DROP RATE (m/year): rate that the depth of the water table decreases. If it is not zero, the unsaturated zone thickness will be created or increased.

i) WELL PUMP INTAKE DEPTH (m below water table):

j) NONDISPERSION OR MASS-BALANCE: selects which of the two models will be used for water/soil concentration ratio calculations

k) INDIVIDUAL'S USE GROUNDWATER (m$^3$/year):

Default values for all items are provided in the program to allow preliminary estimates. Typical parameter values for various soil materials and radionuclides are presented in the Appendix E of the RESRAD manual.

5) UNCONTAMINATED AND UNSATURATED ZONE HYDROLOGICAL DATA:

The uncontaminated and unsaturated zone is the portion of the uncontaminated zone that lies below the bottom of the contaminated zone and above the groundwater table. The program has provisions for up to five different horizontal strata within this zone. Each stratum is characterized by six radionuclide- independent parameters:

a) THICKNESS (m):

b) SOIL DENSITY (g/cm$^3$):

c) TOTAL POROSITY:

d) EFFECTIVE POROSITY:

e) SOIL-SPECIFIC b PARAMETER:

f) HYDRAULIC CONDUCTIVITY (m/year):

Default values for all items are provided in the program to allow preliminary estimates. Typical parameter values for various soil materials and radionuclides are presented in the Appendix E of the RESRAD manual.

6) DISTRIBUTION COEFFICIENTS ($cm^3/g$) AND LEACH RATES ($year^{-1}$):

If the radionuclide leach rates in the contaminated zone are known, these leach rates should be entered. If a leach rate is entered (>0), it will be used to calculate the leaching of radionuclides from the contaminated zone. If a leach rate is not entered (=0), the program will calculate the leach rate using the distribution coefficient for the contaminated zone. In addition to the on-site principal radionuclides, it allows parameters to be entered for decay product principal radionuclides. Default distribution coefficients are provided by the program for most radionuclides. The manual also remarks that these values should be used with care because site-specific distribution coefficients can vary over many orders of magnitude depending on the soil type, pH, redox potential and presence of other ions. Replacement with site-specific values is recommended.

Default values for all items are provided in the program to allow preliminary estimates. Typical parameter values for various soil materials and radionuclides are presented in the Appendix E of the RESRAD manual.

7) EXTERNAL GAMMA AND DUST INHALATION PARAMETERS:

a) INHALATION RATE ($m^3$/year): default=8400
b) MASS LOADING FOR INHALATION ($g/m^3$): default=0.0002
c) OCCUPANCY AND SHIELDING FACTOR (EXTERNAL GAMMA): default=0.6
d) OCCUPANCY FACTOR (INHALATION): default=0.45
e) SHAPE FACTOR (EXTERNAL GAMMA): default=1
f) HEIGHT OF MIXING FOR AIRBORNE DUST (INHALATION)(m): default=3

These values are not strongly site-dependent, in most circumstances the generic default values can be used.

8) INGESTION PATHWAY DATA, DIETARY PARAMETERS

a)FRUITS, VEGETABLES AND GRAIN CONSUMPTION (kg/year):default=160
b) LEAFY VEGETABLE CONSUMPTION (kg/year): default=14
c) MILK CONSUMPTION (l/year): default=92
d) MEAT AND POULTRY CONSUMPTION (kg/year): default=63
e) FISH CONSUMPTION (kg/year): default=5.4
f) OTHER AQUATIC FOOD CONSUMPTION (kg/year): default=0.9
g) DRINKING WATER INTAKE (l/year): default=410
h) FRACTION OF DRINKING WATER FROM SITE (0-1): default=1
i) FRACTION OF AQUATIC FOODS FROM SITE (0-1): default=0.5

The default parameter values have been chosen to correspond to national averages. The parameters, other than h) and i), are not strongly site dependent. The parameters h) and i) allow specification of the fraction of contaminated intake for these pathways.

9) INGESTION PATHWAY DATA, NONDIETARY PARAMETERS

a)LIVESTOCK FODDER INTAKE FOR MEAT (kg/day):default=68
b)LIVESTOCK FODDER INTAKE FOR MILK (kg/day):default=55
c)LIVESTOCK WATER INTAKE FOR MEAT (l/day):default=50
d)LIVESTOCK WATER INTAKE FOR MILK (l/day):default=160
e) MASS LOADING FOR FOLIAR DEPOSITION ($g/m^3$): default=0.0001
f) DEPTH OF SOIL MIXING LAYER (m): default=0.15
g) DEPTH OF ROOTS (m): default=0.9

GROUNDWATER FRACTIONAL USAGE (BALANCE FROM SURFACE WATER)
h) DRINKING WATER (0-1): default=1
i) LIVESTOCK WATER (0-1): default=1
j) IRRIGATION (0-1): default=1

The default parameter values have been chosen to correspond to national averages. The parameters, other than h), i) and j), are not strongly site dependent. The final three parameters are included to allow groundwater (well) and surface water (pond) scenarios. Hence, the fractions will usually be set at 1 or 0. For livestock water and irrigation all usage is assumed to be from the site. The fraction of contaminated drinking water (from the site) can be varied via the parameter h) of item 8) INGESTION PATHWAY DATA, DIETARY PARAMETERS.

**Control of RESRAD Pathways:**

RESRAD always computes the radiation dose resulting from seven potential pathways:
1) Direct exposure to external radiation from contaminated soil material.
2) Internal radiation from inhalation.
3) Internal radiation from ingestion of plant foods grown on-site and irrigated with water drawn from an on-site well or pond.
4)Internal radiation from ingestion of meat from livestock fed with fodder grown on-site and water drawn from an on-site well or pond.
5)Internal radiation from ingestion of milk from livestock fed with fodder grown on-site and water drawn from an on-site well or pond.
6) Internal radiation from ingestion of aquatic foods from an on- site pond.
7)Internal radiation from drinking water from an on-site well or pond.

Since in many situations certain of these pathways are not important, the program allows the user to suppress one or more pathways.

**RESRAD Outputs:**

A summary report (SUMMARY.REP) and a detailed report (DETAILED.REP) are generated. Total dose and the total mixture sum for the various selected times are estimated. The total mixture sum is the estimated effective dose equivalent, expressed as a multiple of the basic dose limit, that a member of the critical population group might receive at time t following the radiological survey as a consequence of the residual radioactivity. A site may be certified in compliance with guidelines only if the mixture sum does not exceed the value of one at any time within the time horizon.

Total dose components for all individual pathways at different times are also presented as actual dose (mrem/y) and percent contribution to the total.

The summary report also presents results for:

- Total dose/source (mrem/yr)/(pCi/g) summed over all pathways for radionuclide i and time t.
- Single-radionuclide soil guidelines (pCi/g) for radionuclide i and time t.
- The results above for values of t which equals the minimum soil guidelines and values of t for the maximum total dose.

The single-radionuclide soil guidelines are the concentration guidelines that would apply if only one radionuclide were present. A single-radionuclide soil guideline is the magnitude of the initial concentration of the $i^{th}$ principal radionuclide that would result in a potential radiation dose equal to the basic radiation limit to a member of the critical population group at time t.

The detailed report allows to verify the code and can be useful for gaining insight into the transport mechanisms by enabling a more detailed investigation of the effect of parameter changes on pathway factors, environmental transport factors, and dose/source ratios for different pathways.

**Appendix B: Current and Proposed Concentration Limits for Insoluble Th in Air (General Public)**

| ISOTOPE | NEW PART 20 (Effective 1/1/94, µCi/ml) | CURRENT PART 20 (µCi/ml) | CURRENT/NEW |
|---|---|---|---|
| Nat Th | N/A | $2 \times 10^{-12}$ | --- |
| $^{232}Th$ | $6 \times 10^{-15}$ | $1 \times 10^{-12}$ | 166 |
| $^{228}Th$ | $2 \times 10^{-14}$ | $2 \times 10^{-13}$ | 10 |
| $^{230}Th$ | $3 \times 10^{-14}$ | $3 \times 10^{-13}$ | 10 |

| ISOTOPE | NEW PART 20 (Effective 1/1/94, $pCi/m^3$) | CURRENT PART 20 ($pCi/m^3$) |
|---|---|---|
| Nat Th | N/A | 2 |
| $^{232}Th$ | 0.006 | 1 |
| $^{228}Th$ | 0.02 | 0.2 |
| $^{230}Th$ | 0.03 | 0.3 |

NOTES:

NEW PART 20: PART VI

Nuclear Regulatory Commission
10 CFR Part 20 et al.
Standards for Protection Against Radiation; Final Rule
Tuesday May 21, 1991.

EXTRACTED FROM: Appendix B to par. 20.1001-20.2401 - Annual Limits on Intake (ALIs) and Derived Air Concentrations (DACs) of Radionuclides for Occupational Exposure; Effluent Concentrations; Concentrations for Release to Sewerage.

CURRENT PART 20: UNITED STATES NUCLEAR REGULATORY COMMISSION
RULES AND REGULATIONS
TITLE 10, CHAPTER 1, CODE OF FEDERAL REGULATIONS- ENERGY
PART20 STANDARDS FOR PROTECTION AGAINST RADIATION

EXTRACTED FROM: Appendix B - Concentrations in Air and Water Above Background

## Appendix C: Radiochemical Techniques

Dissolution of Slag:

A known amount of slag (200-300 mg) ground to a small particle size to facilitate dissolution is transferred into a Teflon beaker. Known amounts of $^{229}Th$ and $^{232}U$ isotopic tracers are added to the sample directly into the Teflon beakers. Approximately 15-20 ml of concentrated $HNO_3$ and 5 ml of HF are added to the Teflon beaker containing the slag. The beaker is heated strongly. The process is repeated several times until there is no insoluble material left. The solution is evaporated to dryness, and the residue is redissolved in concentrated $HNO_3$. The process is repeated two to three times to remove the traces of HF.

Radiochemical Determination of Uranium and Thorium Isotopes:

Uranium and thorium isotopes are determined in the slag samples by radiochemical procedures developed by Singh et al as described below:

a) Co-precipitation of Uranium and Thorium:

Uranium and thorium are co-precipitated with the iron present in the slag sample by adding ammonium hydroxide to the solution obtained after the dissolution of the slag. The pH is adjusted to 10 and the solution is boiled for about 15 minutes. The precipitate is centrifuged, washed several times and dissolved in 10M HCl. The molarity of the solution is adjusted to 10M.

b) Solvent Extraction:

Uranium, present in the slag, is extracted into 20% tri-lauryl amine (TLA) solution in xylene pre-equilibrated with 10M HCl, leaving thorium in the aqueous solution. The organic phase (TLA phase) is washed two times with 10M HCl (by shaking the organic phase with equal volume of 10M HCl) and the washings are discarded. Finally, uranium present in the organic phase is back extracted with 0.1M HCl (by shaking the organic phase with equal volume of 0.1M HCl).

The aqueous phase containing thorium is evaporated to dryness, redissolved in $4MHNO_3$ and the molarity adjusted to 4M. Thorium is extracted into 20% TLA solution in xylene pre-equilibrated with 4M $HNO_3$. The organic phase is washed twice with equal volume of 4M $HNO_3$ and the washings are discarded. Thorium is finally back extracted from the TLA phase by shaking with equal volume of 10M HCl.

c) Electrodeposition of Uranium and Thorium:

Uranium and thorium back extracted separately into 0.1M HCl and 10M HCl, respectively are evaporated to dryness, with addition of a few drops of $HNO_3$ and $H_2O_2$ to decompose the organic materials entrained with the acid. Sodium bisulphate solution in 2M $H_2SO_4$ (5ml) is added to each of the solution and heated strongly with occasional additions of $HNO_3$ and $H_2O_2$. The solution is evaporated to dryness and the residue is dissolved in 5 ml of 1M $(NH_4)_2$ $SO_4$ solution in water. The solution is transferred into the plating solutions and the pH is adjusted to ~2 by using thyomol blue as an indicator. Uranium and thorium are electrodeposited separately onto the polished stainless steel or platinum disc by passing a constant current of 1.2 amperes for one hour.

Alpha-spectrometry:

The radiochemical yields of uranium and thorium tracer and their isotopic compositions in the sample, are determined by counting the discs in an alpha-spectrometer with a surface barrier silicon diode of 450 $mm^2$ active area, 100 micron sensitive thickness, and 30 KeV FWHM resolution, and a multichannel analyzer. The counter efficiencies are determined by counting a standard source electrodeposited on a platinum disc containing three isotopes of Pu (Pu-238, 239 and 242) and the backgrounds are determined by counting a blank disc.

Determination of Radium-226:

Radium-226 in solution is determined by de-emanating its $^{222}Rn$ progeny into an ionization chamber or scintillation cell for measurement. The $^{222}Rn$ can be de emanated by bubbling an inert gas through the solution either after equilibrium has been established or after any known time period. Two half-lives, 7.65 days, for example, give 75% of the maximum buildup. The chambers are standardized by de emanating aliquots of standard reference $^{226}Ra$ solution.

Bioassay Procedures for Uranium, Thorium and Radium:

a) Sample Collection:

Urine and fecal samples have been utilized to determine the daily excretions of radionuclides in order to be able to estimate the total body burden and/or current exposures to these radionuclides.

Urine samples are collected from individuals for a period of 24 hours. The subjects are provided with a 2 liter polyethylene bottle, a pair of gloves and a marking pen. The subjects are asked to wash their hands before collecting the samples. They should discard the first voiding of the early morning and thereafter, start collecting the urine samples in the polyethylene bottle provided to them. They should directly urinate in the same bottle the entire day and evening and also collect the first voiding of the next morning. The urine samples should either be stored in a refrigerator or transferred to the laboratory where 5% hydrochloric should be added immediately to preserve the samples.

Fecal samples are directly collected in a plastic bag which is kept attached to the commode of the bathroom. The tissue wipes should not be collected because the risk of losing the sample is much less as compared to the risk of contaminating the samples.

Techniques for measuring Uranium, Thorium and Radium in Urine and Feces:

Uranium and thorium in urine samples can be determined by the radiochemical procedure developed by Singh et al using alpha spectrometric techniques. The urine samples, spiked with $^{232}U$ and $^{229}Th$ tracer are wet ashed with $HNO_3$ with occasional additions of a few drops of $HNO_3$ and $H_2O_2$. Uranium and thorium are co precipitated with iron as hydroxide or with calcium as oxalate. Uranium and thorium are separated from the bulk of inorganic materials present in the sample and from each other by solvent extraction techniques described earlier. They are electrodeposited on a stainless steel or platinum disc. The samples are counted by alpha-spectrometry.

Other techniques are also available for the measurements of uranium and thorium in bioassay samples. Uranium may be determined by time-resolved laser-induced fluorescence. However, the technique does not give the isotopic composition of uranium. Similarly, thorium can be determined by neutron activation analysis and ICP techniques. However, these techniques are not capable of determining the isotopic composition of thorium.

Radium in bioassay samples can be determined by de-emenating its $^{222}$Rn progeny as described earlier, once the samples are wet ashed and dissolved in appropriate acid and separated from the bulk of materials present in the samples.

Radiochemical Determinations of Ra-226 and Ra-228 in Water:

After sample preparation, $^{226}$Ra is isolated from most other elements by co-precipitation with Barium Sulfate using $^{133}$Ba as carrier. The sulphate precipitate is dissolved in alkaline EDTA to prepare the emanating solution. The chemical yield of barium is determined by measuring the $\gamma$ energy of $^{133}$Ba. Radium is measured by de-emanating its $^{222}$Rn progeny into an ionization chamber or scintillation cell. The $^{222}$Rn can be de-emanated by bubbling an inert gas through the solution either after equilibrium has been established or after any known time period.

Radium-228 is a b emitter. The determination of Ra-228 in the presence of alpha emitting nuclides is difficult because of its weekly energetic b emission. However, Radium-228 decays into 6.13 hour actinium-228, and the procedure for Radium-228 analysis involves the separation and counting of actinium-228.

After preparing the solution, the solution is aged for at least 36 hours for actinium-228 ingrowth. Actinium is extracted into EHPA and extracted with 1.5M HBr. Lead and bismuth are extracted into aliquot 336 leaving actinium in the aqueous phase. Actinium is transferred onto the stainless planchette, dried, baked and counted.

Radium-228 may be determined by another procedure also. Thorium-228 present in the sample is quantitatively removed by extracting Th-228 in the TLA solution. The aqueous phase containing Ra-228 is stored for the ingrowth of Th-228, which may be then determined by the procedure given for thorium.

QA/QC Program:

The management of the RSA is fully committed to the maintenance of an effective quality control/assurance program in order that all work carried out by RSA will be of high quality. An important aspect of the RSA quality control/assurance program is the written documentation of quality assurance and quality control procedures that are used in the performance of projects. The most important requirement for the success of the quality control/assurance program is the commitment in the laboratory that our goal is to always perform high quality work.

Quality assurance involves all those planned and systemic actions necessary to provide adequate confidence that a facility, structure, system, or component will perform satisfactorily and safely in service.

Quality control, which is included within quality assurance, comprises all those actions necessary to control and verify the features and characteristics of a material process products; or service to specified requirements.

For every batch of ten samples, we run one reagent blank (for low level samples), one spiked sample (prepared by a person other than the analyst), and the reference materials obtained from NIST or EPA, for the determinations of isotopic uranium, thorium and radium. Peruvian soil (SRM 4355) obtained from NIST is used as a reference material for uranium and thorium and a standard source of $^{226}Ra$ obtained from EPA is used as the standard for radium determinations.

The alpha-spectrometers are calibrated with a standard source containing 3 alpha emitting isotopes with different energies electrodeposited onto a platinum disc, and energy calibration regularly. Backgrounds of the counters are determined by counting a blank disc over a period of 2 days. A record is maintained for the efficiency and the background for each detector.

References:


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The Radiochemistry of Radium, National Academy of Sciences, National Research Council, H. W. Kirby and Murrel L. Salutsky. Determination of Ra-228, Procedure 20, Page. 150.

Petrow, H. G.; Cover, Arthur; Schiessle, W. and Parsons, Elizabeth. Radiochemical Determination of Ra-228 and Th-228 in Biological and Mineral Samples. Anal. Chem. 36, 1600-1604 (1964).

Wrenn, M. E., Singh, N.P., Ibrahim, S.A., Cohen, N., $^{229}$Th as an isotopic tracer for the radiochemical determination of thorium isotopes in biological samples, Anal. Chem. 50:1712 (1978)

## Appendix D: QA/QC Program

During site characterization, Molycorp will develop and implement a QA/QC program based on the recommendations in section 4.1.1 of NUREG/CR-5849. As recommended in that document, the QA/QC program will draw upon the standard ANSI/ASME NQA-1, Quality Assurance Program Requirements for Nuclear Facilities (ANSI 1989), and Regulatory Guide 4.15, Quality Assurance for Radiological Monitoring Program -- Effluent Streams and the Environment (NRC, 1979).

For the purposes of the SCP, we are presenting the following outline of the central features of the QA/QC plan. The QA/QC plan is presented here in outline form because we recognize that any functional program will be the result of a process of evolution. During the course of the site characterization study, Molycorp will develop its complete QA/QC program for the purpose of documenting it's radiological surveys to be presented in support of license termination. The system will be implemented prior to the submission of the decommissioning plan, and the complete QA/QC plan will be included as part of the decommissioning plan.

<u>Outline of QA/QC Plan</u>

1. <u>Review of the existing QA/QC procedures and the engineering specification system currently in place at the facility</u>. To the extent

consistent with NRC recommendations, existing procedures will be incorporated into the QA/QC plan.

2. QA Co-ordination. Functional and administrative responsibilities will be clearly delineated in the plan. An organizational chart will be prepared and job descriptions written in order to clarify the responsibilities of key individuals. The job descriptions will include education and experience requirements for key individuals, and records will be maintained documenting the education and experience of individuals performing these functions. One individual, reporting directly to the project manager, will be appointed QA co-ordinator. Ideally, the quality co-ordinator would not be directly involved in the collection and analysis of data. However, given the small number of individuals and the multiple responsibilities assumed by key personnel in this project, complete separation of QA co-ordination from survey responsibilities may not prove practical.

3. Documentation. Written procedures will be developed for all sampling and data collection activities performed on-site. The QA co-ordinator will approve all procedures prior to the implementation. The QA co-ordinator will number, file, and maintain all written procedures as part of the permanent record of the decommissioning activity. A formal system for changing procedures will be included as part of the documentation system, and records of all changes, including the date of implementation, will be maintained. A work order will be prepared for each significant activity performed as part of the characterization or decommissioning of the site. The work order will detail the purpose and scope of the activity,

the number of the written procedure to be followed, the date(s) on which the work is done, any deviation from the written procedure, and the names of the person(s) performing the job. The work orders will be filed as a record of the activity on-site.

Independent contractors working onsite will be required to maintain written procedures for the functions they perform. These procedures may either be incorporated into the in-plant documentation system, or they may be maintained separately by the contractor, as circumstances dictate. Outside laboratories contracted to analyze samples and/or provide analysis and interpretation of data will also be required to keep a formal system of written procedures.

Whenever practical or required, consensus or industry standard procedures will be followed.

4. Training/Certification of Survey Staff. Each written procedure will include a list of persons who are qualified to perform the procedure. The process of becoming qualified for a particular procedure will depend on the nature and complexity of the task. The QA coordinator will be responsible for maintaining the lists of qualified personnel and for determining the level of training and testing needed for certification.

5. Equipment Maintenance and Calibration. The written procedures maintained by the QA co-ordinator will include procedures for maintaining and calibrating equipment and instrumentation, as appropriate. Contractors engaged to perform decommissioning activities

on site, and independent laboratories engaged to analyze samples, will be required to certify the maintenance and calibration of their own equipment.

6. Data Management. The guidance on QA/QC plans in NUREG/CR-5849 recommends that "A consistent method of data generation, handling, computations, evaluation, and reporting should be developed." The guide suggests that this system should include a formal system of data review and validation including daily or weekly reviews, under the supervision of project managers and QA officials. Given that the scope and size of the project to decommission and delicense the Molycorp facility is limited in comparison to that of many nuclear facilities (for instance, a nuclear power plant), an overly formal system of data validation may prove impracticable. In most cases, the task of collecting, analyzing, and reporting results for any given aspect of characterization and decommissioning will all fall to a single individual, or to a team consisting of at most two or three people. In such an organizational structure, it will probably prove most efficacious to assign the task of data management, review, and validation to the individual or team responsible for the data generating activity, rather than to create a cumbersome, centralized system. However, each individual or team will be required to maintain a consistent methodology and to document and preserve records of data generation and analysis. In addition, copies of field data, reports, computer files, and computations will be maintained in a central data repository by the QA co-ordinator.

7. <u>Sample Chain-of-Custody</u>. A standardized sample chain of custody form and a written procedure governing the transport and storage of samples will be prepared in order to ensure that there is an accurate record of sample collection, transport, analysis, and disposal. The chain of custody form will assign responsibility to one individual at a time. The person collecting the sample will initiate the chain of custody form. Custody will then be transferred to the QA co-ordinator, who will be responsible for maintaining records, distributing samples for analysis, tracking samples, insuring proper disposal or storage, a receiving and keeping records of analytical results and raw data.

8. The QA coordinator will be responsible for performing periodic audits. The audits will be performed according to formal written procedures. The QA coordinator will submit audit reports, including deficiencies uncovered as part of the audit and actions taken to resolve deficiencies, to the project manager and copies will be maintained as part of the permanent record of the characterization and decommissioning of the site.

## Appendix E: Vail Engineering Drawings MCWA-1 and MCWA-2

Vail Engineering Drawings MCWA-1: Well Locations and Water Level Contours

Vail Engineering Drawings MCWA-2: Cross Section Shallow Water Aquifer

Fiquer 1 & 2

## Appendix F: Legal Land Description of Site

COMMONWEALTH OF PENNSYLVANIA
DEPARTMENT OF ENVIRONMENTAL RESOURCES
BUREAU OF SOLID WASTE MANAGEMENT
DIVISION OF HAZARDOUS WASTE MANAGEMENT

APPLICATION NO. (Department Use Only)

# CONTRACTUAL CONSENT OF LANDOWNER

(I)(We), the undersigned, hereinafter sometimes referred to as "landowner", being the owner(s) of 16.5 acres of land located in Canton Township (TOWNSHIP, BOROUGH, OR CITY), Washington County, Pennsylvania, as described in the deed(s) recorded in the Recorder of Deeds Office at Deed Book(s) and page(s) (See attached page) and shown by crosshatched lines on the map attached hereto which is signed in the original by the landowner upon which Molycorp, Inc. (HAZARDOUS WASTE MANAGEMENT FACILITY OPERATOR) proposes to engage in hazardous waste storage, treatment or disposal activities for which application for permit will be made to the Department of Environmental Resources under the Pennsylvania Solid Waste Management Act, Act of July 7, 1980 P.L.380,35 P.S.§6018.10 *et seq.*, and of which application this consent will be made a part, DO HEREBY ACKNOWLEDGE THAT THE HAZARDOUS WASTE MANAGEMENT FACILITY OPERATOR AND HIS PERSONNEL HAVE THE RIGHT TO ENTER UPON AND USE THE LAND FOR THE PURPOSES OF CONDUCTING HAZARDOUS WASTE MANAGEMENT ACTIVITIES. Furthermore, (I)(We), the undersigned, do hereby irrevocably grant to the hazardous waste management facility operator and to the Commonwealth of Pennsylvania or any of its authorized agents, or employees, the right to enter upon the aforesaid land before the beginning of the hazardous waste management activities, during the hazardous waste management activities and for a period of 20 years after final closure of the facility, for the purposes of inspection and for the purpose of conducting such pollution abatement or pollution prevention activities required under the Act, the regulations promulgated thereunder and the terms of the permit as the Department deems necessary. (I)(We) do hereby grant in addition to the Commonwealth, for the aforesaid period of time, a right of entry across any adjoining or contiguous lands owned by (us)(me) in order to have access to the land described herein. It is specifically agreed and understood that this contractual consent gives the Commonwealth the right to enter, inspect the premises, and abate or prevent pollution as a matter within the police power but does not obligate the Commonwealth to do so, does not constitute any ownership interest by the Commonwealth in the aforesaid land, and does not affect or limit any rights available to the Commonwealth under applicable law.

THE LANDOWNER agrees (AGREES OR DOES NOT AGREE) TO ALLOW THE ABOVE-NAMED HAZARDOUS WASTE MANAGEMENT FACILITY OPERATOR TO TRANSFER OR ASSIGN, BY WRITTEN AGREEMENT, THIS CONTRACTUAL CONSENT TO ANOTHER HAZARDOUS WASTE MANAGEMENT FACILITY OPERATOR.

This Consent shall terminate and become null and void if the hazardous waste management facility operator does not apply to the Department of Environmental Resources for a permit to conduct hazardous waste management activities on the aforesaid land within 2 year(s) from the date of this Consent. Nothing in this Consent shall preclude or limit the landowner's authority to terminate the right or privilege of the hazardous waste management facility operator to conduct hazardous waste management activities on the aforesaid land.

This Contractual Consent shall be deemed to be a recordable document. Prior to the initiation of hazardous waste management facility operations under the permit, this Consent shall be recorded by Molycorp, Inc. (LANDOWNER OR HAZARDOUS WASTE MANAGEMENT FACILITY OPERATOR) and entered into the deed book (d.b.v.) index at the office of the recorder of deeds in the county(ies) in which the hazardous waste management facility is to be located.

In witness whereof and intending to legally bind (myself) (ourselves), (my) (our) heirs, successors and assigns, (I) (we) have hereunto set (my) (our) hand(s) and seal this 3 day of May, 19 84.

(SEAL)

Molycorp, Inc.
LANDOWNER (Print Name)

By: [signature]
Signature

W. N. Warhol
(Print Name)

By: [signature]
Signature Raymond Hawryluk

(Print Name)

RECORDED
JUN - 1 1984 1:13 P.M.
OLGA O. WOODWARD
RECORDER
WASHINGTON CO., PA.

## ACKNOWLEDGEMENT OF INDIVIDUALS OR PARTNERS

STATE OF :

: SS

COUNTY OF :

On ______________ (DATE), before me, the undersigned Notary, personally appeared ______________ (NAME(S)) known to me (or satisfactorily proven) to be the person whose name is subscribed to this instrument, and who acknowledged that ______________ (HE, SHE OR THEY) executed the same and desires it to be recorded.

IN WITNESS WHEREOF, I have hereunto set my hand and official seal.

(SEAL) ______________ NOTARY PUBLIC

My Commission Expires: ______________ (DATE)

## ACKNOWLEDGEMENT OF CORPORATIONS

STATE OF CALIFORNIA :

: SS

COUNTY OF LOS ANGELES :

On May 8, 1984 (DATE), before me, the undersigned Notary, personally appeared W. N. Warhol Raymond Hewold (NAME(S)) who acknowledged (herself) (himself) to be the Vice President, Manufacturing (TITLE OF PERSON) of Molycorp, Inc. (NAME OF CORPORATION), a corporation, and that s(he), as such officer, being authorized to do so, executed the foregoing instrument on behalf of the said corporation and desires that this instrument be recorded.

IN WITNESS WHEREOF, I have hereunder set my hand and official seal.

(SEAL) [signature] NOTARY PUBLIC

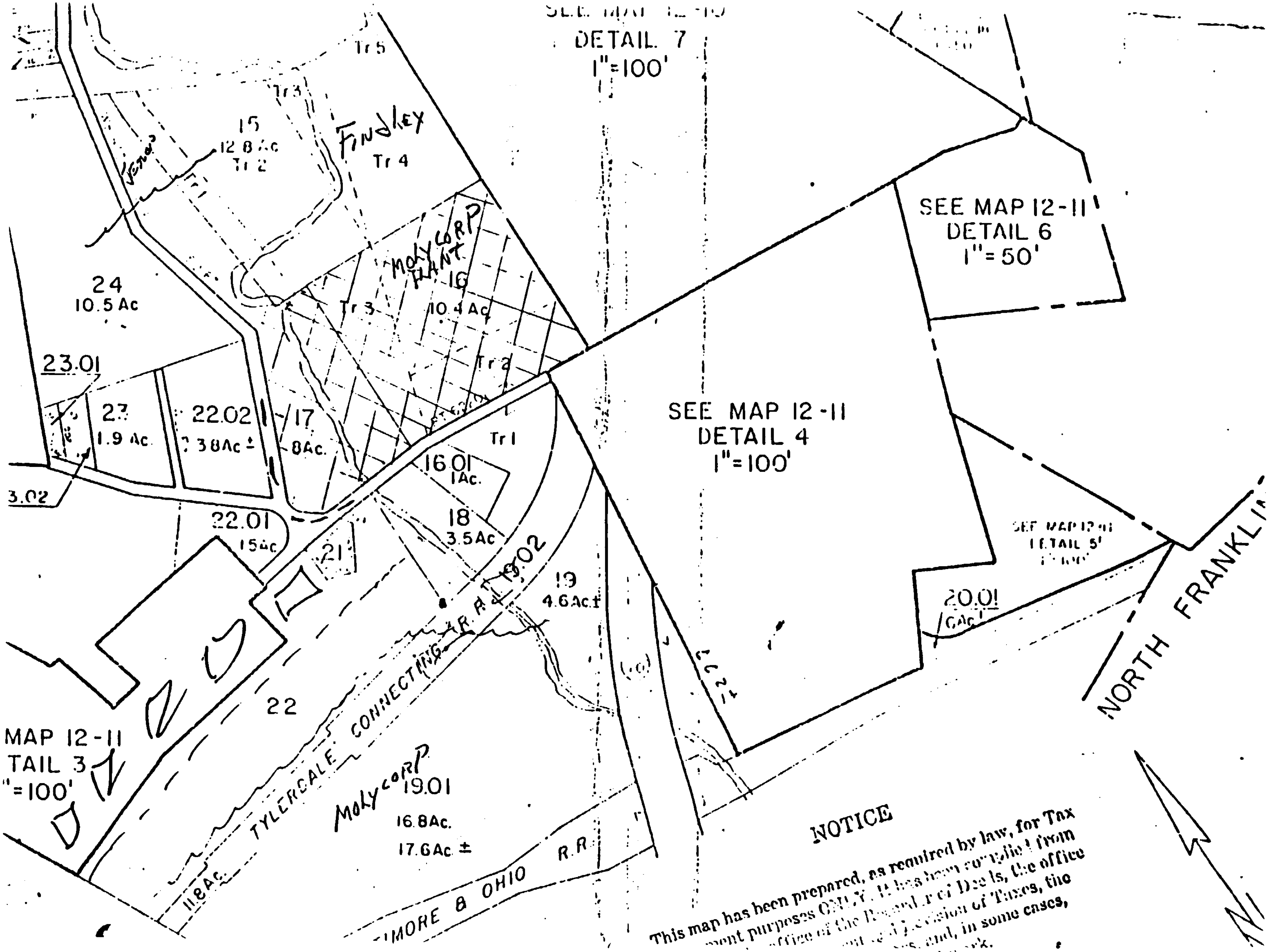
My Commission Expires: Oct. 26, 1984

OFFICIAL SEAL
HYLAJEAN BARNETT
NOTARY PUBLIC-CALIFORNIA
PRINCIPAL OFFICE IN
LOS ANGELES COUNTY
My Commission Expires October 26, 1984

This instrument has been recorded in ______________ County, Pennsylvania, this ______ day of ______________, ______, at Book ______________, Page(s) ______________.

______________ (SIGNED - (PRINT NAME))

______________ (SEALED)


DETAIL 7
1"=100'
Tr 5
Tr 3
15
12.8 Ac
Tr 2
Findley
Tr 4
SEE MAP 12-11
DETAIL 6
1"=50'
24
10.5 Ac
Molycorp
Tr 3
16
10.4 Ac
Tr 2
23.01
23
1.9 Ac.
22.02
3.8Ac ±
17
8Ac.
Tr 1
16.01
1Ac.
SEE MAP 12-11
DETAIL 4
1"=100'
3.02
22.01
1.5Ac
18
3.5Ac
21
19.02
19
4.6Ac±
20.01
NORTH FRANKLIN
22
MAP 12-11
TAIL 3
"=100'
TYLERDALE CONNECTING R.R.
Molycorp
19.01
16.8Ac.
17.6Ac ±
11.8Ac.
MORE & OHIO R.R.
NOTICE
This map has been prepared, as required by law, for Tax
N

Re: Sources of title to real estate in Washington County, Penna.

✓ Deed Book 637 page 496 - Gordon Land Company to Molybdenum Corporation of America - 2.2917 acres
#2
Dated July 8, 1940
Acknowledged July 12, 1940
Recorded July 15, 1940

✓ Deed Book 707 page 603 - Manor Real Estate and Trust Company to Molybdenum Corporation of America - 2.313 ac.
#3
Dated April 30, 1946
Acknowledged April 30, 1946
Recorded May 15, 1946

✓ Deed Book 1036 page 462- Manor Real Estate Company to Molybdenum Corporation of America - 6.076 acres
#X
Dated December 12, 1958
Acknowledged December 16, 1958
Recorded January 6, 1959

✓ Deed Book 483 page 270 - Electric Reduction Company to Molybdenum Corporation of America - 5.34 acres
#4
Dated June 16, 1920
Acknowledged June 16, 1920
Recorded August 25, 1920

✓ Deed Book 1330 page 1056-Findlay Refractories Company to Molybdenum Corporation of America (Quitclaim Deed)
Dated October 29, 1970 .482 acres
Acknowledged October 29, 1970
Recorded January 12, 1971

*Pennsylvania*
*Washington Co.* } S. S.

*Recorded in the office for Recording Deeds & c in and for said county in* Deed *Book* 2153 *Page* 97
*Given under my hand and seal of the said office this* 1st *day of* June *A.D.* 1984

Olga O. Woodward *Recorder*

I (we) hereby certify that I(we) have the authority to respond to the above questions on behalf of the applicant, and that the information provided herein is true and correct to the best of my(our)knowledge, information and belief.

W. K. Warhol
(Signature)

Name: Warren K. Warhol

Title: Vice President Manufacturing

Social Security No.: 476-26-1091

Sworn to and subscribed before me this 8th day of May 1984.

Hylajean Barnett
Notary Public

OFFICIAL SEAL
HYLAJEAN BARNETT
NOTARY PUBLIC-CALIFORNIA
PRINCIPAL OFFICE IN
LOS ANGELES COUNTY
My Commission Expires October 26, 1984

(Signature)

Name: Raymond Hamrght

Title: General Manager

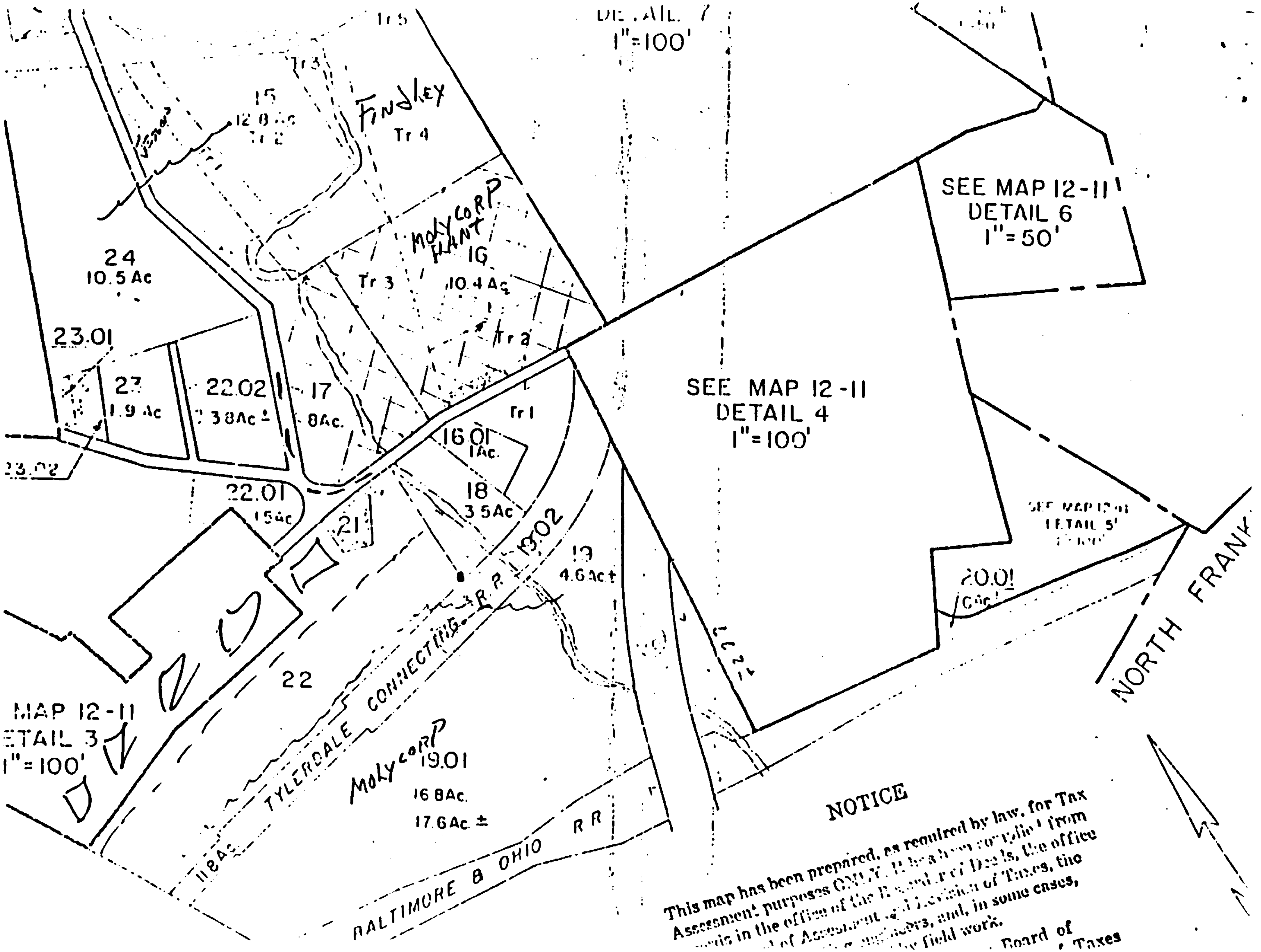
Social Security No.: 142-30-0563

Sworn to and subscribed before me this ______ day of ______, 19__.

Notary Public

Affix Corporate Seal:

(For Corporations, see instructions in A(5) regarding seal and signatures.)

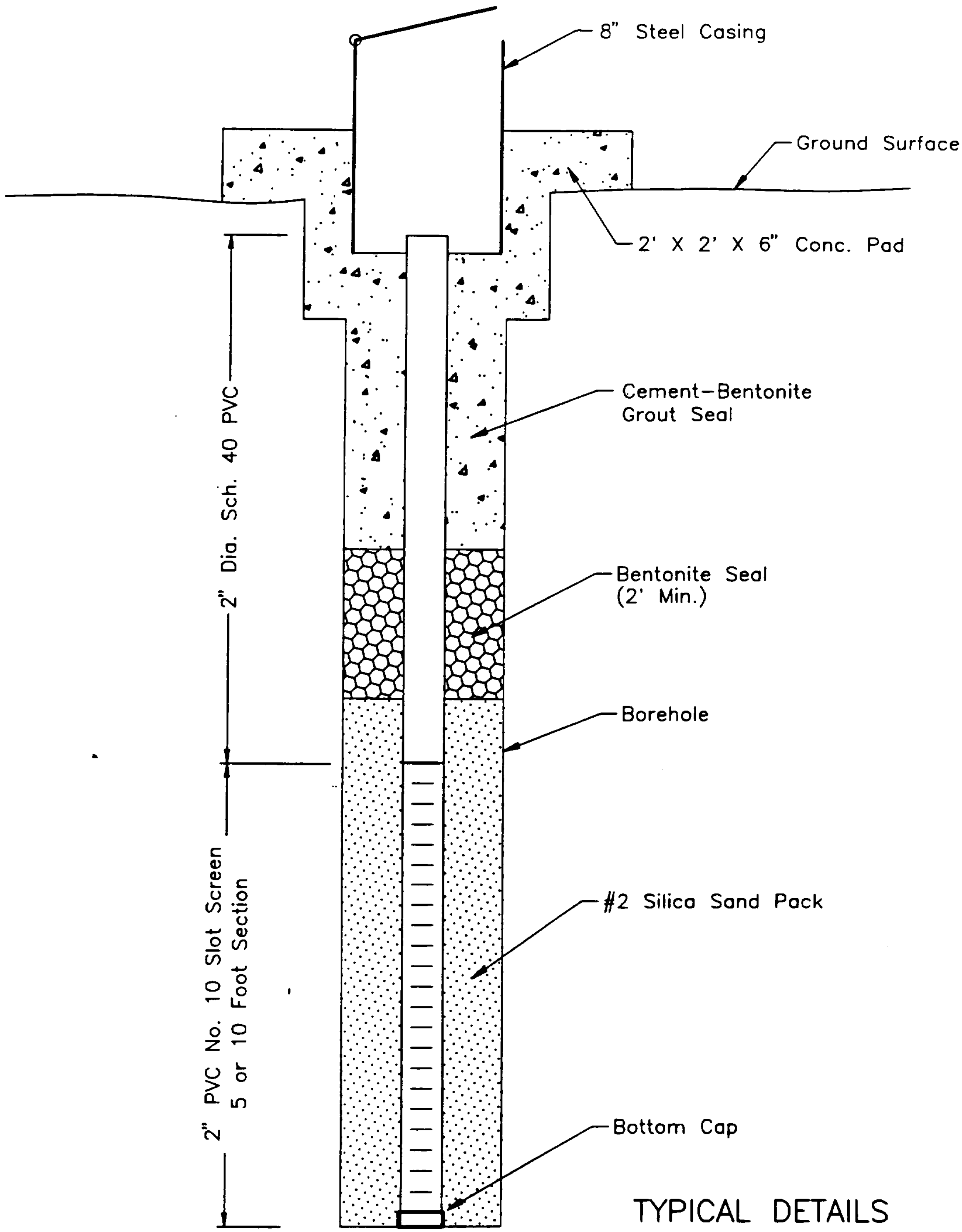



NOTICE

This map has been prepared, as required by law, for Tax Assessment purposes ONLY. It has been compiled from ... in the office of the ... Deeds, the office ... Division of Taxes, the ... of Assessment ..., and, in some cases, ... field work.

... Board of ... Taxes

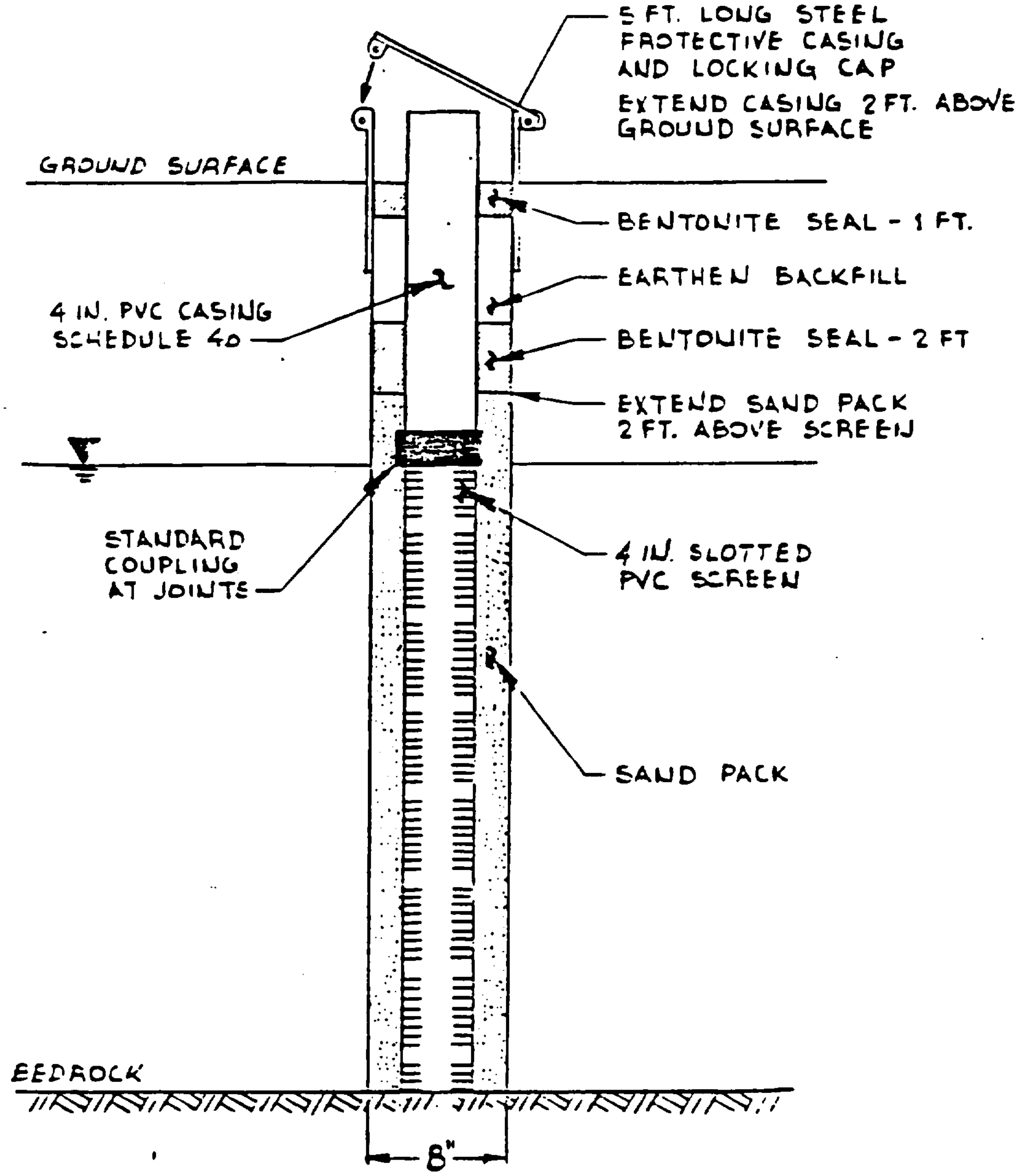
# Appendix G: Driller's Logs and Construction Details for Water Wells




TYPICAL DETAILS

NOT TO SCALE

REMCOR'S WELLS 1 THRU 18




| | | | |
|---|---|---|---|
| DATE: JAN 15, 1982 | | MOLYCORP HOLDING POND AREA<br>WASHINGTON, PENNSYLVANIA | TYPICAL<br>MONITORING<br>WELL |
| SCALE: N.T.S | | | |
| DR: JPL | CK: PLT | SRW ASSOCIATES INC.<br>CARNEGIE, PA. | |
| DWG. NO.: 82300-A8 | | | |

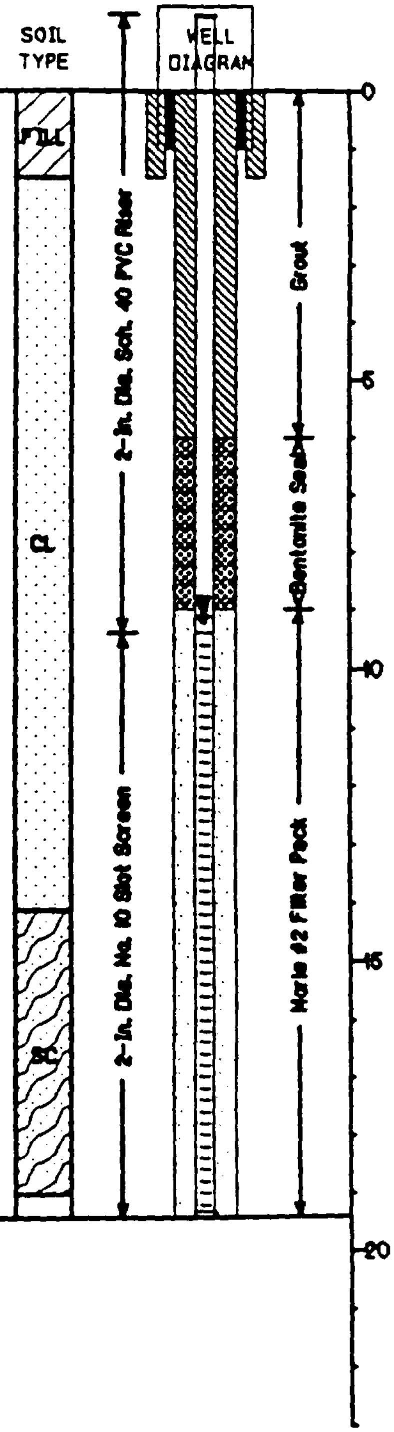
ꟾG NO: M-5
NT NAME: MOLYCORP, INC.
ECT NO.: 91276
STARTED: 9/12/91
E COMPLETED: 9/12/91

GROUND SURF. ELEV.: 1020.8
T.O.C. ELEVATION: 1023.39
DRILLING METHOD: 4-1/4-INCH H.S.A.
DEVELOPMENT METHOD: BAILED
BOREHOLE/WELL DIAM.: 7-1/2, AND 2-INCH

REMCOR

ENGINEER/GEOLOGIST: NJM
CHECKED BY: DMC 12/16/91

| | BLOWS/FT | RECOVERY (INCHES) | DESCRIPTION |
|---|---|---|---|
| | | | **FILL** pea size gravel |
| -1 | 2<br>3<br>4 | 12 | Soft, damp, dark brown (10YR 4/3), **CLAY**, trace gravel and sand |
| -2 | 1<br>2<br>2 | 12 | Soft, damp, dark brown (10YR 4/3), **CLAY** |
| -3 | 1<br>2<br>3 | 18 | Soft, moist, dark brown (10YR 4/3), **CLAY**<br>8.0 feet: moist, dark gray (10YR 3/1), **CLAY** |
| -4 | 3<br>2<br>2 | 18 | Soft, moist, **CLAY** |
| S-5 | 3<br>4<br>5 | 18 | Soft, moist, **CLAY**<br>14.1 feet: soft, moist, dark grayish brown (10YR 3/2), **CLAYEY SAND AND GRAVEL** |
| S-6 | 6<br>12<br>20 | 18 | Medium dense, wet, dark grayish brown (10YR 4/2), **CLAYEY SAND** |
| S-7 | 50/4 | 4 | (19.0) Dry, gray, CLAYSTONE (split spoon refusal) |

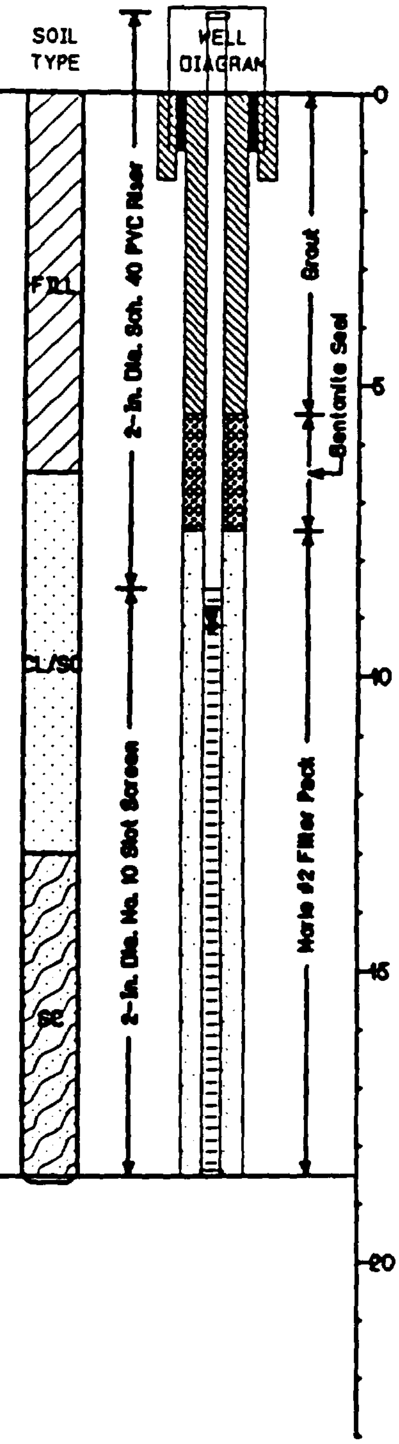



*BOTTOM OF BORING AT 19.4 FEET BELOW GROUND SURFACE*

**WATER LEVEL MEASURED AT 8.12 FT BELOW MEASRUING POINT (9/20/91)**

| | | |
|---|---|---|
| ?RING NO: M-6 | GROUND SURF. ELEV.: 102[illegible] | REMCOR |
| ?IENT NAME: MOLYCORP, INC. | T.O.C. ELEVATION: 1023.35 | |
| ?OJECT NO.: 91276 | DRILLING METHOD: 4-1/4-INCH H.S.A. | |
| ?TE STARTED: 9/17/91 | DEVELOPMENT METHOD: BAILED | ENGINEER/GEOLOGIST: NJM |
| ?TE COMPLETED: 9/17/91 | BOREHOLE/WELL DIAM.: 7-1/2, AND 2-INCH | CHECKED BY: DMC 12/16/91 |

| NUMBER | BLOWS/FT | RECOVERY (INCHES) | DESCRIPTION |
|---|---|---|---|
| GRAB | NA | NA | Black, damp, FILL, mainly slag, and mixture of clay, and sand and gravel |
| S-1 | 1<br>1<br>1 | 18 | Soft, damp, dark grayish brown (10YR 4/2), CLAY trace sand |
| S-2 | 1<br>2<br>2 | 18 | Soft, wet, dark grayish brown (10YR 3/2), SANDY CLAY |
| S-3 | 2<br>2<br>2 | 18 | Soft, wet, SANDY CLAY |
| S-4 | 3<br>3<br>4 | 18 | Soft, wet, SANDY CLAY |
| S-5 | | 18 | SANDY CLAY<br>13.8 feet: Soft, wet, dark grayish brown, CLAYEY SAND AND GRAVEL |
| ST-1 | NA | 24 | BROWN CLAYEY SAND AND GRAVEL |
| S-6 | 3<br>5<br>6 | 15 | CLAYEY SAND AND GRAVEL<br>18.5 feet: Dry, gray, CLAYSTONE |

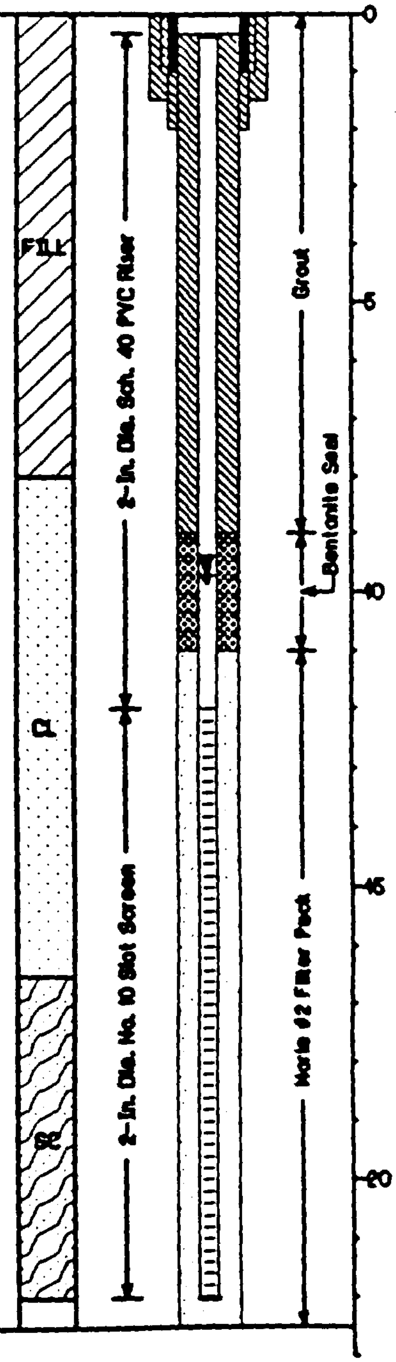



*BOTTOM OF BORING AT 18.5 FEET BELOW GROUND SURFACE*

**WATER LEVEL MEASURED AT 8.16 FT BELOW MEASURING POINT (12/20/91)**

| | | |
|---|---|---|
| NG NO: M-7 | GROUND SURF. ELEV.: 1028.1 | REMCOR |
| NT NAME: MOLYCORP, INC. | T.O.C. ELEVATION: 1025.64 | |
| JECT NO.: 91278 | DRILLING METHOD: 4-1/4-INCH H.S.A. | ENGINEER/GEOLOGIST: NJM |
| E STARTED: 9/19/91 | DEVELOPMENT METHOD: BAILED | |
| TE COMPLETED: 9/19/91 | BOREHOLE/WELL DIAM.: 7-1/2, AND 2-INCH | CHECKED BY: DMC 12/16/91 |

| MBER | BLOWS/FT | RECOVERY (INCHES) | DESCRIPTION |
|---|---|---|---|
| IAB | NA | NA | Dark gray, damp, FILL, slag mixed with sand and gravel |
| -1 | 3<br>2<br>2 | 18 | Soft, damp, very dark gray, FILL, slag, fine to coarse sand and gravel mixed with clay |
| S-2 | 4<br>4<br>2 | 18 | Soft, very dark grayish brown, CLAY |
| S-3 | 2<br>3<br>3 | 18 | Wet, soft, CLAY |
| S-4 | | 18 | Brown gray to yellow brown, wet, CLAYEY SAND AND GRAVEL |
| | | | 22 feet: dark gray CLAYSTONE (SPLIT SPOON REFUSAL) |

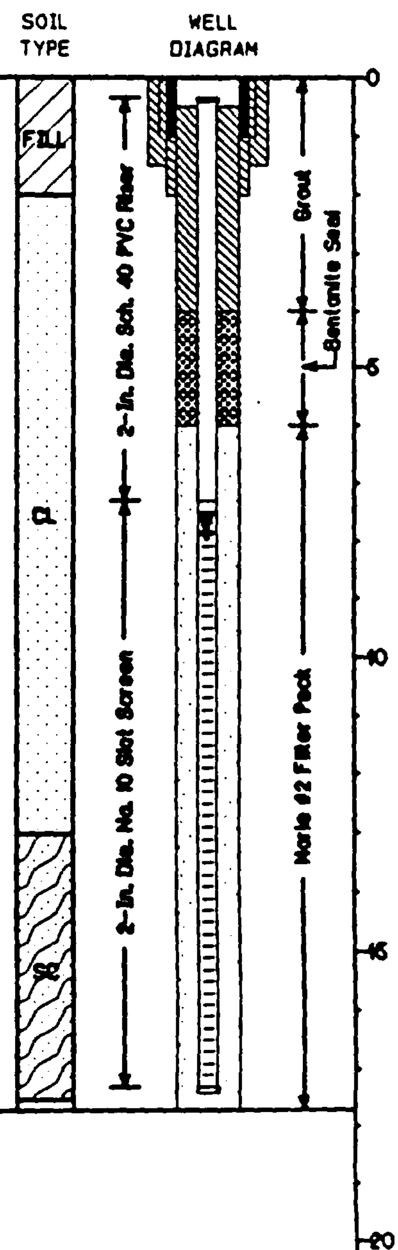



*BOTTOM OF BORING AT 22.5 FEET BELOW GROUND SURFACE*

**WATER LEVEL MEASURED AT 8.74 FT BELOW MEASURING POINT (9/20/91)**

| | | |
|---|---|---|
| T NAME: MOLYCORP, INC. | T.O.C. ELEVATION: 1032.82 | ENGINEER/GEOLOGIST: NJM |
| :CT NO.: 91276 | DRILLING METHOD: 4-1/4-INCH H.S.A. | CHECKED BY: DMC 12/16/91 |
| STARTED: 9/16/91 | DEVELOPMENT METHOD: BAILED | |
| COMPLETED: 9/16/91 | BOREHOLE/WELL DIAM.: 7-1/2, AND 2-INCH | |

| | BLOWS/FT | RECOVERY (INCHES) | DESCRIPTION |
|---|---|---|---|
| | | | BROWN GRAVELLY FILL |
| | 3<br>3<br>4 | 18 | Soft, damp, gray brown [10YR 6/2], CLAY, trace sand |
| | 5<br>8<br>9 | 10 | Soft to medium stiff, damp, dark brown [10YR 4/3], CLAY, trace sand |
| -3 | 10<br>9<br>9 | 18 | Medium stiff, damp, dark brown [10YR 4/3], CLAY 3" black lense of SANDY CLAY |
| -2 | | 18 | SHELBY TUBE SAMPLE: BROWN FAT CLAY |
| -4 | 4<br>7<br>8 | 18 | Medium stiff, damp, greyish brown [10YR 4/2] SANDY CLAY<br>8.2 feet - GRAY CLAY |
| -5 | 8<br>8<br>8 | 18 | Medium dense, damp, dark brown [10YR 3/3], SANDY CLAY<br>10 feet - GRAY CLAY |
| -6 | 3<br>3<br>2 | 18 | Soft, damp, yellowish brown [10YR 4/6], CLAY |
| -7 | 4<br>5<br>5 | 18 | Soft to medium stiff, wet, dark brown [10YR 3/3], CLAYEY SAND AND GRAVEL<br>13.8 feet to 14 feet - GRAYISH BROWN CLAY |
| -8 | 3<br>3<br>4 | 18 | Soft, wet, dark brown [10YR 3/3], CLAYEY SAND AND GRAVEL |
| -9 | 23<br>50/3 | 9 | CLAYEY SAND AND GRAVEL<br>17.5 feet: Extremely hard dark gray CLAYSTONE |

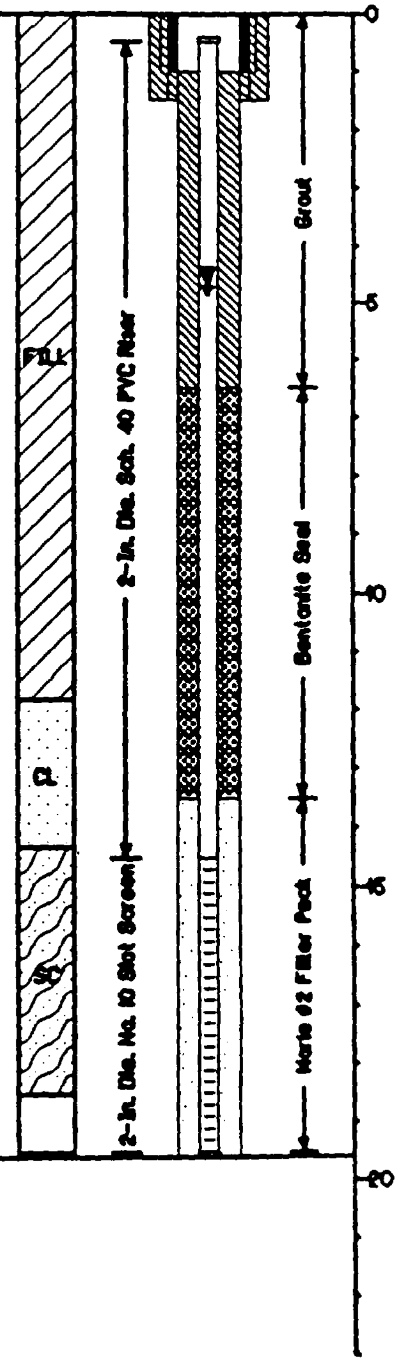



*BOTTOM OF BORING AT 17.7 FEET BELOW GROUND SURFACE*

WATER LEVEL MEASURED AT 7.86 FT BELOW MEASURING POINT (9/20/91)

| | | |
|---|---|---|
| NAME: MOLYCORP, INC. | T.O.C. ELEVATION: 1022.44 | ENGINEER/GEOLOGIST: NJM |
| NO.: 91278 | DRILLING METHOD: 4-1/4-INCH H.S.A. | CHECKED BY: DMC 12/16/91 |
| TARTED: 7/12/91 | DEVELOPMENT METHOD: BAILED | |
| MPLETED: 7/13/91 | BOREHOLE/WELL DIAM.: 7-1/2, AND 2-INCH | |

| | BLOWS/FT | RECOVERY (INCHES) | DESCRIPTION |
|---|---|---|---|
| | 5<br>11<br>18 | 18 | Loose to medium dense, moist, very dark gray (10YR 3/1) FILL, fine to medium sand and gravel, some clay and silt, trace coarse sand. |
| | 28<br>18<br>50/3 | 18 | Medium dense to dense, moist, black FILL, fine to coarse sand and gravel, and mill scalings. |
| | 2<br>4<br>3 | 18 | Very loose, wet, black to gray-white FILL, mainly fire brick with wood chunks, and coarse sand and gravel. |
| | 8<br>3<br>1 | 14 | FILL<br>(11.8 ft) Very soft, moist, dark grayish brown (10YR 3/2) plastic CLAY, trace fine to coarse sand and silt. |
| 5 | 3<br>50/3 | 8 | Dark brown, wet, fine to coarse SAND and fine to coarse GRAVEL, little silt and clay |
| -8 | 28<br>31<br>57/3 | 18 | 18.5 feet: dry, gray, CLAYSTONE (SPLIT SPOON REFUSAL) |




*BOTTOM OF BORING AT 19.8 BELOW GROUND SURFACE*

**WATER LEVEL MEASURED AT 4.74 FT BELOW MEASURING POINT (8/20/91)**

APPENDIX B

BORING NO: M-85
CLIENT NAME: MOLYCORP, INC.
PROJECT NO.: 91278
DATE STARTED: 9/18/91
DATE COMPLETED: 9/18/91

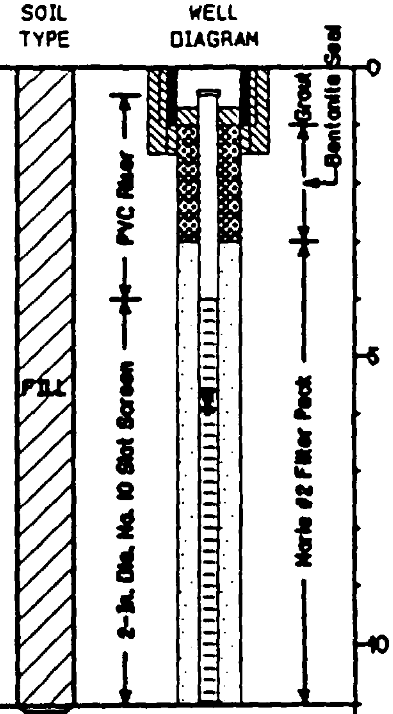
[illegible]
T.O.C. ELEVATION: 1022.44
DRILLING METHOD: 4-1/4-INCH H.S.A.
DEVELOPMENT METHOD: BAILED
BOREHOLE/WELL DIAM.: 7-1/2, AND 2-INCH

REMCOR

ENGINEER/GEOLOGIST: NJM
CHECKED BY: Dmc 12/16/91

| SAMPLE NUMBER | BLOWS/FT | RECOVERY (INCHES) | DESCRIPTION |
|---|---|---|---|
| S-1 | 5<br>11<br>18 | 18 | Loose to medium dense, moist, very dark gray (10YR 3/1) FILL, fine to medium sand and gravel, some clay and silt, trace coarse sand. |
| S-2 | 28<br>18<br>50/3 | 18 | Medium dense to dense, moist, black FILL, fine to coarse sand and gravel, and mill scale. |
| S-3 | 2<br>4<br>3 | 18 | Very loose, wet, black to gray-white FILL, mainly fire brick with wood chunks, and coarse sand and gravel. |

SOIL TYPE — WELL DIAGRAM




*BOTTOM OF BORING AT 11.0 BELOW GROUND SURFACE*

WATER LEVEL MEASURED AT 5.82 FT BELOW MEASURING POINT (9/20/91)

BORING NO.

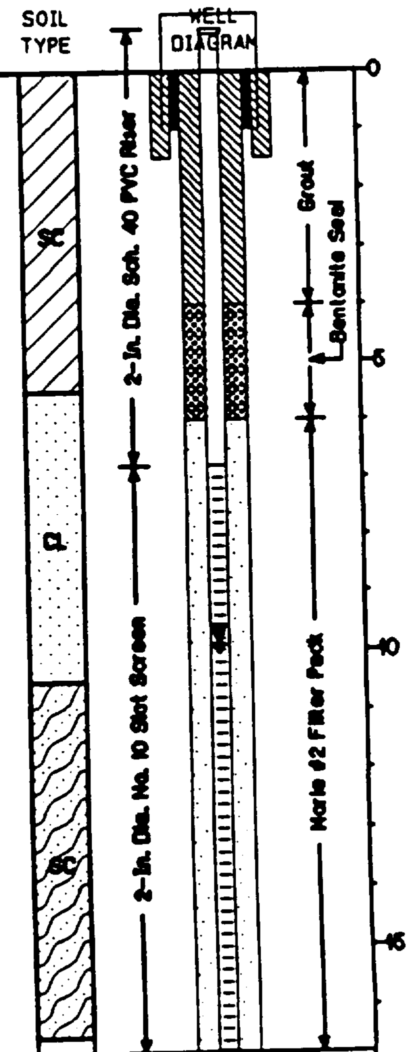
CLIENT NAME: MOLYCORP, INC.
PROJECT NO.: 91278
DATE STARTED: 9/9/91
DATE COMPLETED: 9/9/91

T.O.C. ELEVATION: 1021.17
DRILLING METHOD: 4-1/4-INCH H.S.A.
DEVELOPMENT METHOD: BAILED
BOREHOLE/WELL DIAM.: 7-1/2, AND 2-INCH

REMCOR

ENGINEER/GEOLOGIST: NJM
CHECKED BY: DMC 12/16/91

| SAMPLE NUMBER | BLOWS/FT | RECOVERY (INCHES) | DESCRIPTION |
|---|---|---|---|
| S-1 | 3<br>3<br>4 | 18 | Very loose, dry, yellow brown (10YR 4/8), fine SAND |
| S-2 | 2<br>2<br>3 | 18 | Very loose, dry, yellowish brown (10YR 5/8), fine to medium SAND trace clay and gravel. |
| S-3 | 3<br>3<br>4 | 18 | Very loose, dry, fine to medium SAND |
| S-4 | 3<br>4<br>4 | 14 | Soft, moist, very dark greyish brown (10YR 3/2) CLAY, and trace silt. |
| S-5 | 4<br>3<br>3 | 18 | Soft, moist, dark greyish brown (10YR 4/2), CLAY. |
| S-6 | 2<br>2<br>3 | 18 | Soft, moist, CLAY |
| S-7 | 5<br>8<br>8 | 18 | Loose, wet, black to brown, CLAYEY SAND AND GRAVEL |
| S-8 | 4<br>2<br>2 | 18 | CLAYEY SAND AND GRAVEL |
| S-9 | 3<br>4<br>4 | 12 | CLAYEY SAND AND GRAVEL |
| S-10 | 4<br>9<br>11 | 18 | CLAYEY SAND AND GRAVEL |
| S-11 | 33<br>50/4 | 9 | 16.5 feet: dry, gray, CLAYSTONE (SPLIT SPOON REFUSAL) |




*BOTTOM OF BORING AT 16.8 BELOW GROUND SURFACE*

**WATER LEVEL MEASURED AT 8.81 FT BELOW MEASURING POINT (9/29/91)**

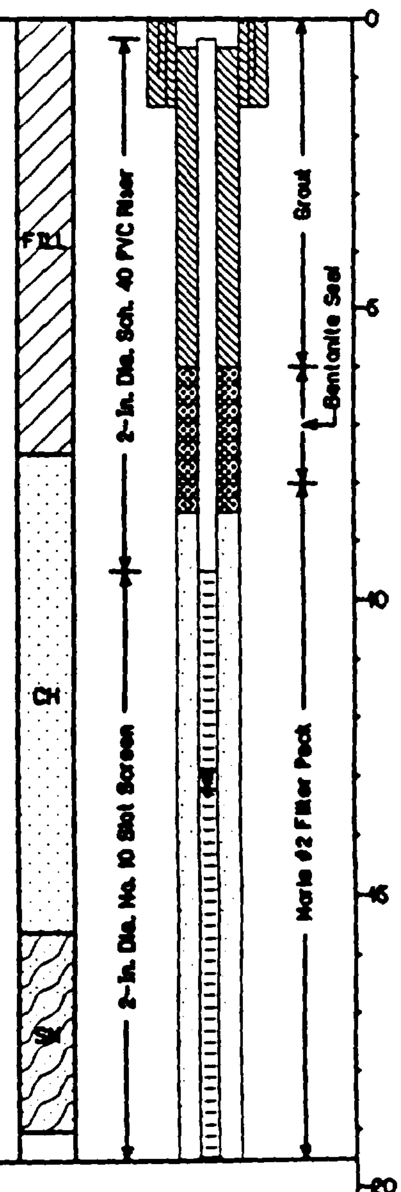
ORING NO: M-11
LIENT NAME: MOLYCORP, INC.
ROJECT NO.: 91278
ATE STARTED: 8/11/91
ATE COMPLETED: 8/11/91

GROUND SURF. ELEV.: 1029.8
T.O.C. ELEVATION: 1029.15
DRILLING METHOD: 4-1/4-INCH H.S.A.
DEVELOPMENT METHOD: BAILED
BOREHOLE/WELL DIAM.: 7-1/2, AND 2-INCH

REMCOR

ENGINEER/GEOLOGIST: NJM
CHECKED BY: DMC 12/10/91

| NUMBER | BLOWS/FT | RECOVERY (INCHES) | DESCRIPTION |
|---|---|---|---|
| | | | Soft, dry to most, brown to black **FILL**, mainly sand and gravel, slag, and mill scale. |
| S-1 | 2<br>2<br>2 | 18 | **FILL**<br>8.8 feet: soft, moist, very dark gray (10YR 3/1), **CLAY**, trace sand. |
| | | | Shelby tube sample Gray, **SANDY FAT CLAY TO FAT CLAY WITH SAND** |
| S-2 | 8<br>13<br>21 | 18 | **SANDY CLAY AND GRAVEL**<br>Medium dense, wet, yellowish brown (10YR 4/4), **CLAYEY SAND AND GRAVEL**. |
| S-3 | 8<br>28<br>50/3 | 16 | **SANDY CLAY AND GRAVEL**<br>19.0 feet: dry, gray **WEATHERED CLAYSTONE** (SPLIT SPOON REFUSAL) |




*BOTTOM OF BORING AT 19.5 BELOW GROUND SURFACE*

**WATER LEVEL MEASURED AT 13.20 FT BELOW MEASURING POINT (8/20/91)**

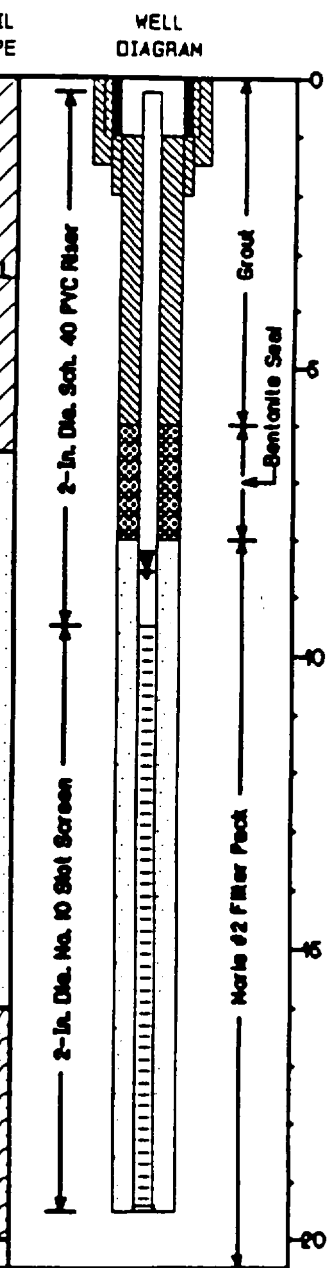
| | |
|---|---|
| CLIENT NAME: | MOLYCORP, INC. |
| PROJECT NO.: | 91278 |
| DATE STARTED: | 9/9/91 |
| DATE COMPLETED: | 9/9/91 |
| T.O.C. ELEVATION: | 1022.74 |
| DRILLING METHOD: | 4-1/4-INCH H.S.A. |
| DEVELOPMENT METHOD: | BAILED |
| BOREHOLE/WELL DIAM.: | 7-1/2, AND 2-INCH |

REMCOR

ENGINEER/GEOLOGIST: NJM

CHECKED BY: DMC 12/16/91

| SAMPLE NUMBER | BLOWS/FT | RECOVERY (INCHES) | DESCRIPTION | SOIL TYPE |
|---|---|---|---|---|
| S-1 | 12<br>12<br>15 | 18 | Medium dense, dry, black, **FILL** glassy slag | FILL |
| S-2 | 4<br>5<br>5 | 10 | Very loose, dry, black to brown, **FILL**, sand and gravel wih black hard slag | FILL |
| S-3 | 4<br>5<br>50/3 | 0 | No recovery | FILL |
| S-4 | 2<br>3<br>3 | 18 | Soft, damp, brown (10YR 4/3), **CLAY**, trace to some sand | CL |
| S-5 | 3<br>4<br>5 | 8 | Soft, damp, brown (10YR 4/3), **CLAY**, trace sand | CL |
| S-6 | 4<br>3<br>2 | 14 | Soft, moist, yellowish brown (10YR 4/4), **CLAY**, trace sand | CL |
| S-7 | 2<br>2<br>3 | 12 | Very soft to soft, yellowish brown (10YR 4/4), **CLAY**, some fine to coarse sand | CL |
| S-8 | 2<br>2<br>2 | 16 | Very soft, moist, brown (10YR 4/3), **CLAY**, some fine to coarse sand | CL |
| S-9 | 2<br>2<br>3 | 18 | Very soft to soft, dark yellow brown (10YR 4/6), **SANDY CLAY** | SC |
| S-10 | 8<br>10<br>22 | 18 | Loose to medium dense, grayish brown (10YR 3/2), **CLAYEY SAND AND GRAVEL** | SC |
| | | | 20 feet: dry, gray, **CLAYSTONE** | SC |



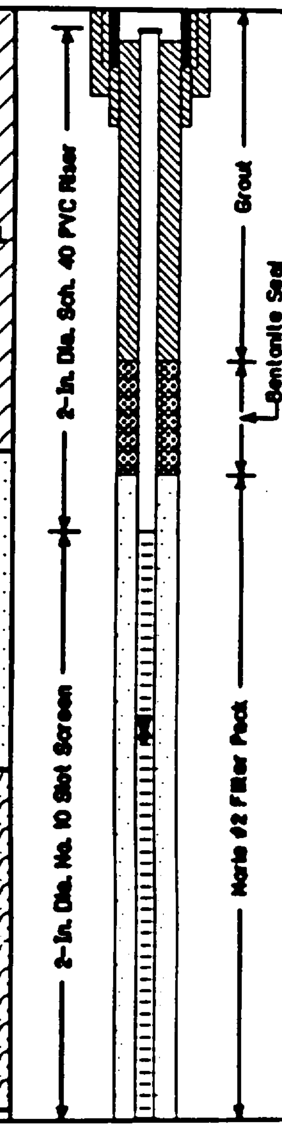

*BOTTOM OF BORING AT 20.5 FEET BELOW GROUND SURFACE*

**WATER LEVEL MEASURED AT 8.58 FEET BELOW MEASURING POINT (9/20/91)**

| CLIENT NAME: MOLYCORP, INC. | T.O.C. ELEVATION: 1031.90 | REMCOR |
|---|---|---|
| PROJECT NO.: 91278 | DRILLING METHOD: 4-1/4-INCH H.S.A. | |
| DATE STARTED: 9/17/91 | DEVELOPMENT METHOD: BAILED | ENGINEER/GEOLOGIST: NJM |
| DATE COMPLETED: 9/17/91 | BOREHOLE/WELL DIAM.: 7-1/2, AND 2-INCH | CHECKED BY: Dmc 12/16/91 |

| DEPTH (FT) | SAMPLE NUMBER | BLOWS/FT | RECOVERY (INCHES) | DESCRIPTION | SOIL TYPE |
|---|---|---|---|---|---|
| 0 | | | | | FILL |
| | GRAB | | NA | 1 to 3 feet: dry, yellow to black, gravelly FILL, slag | FILL |
| | GRAB | | NA | 4 to 5 feet: gravelly, moist FILL, wood fragments | FILL |
| 5 | | | | | FILL |
| | S-1 | 5<br>5<br>5 | 0 | Medium stiff, moist, CLAY | CL |
| 10 | S-2 | 3<br>8<br>10 | 18 | Medium stiff, damp, dark grayish brown (10YR 3/2), CLAY | CL |
| | S-3 | | 18 | Medium stiff, moist, graylsh brown (10YR 5/4), SANDY CLAY<br>13.9 feet: moist, GRAVELLY CLAY AND SAND | SC |
| 15 | | | | | SC |
| | S-4 | 2<br>2<br>2 | 18 | 4-inch CLAY varve<br>Soft, moist, dark yellowish brown (10YR 4/6), GRAVELLY CLAY AND SAND | SC |
| | S-5 | 36<br>50 | 12 | GRAVELLY CLAY AND SAND<br>18.8 feet: dry, gray, CLAYSTONE (SPLIT SPOON REFUSAL) | SC |
| 20 | | | | | |

WELL DIAGRAM

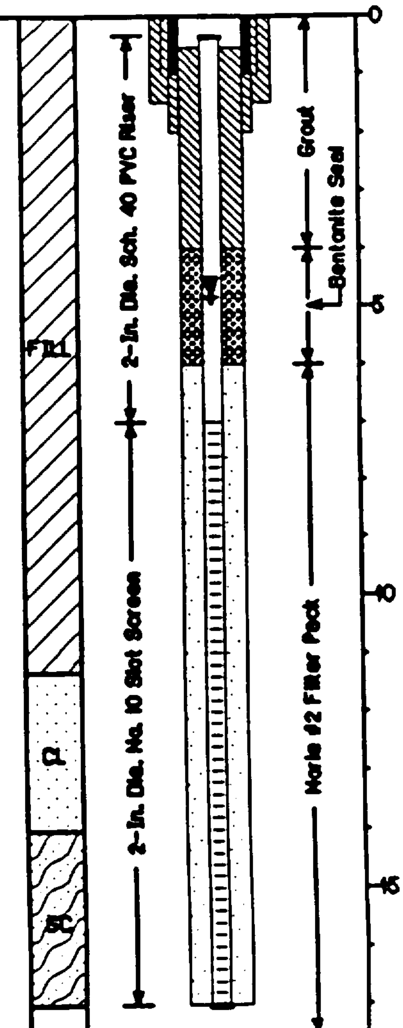



*BOTTOM OF BORING AT 19 FEET BELOW GROUND SURFACE*

**WATER LEVEL MEASURED AT 12.46 FT BELOW MEASURING POINT (9/20/91)**

| | | | |
|---|---|---|---|
| CLIENT NAME: MOLYCORP, INC. | T.O.C. ELEVATION: 1030.30 | REMCOR | |
| PROJECT NO.: 91276 | DRILLING METHOD: 4-1/4-INCH H.S.A. | | |
| DATE STARTED: 9/18/91 | DEVELOPMENT METHOD: BAILED | ENGINEER/GEOLOGIST: NJM | |
| DATE COMPLETED: 9/18/91 | BOREHOLE/WELL DIAM.: 7-1/2, AND 2-INCH | CHECKED BY: DMC 12/16/91 | |

| SAMPLE NUMBER | BLOWS/FT | RECOVERY (INCHES) | DESCRIPTION |
|---|---|---|---|
| | | | |
| S-1 | 23<br>28<br>21 | 18 | Medium dense, dry, gray to black, FILL, backfill and mill scale |
| | | | |
| S-2 | 28<br>20<br>20 | 10 | Medium dense, dry, FILL, piece of rope |
| | | | |
| S-3 | 2<br>13<br>50 | 18 | Soft, damp, gray, FILL, some sand and clay |
| | | | |
| S-4 | 2<br>3<br>5 | 18 | Soft, damp, gray FILL, ammonia ODOR<br>11.3 feet – moist, dark grayish brown (10YR 4/2), SANDY CLAY |
| | | | |
| S-5 | 8<br>12<br>21 | 18 | Soft to mdium stiff, moist, yellowish brown (10YR 5/8), CLAYEY SAND AND GRAVEL |
| S-6 | 19<br>20<br>38 | 18 | CLAYEY SAND AND GRAVEL<br>17 feet: dark, gray, CLAYSTONE |




BOTTOM OF BORING AT 17.5 FEET BELOW GROUND SURFACE

WATER LEVEL MEASURED AT 4.85 FT BELOW MEASURING POINT (9/20/91)

| | |
|---|---|
| BORING NO: | M-15 |
| CLIENT NAME: | MOLYCORP, INC. |
| PROJECT NO.: | 81278 |
| DATE STARTED: | 9/18/91 |
| DATE COMPLETED: | 9/18/91 |

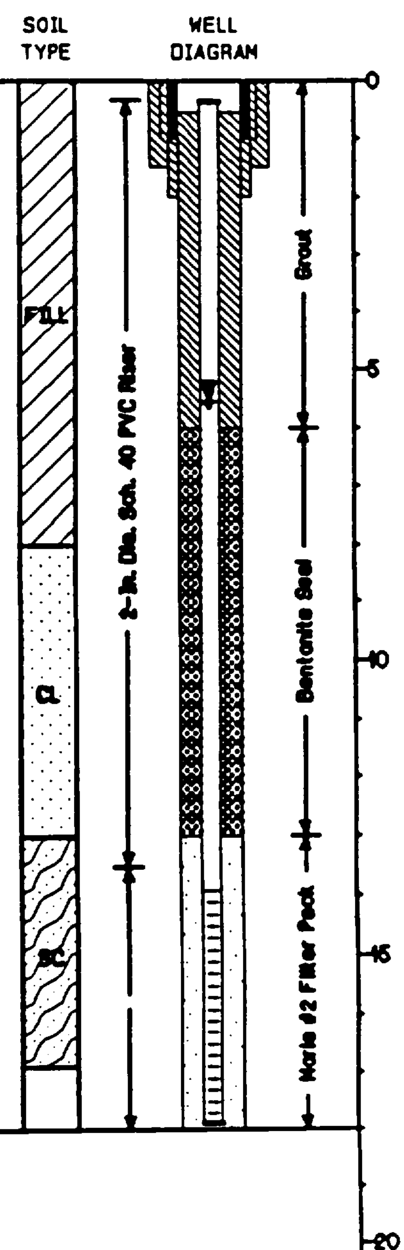
| | |
|---|---|
| GROUND SURF. ELEV.: | 1033.0 |
| T.O.C. ELEVATION: | 1032.73 |
| DRILLING METHOD: | 4-1/4-INCH H.S.A. |
| DEVELOPMENT METHOD: | BAILED |
| BOREHOLE/WELL DIAM.: | 7-1/2, AND 2-INCH |

**REMCOR**

ENGINEER/GEOLOGIST: NJM

CHECKED BY: DMC 12/16/91

| SAMPLE NUMBER | BLOWS/FT | RECOVERY (INCHES) | DESCRIPTION |
|---|---|---|---|
| GRAB | | NA | 1 to 3 feet: dry, black, gravelly FILL |
| | | | 3 to 4.5 feet: gravelly FILL |
| | | | 4.5 to 8 feet: very dark gray to dark brown, wet gravelly FILL oily sheen on cuttings, ammonia odor |
| S-1 | 4<br>2<br>2 | 18 | FILL, ammonia odor<br>8.0 feet: wet, dark brown (10YR 2/2), CLAY |
| S-2 | 7<br>7<br>5 | 18 | Medium stiff, wet, FILL |
| S-3 | 4<br>4<br>4 | 18 | Soft, wet, yellow brown (10YR 5/4), CLAYEY SAND AND GRAVEL |
| S-4 | 12<br>18<br>20 | 18 | Medium stiff to stiff, yellow brown (10YR 5/4), CLAYEY SAND AND GRAVEL<br>18.9 feet: dark gray CLAYSTONE |

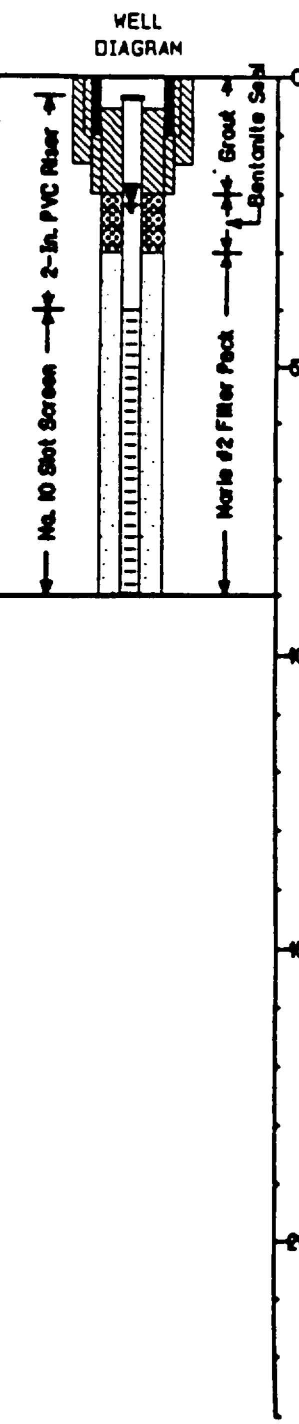



*BOTTOM OF BORING AT 218 FEET BELOW GROUND SURFACE*

WATER LEVEL MEASURED AT 6.58 FT BELOW MEASURING POINT (9/20/91)

| | | |
|---|---|---|
| BORING NO: N-15S | GROUND SURF. ELEV.: 1033.3 | REMCOR |
| CLIENT NAME: MOLYCORP, INC. | T.O.C. ELEVATION: 1033.01 | |
| PROJECT NO.: 91278 | DRILLING METHOD: 4-1/4-INCH H.S.A. | |
| DATE STARTED: 9/19/91 | DEVELOPMENT METHOD: BAILED | ENGINEER/GEOLOGIST: NJM |
| DATE COMPLETED: 9/19/91 | BOREHOLE/WELL DIAM.: 7-1/2, AND 2-INCH | CHECKED BY: DMC 12/16/91 |

| SAMPLE NUMBER | BLOWS/FT | RECOVERY (INCHES) | DESCRIPTION | SOIL TYPE |
|---|---|---|---|---|
| GRAB | | NA | 1 to 3 feet: dry, black, gravelly FILL | FILL |
| | | | 3 to 4.5 feet: gravelly FILL | FILL |
| | | | 4.5 to 8 feet: very dark gray to dark brown, wet gravelly FILL oily sheen on cuttings, smell of ammonia | FILL |
| S-1 | 4<br>2<br>2 | 18 | FILL, ammonia odor<br>8.0 feet: wet, dark brown (10YR 2/2), CLAY | FILL<br>CL |



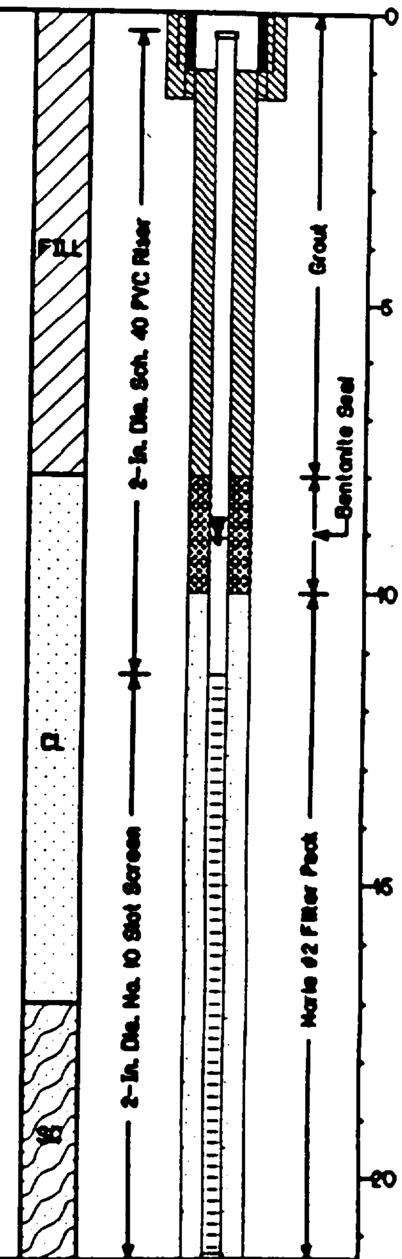

*BOTTOM OF BORING AT 8.0 FEET BELOW GROUND SURFACE*

**WATER LEVEL MEASURED AT 2.20 FT BELOW MEASURING POINT (9/20/91)**

PROJECT NO.: [illegible] | DRILLING METHOD: 4-1/4-INCH H.S.A. | [redacted]
---|---|---
DATE STARTED: 9/11/91 | DEVELOPMENT METHOD: BAILED | ENGINEER/GEOLOGIST: NJM
DATE COMPLETED: 9/11/91 | BOREHOLE/WELL DIAM.: 7-1/2, AND 2-INCH | CHECKED BY: DMC 12/16/91

| Depth (ft) | SAMPLE NUMBER | BLOWS/FT | RECOVERY (INCHES) | DESCRIPTION |
|---|---|---|---|---|
| 5 | S-1 | 5<br>10<br>32 | 0 | Loose to medium dense, damp, black to dark brown, FILL, slag and mill scale |
| | S-2 | 10<br>5<br>3 | 12 | Soft to medium stiff, dark gray (2.5YR 2/4), SANDY CLAY |
| 10 | S-3 | 5<br>2<br>3 | 18 | Soft, dry , dark yellow brown (10.5YR 4/4), SANDY CLAY |
| 15 | S-4 | 4<br>3<br>4 | 18 | Soft, wet, yellow brown (10.5YR 5/8), SANDY CLAY |
| | S-5 | 20<br>20<br>18 | 18 | Medium dense, wet, brown (10YR 5/3), SILTY SAND AND GRAVEL |
| 20 | S-6 | 28<br>40<br>60/3 | 15 | SILTY SAND AND GRAVEL<br>21.4 feet: CLAYSTONE (SPLIT SPOON REFUSAL) |

SOIL TYPE / WELL DIAGRAM




*BOTTOM OF BORING AT 21.4 FEET BELOW GROUND SURFACE*

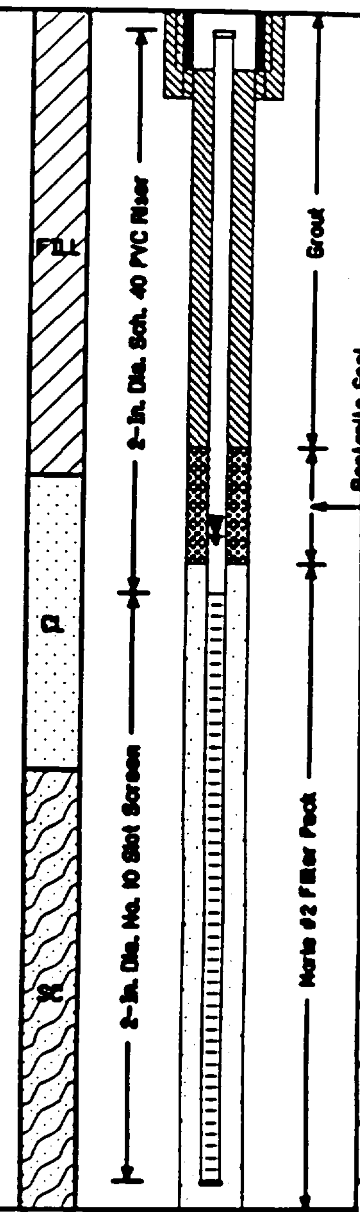
**WATER LEVEL MEASURED AT 9.08 FT BELOW MEASURING POINT (9/20/91)**

[redacted]

| | | | |
|---|---|---|---|
| CLIENT NAME: MOLYCORP, INC. | T.O.C. ELEVATION: 1027.38 | **REMCOR** | |
| PROJECT NO.: 91278 | DRILLING METHOD: 4-1/4-INCH H.S.A. | | |
| DATE STARTED: 9/10/91 | DEVELOPMENT METHOD: BAILED | ENGINEER/GEOLOGIST: NJM | |
| DATE COMPLETED: 9/10/91 | BOREHOLE/WELL DIAM.: 7-1/2, AND 2-INCH | CHECKED BY: DMC 12/16/91 | |

| SAMPLE NUMBER | BLOWS/FT | RECOVERY (INCHES) | DESCRIPTION |
|---|---|---|---|
| S-1 | 20<br>50/.1 | 8 | Medium dense to dense, dry, blue, FILL, mainly sand and gravel, and blue slag |
| S-2 | 11<br>15<br>70/.3 | 18 | Medium dense, dry, brown, FILL, sand and gravel and blue slag |
| S-3 | 88 | 6 | FILL |
| S-4 | 2<br>2<br>3 | 18 | Soft, damp, grayish brown (2.5YR 4/2), CLAY, trace sand |
| S-5 | 3<br>4<br>5 | 18 | Soft, moist, dark brown (10YR 4/3), SANDY GRAVELLY CLAY |
| S-6 | 3<br>4<br>5 | 18 | Soft, moist to wet, yellowish brown (10YR 5/4), SANDY CLAY |
| S-7 | 21<br>35<br>70 | 18 | SANDY CLAY<br>20.5 feet: CLAYSTONE (SPLIT SPOON REFUSAL) |

SOIL TYPE / WELL DIAGRAM




*BOTTOM OF BORING AT 20.5 FEET BELOW GROUND SURFACE*

**WATER LEVEL MEASURED AT 8.04 FT BELOW MEASURING POINT (9/20/91)**

[illegible]

OJECT NO.: 91278

TE STARTED: 9/10/91

TE COMPLETED: 9/10/91

DRILLING METHOD: 4-1/4-INCH H.S.A.

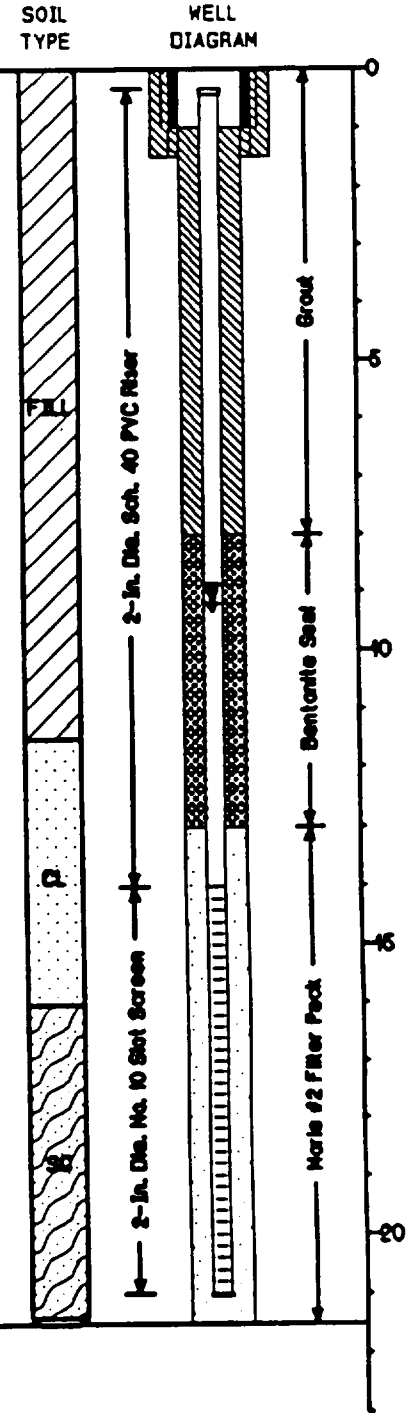
DEVELOPMENT METHOD: BAILED

BOREHOLE/WELL DIAM.: 7-1/2, AND 2-INCH

ENGINEER/GEOLOGIST: NJM

CHECKED BY: DMC 12/16/91

| NUMBER | BLOWS/FT | RECOVERY (INCHES) | DESCRIPTION |
|---|---|---|---|
| -1 | GRAB | | 5.0 TO 7.0: Grab sample, dry, brown, FILL, slag, with sand and clay |
| -2 | 4<br>4<br>32 | 12 | Loose, moist, black, FILL, scaly slag with sand, gravel, and clay |
| -3 | 13<br>3<br>2 | 14 | Loose, black, wet, FILL, mill scale and flyash |
| -4 | 3<br>3<br>2 | 18 | Soft, moist, dark grayish brown (10YR 3/2) CLAY, trace fine sand<br>Soft, moist, dark brown (10YR 4/3), SANDY CLAY |
| -5 | 5<br>8<br>8 | | |
| S-6 | 3<br>3<br>3 | 18 | Soft, wet, yellowish brown (10YR 5/6) CLAYEY SAND AND GRAVEL |
| S-7 | 2<br>2<br>3 | 18 | CLAYEY SAND AND GRAVEL |
| -8 | 50/4 | 4 | CLAYEY SAND AND GRAVEL |




21.4 feet: CLAYSTONE (SPLIT SPOON REFUSAL)

*TOTAL DEPTH OF BOREHOLE AT 21.4 FEET BELOW GROUND SURFACE*

WATER LEVEL MEASURED AT 8.04 FT BELOW MEASURING POINT (9/20/91)

APPENDIX B

| | | | |
|---|---|---|---|
| CLIENT NAME: MOLYCORP, INC. | T.O.C. ELEVATION: 1026.80 | REMCOR | |
| PROJECT NO.: 91278 | DRILLING METHOD: 4-1/4-INCH H.S.A. | | |
| DATE STARTED: 9/19/91 | DEVELOPMENT METHOD: BAILED | ENGINEER/GEOLOGIST: NJM | |
| DATE COMPLETED: 9/19/91 | BOREHOLE/WELL DIAM.: 7-1/2, AND 2-INCH | CHECKED BY: DMC 12/16/91 | |

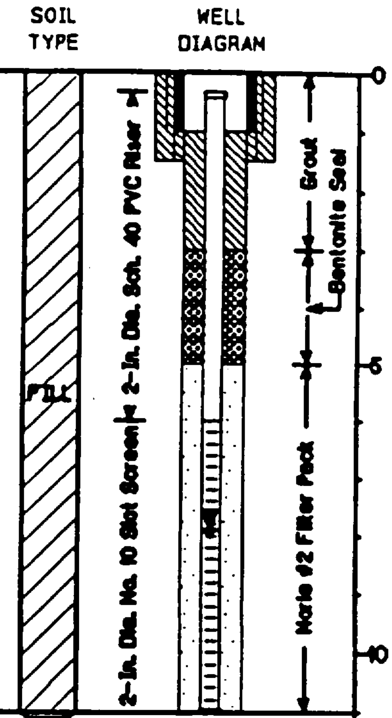
| Depth (ft) | SAMPLE NUMBER | BLOWS/FT | RECOVERY (INCHES) | DESCRIPTION |
|---|---|---|---|---|
| 0 | S-1 | GRAB | | |
| 5 | | | | 5.0 TO 7.0: Grab sample, dry, brown, FILL slag, with sand and clay |
| | S-2 | 4<br>4<br>32 | 12 | Loose, moist, black, FILL, scaly slag with sand, gravel and clay |
| 10 | S-3 | 13 | 14 | Loose, black, wet, FILL, mill scale, and flyash |

*TOTAL DEPTH OF BOREHOLE AT 11.0 FEET BELOW GROUND SURFACE*

**WATER LEVEL MEASURED AT 7.80 FT BELOW MEASURING POINT (9/20/91)**

15

20



# Appendix H: NRC Comments on Molycorp's First Draft of the Site Characterization Plan, and Molycorp's Response

8/6/93

UNITED STATES
NUCLEAR REGULATORY COMMISSION
WASHINGTON, D. C. 20555

FEB 2 5 1993

Docket No. 40-8778
License No. SMB-1393

Molycorp, Inc.
ATTN: Ms. Barbara K. Dankmyer
Resident Manager
300 Caldwell Avenue
Washington, Pennsylvania 15301

Dear Ms. Dankmyer:

SUBJECT: NRC COMMENTS ON THE PLAN FOR SITE CHARACTERIZATION IN SUPPORT OF DECOMMISSIONING OF THE MOLYCORP INC. WASHINGTON, PA FACILITY

The Nuclear Regulatory Commission staff has completed its review of the report entitled "Plan for Site Characterization in Support of Decommissioning of the Molycorp Inc. Washington, Pa Facility." This document is herein referred to as Molycorp's Site Characterization Plan (SCP) or the SCP. In its review of Molycorp's SCP, the staff also considered a supporting report, submitted by Radiation Surveillance Associates, Inc. on January 4, 1993, entitled "Justification of the Calibration Factor used for Borehole Measurements of Underground Radiation Exposure Rates and Average $^{232}$Th Concentration."

We commend Molycorp for developing the SCP in a format consistent with NRC's Draft Branch Technical Position (BTP) on Site Characterization for Decommissioning Sites, July 1992. This greatly facilitated our review of this document.

Our review was complicated by uncertainty in Molycorp's preferred approach for decommissioning the site. We recognize that Molycorp is now in the process of evaluating a range of decommissioning and disposal alternatives. We encourage Molycorp to conceptualize its preferred decommissioning approach as early as possible. This will help to clarify what information needs to be collected during site characterization, and thus better focus the characterization effort.

In the course of our review, we identified a number of general comments (Enclosure #1) on the SCP. If Molycorp addresses and resolves these comments now, a great deal of time and site characterization effort may be saved. Some of our major comments include:

1. The utility of the proposed gamma logging technique for deriving subsurface thorium concentrations has not been demonstrated. Therefore, directly measured concentration data (based on conventional sampling and radiochemical analysis) should be used rather than diluted and approximate concentrations derived from gamma logging for demonstrating compliance with NRC decommissioning criteria. The staff continues to accept the use of gamma logging for identifying the general zone (depth and lateral extent) of radioactive contamination.

FEB 2 5 1993



2. The SCP and RSA's 1992 report suggest that Molycorp may propose a dose criterion in place of NRC's decommissioning criteria. Molycorp should not proceed with site characterization with the expectation that some alternate decommissioning criteria, based on dose or exposure rate, will be approved for release of this site for unrestricted use. If Molycorp wishes to pursue an alternate decommissioning criterion, Molycorp needs to propose the criterion and justify it by demonstrating that it will achieve residual concentration levels that are As Low As Reasonably Achievable (ALARA). The establishment of an alternate decommissioning criterion may require Commission review and approval.

3. A great deal of characterization information has already been collected for this site. Molycorp should review and analyze this information, and the SCP should discuss how the results of this analysis have been used in planning future site characterization activities. For example, the SCP presently lacks an adequate description of what is presently known about the hydrogeology, and how this information was used in planning future hydrological characterization. The SCP should review the results of past hydrogeologic work in discussing the rationale for future characterization work in this area.

The staff has also identified a number of specific technical comments (Enclosure #2) on the SCP. If you would like to meet with NRC staff to discuss these comments, we would be happy to arrange such a meeting. If you have any questions, please contact me at (301) 504-2546.

Sincerely,

Chad Glenn

Chad J. Glenn, Project Manager
Decommissioning and Regulatory
Issues Branch
Division of Low-Level Waste Management
and Decommissioning
Office of Nuclear Material Safety
and Safeguards

Enclosures: As stated
cc:
G. Dawes, Molycorp
B. Belanger, EPA Region III
J. Yusko, PA-DER-RP
J. Kinneman, Region I
M. Landis, ORAU

Enclosure #1

# NRC Review and Comments On:
# Plan For Site Characterization In Support Of Decommissioning Of The Molycorp Inc. Washington, Pa Facility

## GENERAL COMMENTS

1. Review and Analysis of the Previous Characterization Work:

The SCP does not discuss how the results of past site characterization efforts have been used in planning future characterization work. Previous characterization work performed by Applied Health Physics (AHA), Radiation Surveillance Associates, Inc., (RSA), and Oak Ridge Associated Universities (ORAU) have contributed significantly to the existing information base relevant to site characterization. Much of this characterization work is documented in three reports (AHA, 1971; ORAU, 1985; and RSA, 1990). These reports contain information on radiation surveys, core sampling, soil and slag concentrations based on laboratory analysis, and sub-surface gamma logging. The SCP should summarize the results of these previous characterization efforts, and explain how this information was used to guide future site characterization work. The NRC staff believes that this evaluation will assist in providing a sound basis for planning future site characterization work and potentially reduce the time and cost of site characterization by eliminating unnecessary site characterization efforts.

2. Location of Boreholes and Selection of Samples:

The SCP does not provide a clear rationale for selecting the number of boreholes and quantity of samples collected during site characterization. For example, Molycorp is planning to drill an additional 300 boreholes down to bedrock to measure the intensity of the subsurface gamma field (Section 5.2.2 page 39), analyze 200 soil samples from the cores for $^{232}Th$ by ICP (Section 5.2.3 page, 41), and analyze 20 well-water samples for $^{232,230,228}Th$, $^{238,234}U$, and $^{228,226}Ra$ (Section 5.5, page 45). The SCP should discuss the rationale for the number and selection of borehole locations, types and quantities of samples collected during site characterization, and clarify how these data will be used in planning site decommissioning or conducting a termination survey.

3. Decommissioning Criteria:

A dose criterion should not be used in place of NRC's existing decommissioning criteria. The SCP indicates that Molycorp is proposing to use a dose criterion as either the major or the sole criterion to demonstrate compliance with NRC cleanup and decontamination guidelines. Recent discussions with Molycorp consultants also indicate that Molycorp may propose a remediation guideline value based on a dose rate in place of NRC's existing soil concentration guidelines in the 1981 Branch Technical Position (BTP) entitled *Disposal or Onsite Storage of Thorium or Uranium Wastes from Past Operations*. It is important to note, that the decommissioning guidelines for residual soil concentrations that have been approved by the Commission for the release of sites for unrestricted use are the soil concentration limits in Options 1 and 2 of NRC's 1981 BTP. The ultimate decision to terminate a license and release a site for unrestricted use will be based on NRC's existing decommissioning guidelines. These remediation guidelines are applied on a site-specific basis with emphasis on residual contamination levels that are As Low As Reasonably Achievable (ALARA). Therefore, Molycorp should not proceed with site characterization with the expectation that some alternative decommissioning criterion, based on dose or exposure rate, will be approved for the release of this site for unrestricted use. If Molycorp wishes to pursue an alternate decommissioning guideline, Molycorp needs to propose the criterion and justify it by demonstrating that it will achieve residual contamination levels that are ALARA.

4. <u>Radiological Characterization of Site</u>:

The primary objectives of Molycorp's radiological characterization efforts should be to assess the extent of contamination above background levels, and to identify locations and distributions of highly contaminated areas that may propose special handling concerns during decommissioning. This radiological characterization may require the use of a combination of techniques. For example, gamma logging may be quite useful during characterization in identifying the general zone of contamination (vertical and horizontal boundaries). However, for determination of thorium concentrations after the completion of remediation, the staff believes that an approach based on gamma screening coupled with direct measurement of thorium concentrations is more appropriate. The staff believes that this coupling is appropriate given: 1) the inherent limitations of the gamma logging technique in determining thorium concentrations (discussed below), and 2) due to the nature of the thorium contamination (e.g., occurs in patchy, or randomly distributed discrete hot spots). This should be addressed further in the Decommissioning Plan as a part of the sampling plan for the termination survey.

5. <u>Characterization to Evaluate Volume Reduction Technologies</u>:

Due to the nature and form of contamination at this site, NRC staff encourages Molycorp to consider an alternate approach of characterizing and remediating the site simultaneously. If the remediation of the site disturbs and redistributes contaminated material onsite, there would be limited value in conducting detailed characterization of the distribution of radionuclides as a part of site characterization. Under this alternate approach, Molycorp might excavate contaminated and potentially contaminated soil and process this material via physical screening or separation (e.g., sieving or heavy liquid separation). For example, one soil remediation process that has been commercially demonstrated excavates and places contaminated soils on a continuously moving conveyor belt. An array of radiation detectors monitors the soil on the belt and identifies and segregates highly contaminated soil from clean soil. This type of simultaneous characterization and remediation approach might effect sizable reductions in volumes of waste requiring disposal in a licensed facility and accelerate the decommissioning process at Molycorp's Washington site.

The SCP does not, however, discuss the collection of information needed to evaluate the feasibility of using volume reduction technologies for site remediation and decommissioning. Certain physical characteristics of the contamination at Molycorp's Washington, PA site may provide favorable characteristics for the physical separation of contaminants. For example, grain size distribution, density, solubility, metallic and magnetic properties, and apparent inhomogeneity of the contaminated material may be useful characteristics in separating contaminated slag from uncontaminated slag and soil. The NRC staff believes that a careful evaluation of these properties may provide insight into an effective approach for site remediation. Volume reduction technologies may significantly reduce decommissioning costs by decreasing the volume of contaminated material requiring off-site disposal. Many of these volume reduction methods are based on physical/mechanical technologies that are common to the coal and ore processing industries.

In order to evaluate potential applicability of volume reduction methods to Molycorp's Washington site, it is important to characterize the physical and mineralogical properties of the contaminated material (soil and slag). Section 4.4.2 of NRC's BTP on *Site Characterization for Decommissioning Sites* (July 1992) suggests that detailed information be obtained on the composition of surface and subsurface deposits, including mineralogy and other physical characteristics. Important physical properties of contaminated material in consideration of applicability of volume reduction technologies include: grain size distribution, relationship of radioactivity to particle size, magnetic properties, and mineralogical/chemical composition. NRC staff suggests that Molycorp consider the collection of this type of information during characterization to determine if volume reduction methods may be applicable to this site.

The U. S. Environmental Protection Agency has prepared a "Characterization Protocol for Radioactive Contaminated Soils" designed to evaluate the feasibility of applying one or more volume reduction technologies for remediation of contaminated soils. This protocol may provide some useful information on how to evaluate the potential applicability of volume reduction technologies. This protocol is attached (Attachment 1) for your consideration.

6. <u>Surface/Subsurface Contamination and Affected/Unaffected Areas</u>:

Surface gamma exposure rates should not be used as the sole indicator of potential subsurface contamination in determining "affected" and "unaffected" areas. The SCP indicates (Section 5.2.1, pp. 36-38) that surface gamma exposure data, below background levels, are indicative of uncontaminated subsurface soils and may be useful in dividing the site into affected and unaffected areas. NRC staff has examined the subsurface gamma log data in the 36 boreholes given in RSA 1990 report, and the gamma survey data of surface soils at locations corresponding to each borehole location. NRC staff observed a large number of subsurface locations in the boreholes that showed elevated gamma exposure rates, whereas the corresponding gamma survey of surface soil indicated approximately background levels (For example, see surface gamma survey and gamma logging data for boreholes: BH21, BH26, BH7, BH29, and BH6). This indicates that background gamma exposure rates at the surface should not be used as the sole indicator of subsurface contamination. Thus, Molycorp should base its classification of affected and unaffected areas on surface as well as subsurface sampling and analysis, and on the historical usage of source material at the site. NUREG/CR-5849 provides guidance on the classification of affected and unaffected areas.

Also, historical information on source material processing and radiological surveys at this site suggest that the boundary of the affected area outlined in Figure 5-2 should be extended in the "active plant area" north of Caldwell Avenue. The discussion in the SCP relating to this Figure supports this position. The SCP states (Section 5.2, page 37) that "due to the historical usage patterns, there is a potential for contamination under or adjacent to the R & D offices and the process buildings west of Building 34, where the FeCb slag was produced". ORAU's previous survey of the site also identified elevated radiation levels under and adjacent to Building 34 and adjacent to Buildings 20, 25, 26, 28, 29 (R & D Bldg,), 30 and the Bag House east of Building 20. Also, based on a 1971 AHP report, Building 33 was a former radioactive material storage area for FeCb ore. According to the guidance provided in NUREG/CR-5849, affected areas are defined as areas that have potential radioactive contamination (based on plant history) or known radioactive contamination (based on surveys). Therefore, the areas described above, currently outside of the affected area shown in Figure 5-2, should be included as affected areas unless Molycorp can demonstrate that these areas are unaffected (i.e., no radioactive material above background concentrations). The SCP should also identify any affected areas outside the site boundary resulting from past operations at this facility. For example, areas adjacent to Chartiers Creek and outside the facility fenceline, that are either known or suspected to be contaminated, should be included as an affected area.

In addition, Molycorp will also need to provide adequate administrative control procedures in its remediation plan to ensure that "unaffected" areas do not become contaminated during remediation. If adequate control procedures are not established, the unaffected area will need to be resurveyed as part of the termination survey after decommissioning.

7. <u>Use of NUREG/CR-5849 for Guidance on Sampling and Hot-Spot Characterization</u>:

NUREG/CR-5849 provides instructions for performing final radiological surveys along with guidance on sampling and hot-spot characterization to support a facility's license termination application. This guidance would not specifically apply to the collection of information during site characterization. However, if Molycorp plans to use site characterization data to support a final termination survey, then Molycorp needs to ensure that the information is collected under a rigorous QA/QC program and in accordance with the procedures discussed in NUREG/CR-5849.

8. <u>Use of the Gamma Logging Technique to Derive $^{232}$Th concentrations</u>:

Molycorp's consultant (RSA) provided a report (RSA, December 1992) that attempted to justify the calibration factors used to derive $^{232}$Th concentrations from subsurface gamma radiation data (count rates) in borehole gamma logging measurements. The NRC staff has reviewed this report and believes that data from this technique will not be adequate to demonstrate compliance with NRC's existing decommissioning guidelines for thorium and uranium contamination in soil (1981 BTP). These concerns were raised previously in NRC's October 1992 comments. In its earlier comments, the NRC staff indicated that it is important to establish how data from this technique would be used. RSA's report clarifies the intended use of these data. The report states (bottom of page 26) that "We believe it is appropriate that Molycorp use the quantitative determination of average $^{232}$Th concentration underground determined with in situ gamma measurements as a basis to establish cleanup criteria, as a basis for the dose assessment, and to demonstrate compliance."

This report indicates that Molycorp intends to use a four-step approach to comply with NRC decommissioning criteria. These procedures include: i) collection of exposure data (count rate) from subsurface gamma logging measurements, ii) conversion of gamma data (count rate) to exposure data (μR/h) using a calibration factor derived from field exposure data of a Pressurized Ion Chamber (PIC) detector located 1 meter above the surface, iii) conversion of the derived exposure data from step "ii" to concentration using Spiers (1968) and Beck (1972) conversion factors, iv) calculation of exposure or dose to critically exposed individual using RESRAD code with the input data derived in step "iii" for thorium concentrations. The following observations and concerns were identified based on the staff review of RSA's report.

1. Figure 10 of the report indicates that <u>no</u> correlation exists between gamma exposure rates and conventionally measured thorium concentrations.

2. This method tends to average contaminated slag present in localized high-activity spots over larger volumes of non-contaminated soil.

3. The 2.82 (μR/hr)/(pCi/g) calibration factor is based on direct radiation emanating from an infinite (area > 100 $m^2$ and thickness > 1 meter) slab source containing uniformly distributed radionuclides of the $^{232}$Th chain in secular equilibrium. At Molycorp's Washington facility, the subsurface contamination is not uniformly distributed, but rather occurs as discrete heterogeneous, and finite volumes of soil and slag.

Other concerns with the calibration for this technique exist. For example, Molycorp is calibrating NaI scintillometer count rate data (for subsurface samples, collected at depths 1-9 feet, which has an effective volume of soil with a mass of 0.5 metric ton) with PIC exposure rate data (for surface samples 0.66 meters thick with an effective volume of 100 metric tons) [See RSA 1992 report as amended on February 11, 1993, by letter from RSA to NRC]. These calibration procedures were presented on pages 20-23 and Graphs 2-6 (page 27) of the RSA 1990 report. The RSA calibration approach may also produce errors in the calibration due to the correlation of two different gamma distributions arising from two different volumes of samples representing different locations at the site. Thus, although RSA provided different correction factors for the two different geometries, NRC staff believes that the validity of this correlation is questionable.

The staff noted that the SCP presently lacks an adequate description of what is presently known about the site hydrogeology, and what future tasks are necessary to characterize the hydrogeology of the site. The SCP should also analyze previous site characterization work to provide the rationale and justification for the proposed site characterization activities outlined in the SCP. In its comments, the staff indicated that the SCP should include:

(a) An analysis and summary of information on the site background and physical setting;

(b) Analysis and summary of previous site characterization work relating to hydrogeology (e.g., flow direction, location of previous wells, leaching and mass transport properties, etc.);

(c) Analysis and summary of radiologic characteristics of surface water and groundwater; and

(d) A presentation of the conceptual site model, including an analysis and summary of the nature and extent of contamination; preliminary assessment of human and environmental impact; and the additional data needed to conduct a dose assessment.

The staff also noted other specific elements in the SCP that should be described in more detail, including the quality assurance plan, field sampling plan, types of tests that will be conducted to characterize the site hydrogeology, location and rationale for the selection of sites for new water wells, methods used to drill water wells, design and completion of water wells, type and frequency of water sampling and analysis performed on samples, and the identity of any computer codes under consideration for groundwater flow and transport modelling if known at this time.

11. Evaluation of Mixed Waste Contamination:

Molycorp should contact the Pennsylvania Department of Environmental Resources to determine the extent to which the potential presence of hazardous materials should be evaluated and characterized. The NRC believes that any characterization for hazardous chemicals should be comparable to characterization for radiological contamination. The NRC favors a single characterization plan dealing with both radiological and hazardous chemical wastes if possible.

12. Hot Spot Definition and Guideline Limits:

The SCP states (Section 1.2, p. 3) that "based on a limited underground survey (RSA, 1990) (32 boreholes) the thorium waste buried under and adjacent to the eight holding ponds on the west side of the site meets the Option 4 limits at all locations surveyed and on average, meets options 2 limits. Local hot spots underground generally do not exceed the Option 2 limits by more than a factor of 10." In accord with NUREG/CR-5849, contamination levels above 3 times NRC guideline levels are considered hot spots. Therefore, the contamination levels noted in these areas exceed NRC's current cleanup criteria. Also, Option 4 of the 1981 BTP is no longer viable because its reliance on institutional controls is inconsistent with NRC's definition of decommissioning. NRC's guideline value for total thorium under Option 2 of the BTP is 50 pCi/g. The SCP indicates that local hot spots generally do not exceed Option 2 limits by more than a factor of 10 (e.g., 500 pCi/g). As indicated above, NRC guidance states that the activity at any location should not exceed 3 times the guideline value, or 150 pCi/g total thorium in the case of Option 2. Further, the specific activity of $^{232}$Th in slag has been measured at 1250 pCi/g. Therefore, the concentration of thorium slag ($^{232}$Th and $^{228}$Th) where all daughters are present and in secular equilibrium could exceed 2000 pCi/g. Molycorp should use NRC's guidance in NUREG/CR-5849 for identifying hot spots in the termination survey or justify an alternative hot spot criterion.

13. Information on Regional Characteristics of Site:

The SCP indicates that the site characterization report will include a discussion of regional geology, if this information is obtainable without prohibitively costly studies. One available source of regional information for this area is the U.S. Department of Energy's (DOE's) 1983 Final Environmental Impact Statement (FEIS) on the Cannonsburg uranium mill tailings site. This FEIS (DOE/EIS-0096-F) is entitled *Remedial Actions at the Former Vitro Rare Metals Plant Site, Cannonsburg, Washington, Pennsylvania*. The Cannonsburg site is located less than 10 miles north of Molycorp's site in Washington, Pennsylvania. Given the proximity of these two sites and the fact that both sites are situated on Chartiers Creek, the FEIS may provide a valuable source of information for characterization with respect to regional geologic, hydrologic, meteorologic and other features relating to Molycorp's Washington site.

14. Determination of Background Soil Concentrations:

The determination of surface and subsurface background soil concentrations should be based on measurement of both direct radiation levels (gamma exposure rates) and laboratory analysis of soil samples. The SCP indicates (Section 5.4, p. 45) that 9 boreholes will be logged using a NaI probe in order to establish the background count rate due to gamma exposure from naturally occurring radionuclides in native soils and in other fill material. Soil samples should also be collected at regular intervals and analyzed to determine background soil concentrations. The SCP should also describe the methodology that will be used to select representative areas for determining background concentrations of $^{232}$Th and other radionuclides in subsurface media. NUREG/CR-5849 should also be consulted for guidance on conducting background surveys.

Enclosures:
1. EPA Characterization Protocol for Radioactive Contaminated Soils
2. ORISE Comments on Gamma Logging Technique

Enclosure #2

## SPECIFIC TECHNICAL COMMENTS

| Page No. | Paragraph | Line | Issue |
|---|---|---|---|
| 6 | 2nd | 1 | The SCP should include a "Legal Land Description" of the site. |
| 13 | 2nd | 1 | In using the MILDOS code to evaluate dose from airborne exposure, the SCP should indicate what values will be used for the "Dust Mass Loading Factor" and should present or describe plans to collect adequate wind and population data. |
| 13 | 1st | 12 | Molycorp should use the sensitivity analysis in the RESRAD code to assess effects of uncertainties estimates of certain parameters on projected doses. |
| 14 | 4th | 12 | The SCP should also include soil ingestion as one of the potential exposure pathways, or justify why exposure from this pathway is highly unlikely. |
| 18 | 3rd | 8 | If Molycorp is considering onsite stabilization/disposal of large volumes of contaminated material, above the 1981 BTP Option 1 levels, the SCP should describe what additional characterization will be performed to evaluate suitability of the site if such an alternative is selected. |
| 21 | 3rd | 4 | The SCP indicated that various other materials are present in layers between 0 and 10-12 feet thick. The SCP should elaborate on the characteristics of these materials or describe plans to characterize them. |
| 25 | 1st | 7 | The SCP indicates that the cinder and slag deposit will have a major influence on the overall conductivity of the aquifer. Molycorp should explain how this observation or phenomenon will affect selection of groundwater modeling codes and input parameters for such codes. |

| | | | |
|---|---|---|---|
| 26 | 1st & 2nd | 2 & 5 | The soil and vadose zone characterizations did not include determinations of the distribution coefficients ($K_d$'s) for each radionuclide using non-contaminated local soil. These parameters may be needed to assess transport properties of local soil if significant quantities of radionuclides, above the 1981 BTP Option 1 levels, will remain after remediation. |
| 27 | 1st | 4 | The SCP should indicate whether fracture-flow codes are necessary for simulation of groundwater flow conditions, and if so, which codes will be used. |
| 32 | 1st | 2 | The SCP should provide data on the mineralogical, chemical and radiological characteristics of the ore imported from Araxa, Brazil. |
| 32 | 4th | 2 | The SCP indicates that chemical analysis will be performed on a sample of FeCb slag. Will this sample represent the chemical composition of the bulk slag? Is the slag chemically, physically and radiologically homogeneous? Molycorp will need to justify the number of samples and frequency of sampling considering the NRC guidance document NUREG/CR-5849. |
| 33 | 5th | 2 & 3 | The SCP indicates that slag sampling will comprise six samples: three samples to be collected from the slag pile, two samples from the crushed slag which was pumped to a settling basin, and one slag sample from an undefined area at the site. The issue of sampling representation needs to be addressed in this regard. As a minimum, approximately 30 samples from each type of slag should be collected and analyzed. |
| 35 | 3rd | 1-15 | The licensee indicated that leachability studies will be conducted on slag samples. The number of samples was not identified. The applicant stated that one of the methods to be adopted for determination of leachability is EPA's Toxicity Characteristics Leaching Procedure (TCLP) test. Molycorp did not indicate in the SCP any plans to determine the host soil distribution coefficient for thorium. Molycorp should provide the specific number of leachability tests to be conducted and the basis for selecting such a number. The applicant should use ANSI/ANS-16.1-1986 |

| | | | |
|---|---|---|---|
| | | | leachability test in addition to EPA's TCLP test. Molycorp should also determine the distribution coefficient of the host soil for thorium and decay products, and other possible radionuclides that may be present in the soil (e.g., $^{238}U$ and decay products). |
| 38 | 2nd | 1-9 | The SCP indicates that the external gamma survey will be useful in quantifying concentrations of thorium within a radius of 10 meters of the measurements. This has not been demonstrated. The applicant needs to consider all comments discussed above associated with this issue. |
| 38 | 2 | 4-9 | Based on the 1981 BTP, Option 1 soil concentrations are sufficiently low so that no individual will receive a direct exposure rate in excess of 10 μR/h above background. Therefore, 10 μR/h should be used in place of 14 μR/h for 5pCi/g of $^{232}Th$ (in equilibrium with its daughters). Also, the NRC meaning of background radiation includes radiation from cosmic sources and naturally occurring radioactive materials. |
| 38 | 4 | 1-4 | In conducting the surface survey in unaffected areas, it is not clear why readings will not be recorded below 20 μR/h. Readings should be documented in all areas surveyed. |
| 41 | 2nd | 1-4 | Molycorp is planning to collect 200 soil samples from the cores and is planning to conduct $^{232}Th$ analysis by ICP. Molycorp should describe its sampling procedures to ensure that samples are representative and collected using appropriate methods. |
| 45 | 3rd | 1-10 | The SCP states that 21 wells have been drilled from which groundwater samples can be and have been taken. The licensee needs to explain and illustrate the following: i) locations of these wells, ii) hydraulic gradient based on water level measurements, iii) construction of the wells and their ability to yield water levels and samples that are representative of in-situ conditions, and iv) techniques used to analyze water samples and results of such analyses. |

| | | | |
|---|---|---|---|
| 57 | 2nd | 1-10 | Appendix A of the SCP describes an approach for selecting input data for leach rate and distribution coefficients. This approach is not acceptable because it relies on the leach rate of the slag in a bulk form. If significant quantities of radionuclides above the 1981 BTP Option 1 levels will remain after remediation, the licensee needs to also assess the leach rate for the finely ground slag which would have a much larger surface area and could be expected to exhibit increased leachability. |
| 57 | 3rd | 1-3 | The applicant stated that default values are presented in Appendix E. There is no such appendix attached to the SCP document. The default values should be incorporated in the SCP. |
| Figure 5-2 | | | Add building numbers to figure. |

United States Environmental Protection Agency

Office of Solid Waste and Emergency Response

Publication 9380.1-10FS
May 1992

EPA

# Characterization Protocol for Radioactive Contaminated Soils

Office of Emergency and Remedial Response
Office of Radiation Programs, ANR-458

Quick Reference Fact Sheet

The Superfund Amendments and Reauthorization Act of 1986 (SARA) mandates that remediation at Superfund sites must utilize a permanent solution and alternative treatment technologies or resource recovery options to the maximum extent practicable. Treatment technologies that permanently and significantly reduce the mobility, toxicity, or volume of hazardous substances are preferred in this requirement. However, in most remedial actions conducted to date at radioactive sites, the radioactive soil has been excavated and stored in temporary above-ground containment facilities. To alleviate this storage situation the Office of Radiation Programs has developed an innovative soil characterization process applicable in the RI/FS stages of the Superfund process to support the development of technologies for on-site volume reduction of radioactive soils by physical separation[1,2] technologies.

## BACKGROUND

The volume reduction methods employed are based on physical/mechanical technologies that are common to the coal and ore processing industries. These common technologies have been adapted, modified, and directed toward the task of soil restoration. This soil characterization protocol is designed to demonstrate the suitabilitiy (or lack thereof) of various radioactivity contaminated soils for physical or chemical separation processes. These could potentially remove the radioactive fraction from the soil, thus producing a smaller volume requiring disposal. The protocol combines radiochemical and petrographic analysis of soil fractions, focusing on the contaminant waste and its particle size distribution in the host media. Soil remediation by volume reduction takes advantage of the fact that radionuclide contaminants concentrate generally in the smaller soil size fractions, and tend to selectively associate with materials that possess unique physical and/or chemical properties. The data obtained by following this protocol are used as the first phase of remediation assessment to determine if volume reduction is feasible.

## CHARACTERIZATION DESCRIPTION

This soil characterization protocol examines the various size fractions of a representative sample of radioactive soil from a Superfund site, to provide the following information:

- Grain size distribution curve which relates weight percent versus particle size.
- Relationship of radioactivity to particle size.
- Identification of the mineral/material composition and physical properties of the radioactive contaminants for the various size fractions.
- Identification of the mineral composition and physical properties of the host material for the various size fractions.
- Addtional information on contaminant and host material mineralogical and physical properties in support of feasible volume reduction techniques, e.g., magnetic properties.



Attachment 1

These data are used to conceptualize a site-specific volume reduction process based on one or more of the following technologies:

- screening,
- classification,
- gravity separation,
- magnetic separation,
- flotation,
- chemical extraction,
- washing,
- scrubbing,
- surface de-bonding, and
- attrition.

The two-tiered soil characterization protocol, as shown in Figure 1, consists of feasibility analyses (Tier I), and optimization analyses (Tier II), as necessary, to cost-effectively maximize the volume reduction.

## Pre-Tier I

Prior to Tier I laboratory tests, the representative contaminated soil samples obtained in compliance with EPA and DOE directives from a site[3,4,5] are radiologically screened to assure that the activity levels are within laboratory license requirements and that proper safety practices will be applied. Additional chemical analyses should be performed on a portion of each soil sample for the presence of organic and heavy-metal constituents if that information has not been previously collected. This information not only identifies hazardous constitutents (e.g., cyanide, heavy metals, chlorinated hydrocarbons), but also contributes to the mineralogical determination of the soil.

The remaining portions of each soil sample are oven dried at 60°C prior to weighing. The upper limit of 60°C is specified in order to maintain the mineral integrity of the soil by preventing the loss of water of hydration associated with the mineral structures which occur in some clays and other minerals at low temperatures.

## Tier I

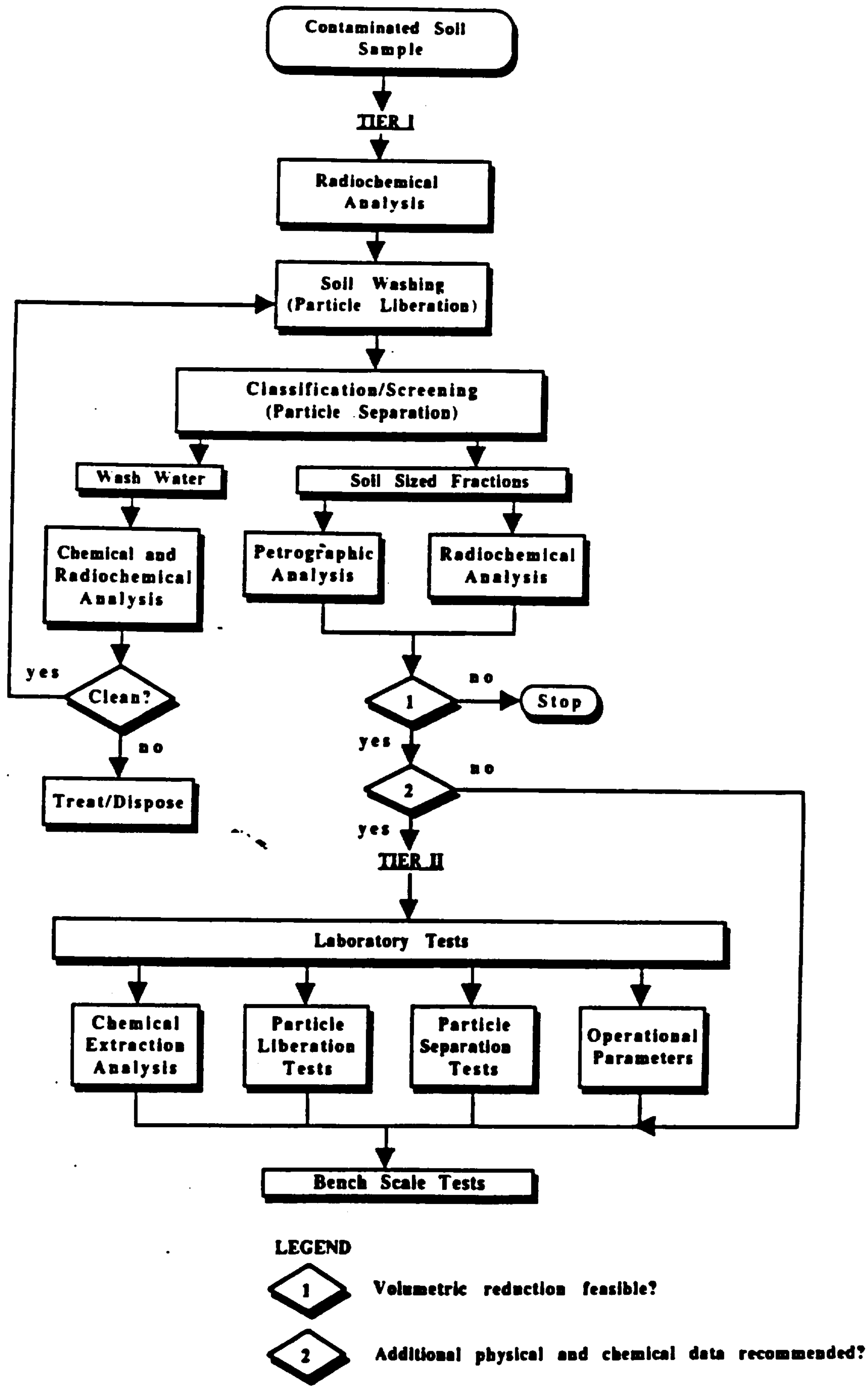
Tier I begins with radioanalysis of the dry soil samples by high-resolution gamma spectroscopy, and if necessary, alpha and beta spectroscopy analysis (using standard leaching/digestion and chemical methods[6]) to determine the level and type of activity present in each sample.

Physical separation of the soil particles is accomplished by mixing at least 250 grams of each soil sample with water to produce a liquid-to-solid (L/S) ratio of 5/1, agitating the mixture with a vigorous motion for 30 minutes at ambient temperature, and wet screening[7] through a set of nested sieves. In some site specific cases it may be advantageous to perform a less vigorous wash because of the nature of the constituents. The standard sieves include at least mesh sizes 4 (4.75 mm), 50 (0.30 mm), 100 (0.15 mm), and 200 (0.075 mm). Each soil fraction is dried at 60°C, weighed, and analyzed for radionuclide activity. From this procedure the weight and radionuclide distribution by particle size is determined. A similar separation is also performed using hydroclassification methods. The results of these tests indicate the compatability of the soil to remediation by particle-size hydroseparation techniques.

[NOTE: All water used must be collected and analyzed since it may contain transferred radioactive contaminants, Target Analyte List metals, volatile organic solvents, and/or pesticides. The analytical results will determine if the water can be recycled, safely disposed down a drain, or if it must be treated as a hazardous waste.]

Petrographic analysis is conducted on each of the size fractions to identify the mineral/material composition and physical properties of the radioactive contaminants and host materials. Petrographic procedures[8,9,10] include the use of binocular and petrographic microscopes to provide a statistical point count of all materials larger than silt-size to 0.038 mm (400 mesh size), and x-ray diffraction analysis of fines less than 0.038 mm size. Density separations are made on sand and silt size fractions (0.30 to 0.045 mm) to concentrate heavy particles greater than 3.0 specific gravity using sodium polytungstate as the separating liquid. The heavy fractions, in many cases, provide focus on radioactive particles which tend to concentrate in minerals or anthropogenic radioactive materials of the heavy fractions. The degree of weathering, presence of coatings, particle shape, surface texture,

Figure 1: Soil Characterization Flow Chart



hardness, magnetism, and degree of aggregation or homogeneous nature are also physical properties examined for interpretations that relate to adsorption, waste form, and potential physical separation methods.

## Tier I Report

Tier I tests results are gained from the petrographic and radiochemical analysis of the size fractions, as depicted in Figure I, to assess the feasibility of using volume reduction as a remediation technology. The test results include a grain size distribution curve of weight percent versus particle size, graphic data on activity level versus particle size, and tables and graphs on complete physical and mineralogic descriptions. This data is instrumental to the interpretation of the radioactive contaminants concentration in specific size ranges and the physical similarity and difference of the contaminants in relation to host materials.

It is assumed that the petrography and radiochemistry will be performed by personnel who are qualified by education and experience to employ the methodology specified and that recommendations for additional tests to validate key parameters for future tests will be incorporated in the report, e.g., recommend analysis of diagnostic elements that constitute chemical signatures to radioactive compounds. Radiochemical data should also be correlated with mineralogic data for interpretations, e.g., secular equilibrium of radionuclides to validate natural radioactive mineral assemblages reported or in the event of non-secular equilibrium of radionuclides, to reflect on anthropogenically enhanced radioactive waste forms in the radioactive soil. Any historic data on the ore minerals used and chemical processes used to convert the radionuclides to anthropogenic compounds should also be reported for the forensic data it might provide to support the list of radioactive compounds reported in the Tier I testing.

The Tier I report will provide an assessment of the technical feasibility of using one or more of the volume reduction technologies. Based on the feasibility of the most promising alternative, the Tier I report will also provide recommendations on further testing (Tier II) focusing on the validation of key factors that affect volume reduction. On the other hand, an evaluation of the test data could lead to the preliminary conclusion that volume reduction is not technically feasible.

## Tier II

If the Tier I test data indicates the soil is satisfactory for remediation consideration Tier II testing is conducted. Tier II tests are designed to collect additional data for further characterization of contaminated soils. For example, additional soil fractions may be tested to focus on the mineral phase of opaque constituents, particle coatings, or special materials requiring more precise instrumentation for validation of particles than was made available for Tier I tests. Additional tests may also be necessary to provide optimum soil separation sizes. These tests can be performed with small soil volumes. The results are to be used to plan bench-scale tests that are designed to take advantage of unique physical and chemical characteristics of radioactive contaminants and host soil constituents. Tier II tests to be considered are in support of one of the following general categories of treatment technologies:

- Particle separation,
- Particle liberation, and
- Chemical extraction.

Particle separation is the separation of a mixture of various particles into two or more portions. For example, magnetic separation separates a mixture of soil particles based on the difference in magnetic susceptibilities.

Particle liberation is the physical de-bonding of contaminated particles or coatings from clean particles. For example, attrition removes friable coatings from soil particles.

When performing chemical extraction, the soil is immersed in a solvent that has been carefully chosen to preferentially extract the contaminant.

Selected chemical extraction tests may be performed in Tier II (as shown in Figure 1) to determine the potential for remediation by simple chemical extraction. Chemical extraction tests are designed to remove contaminants from selected particle-size fractions or from whole soil if it proves to be unsuitable for remediation by physical separation techniques. For example, the latter possibility exists for soils with uniform radionuclide distribution among the various particle sizes.

The chemical extraction tests are conducted on 100 gram samples of selected soil fractions or whole soil. On a sample in which the nature of the contaminant is poorly known, extractions are performed at 90°C with water and each of four extracting reagents known to be effective in removing various radionuclides from contaminated soils. These reagents include dilute solutions of hydrochloric acid, nitric acid, sodium chloride with hydrochloric acid, and sodium hexametaphosphate. With foreknowledge of the presence of a contaminant in a particular mineral form, one or two other select extracting reagents specific for the mineral are also included in these preliminary tests. The results of these tests provide information about the potential of chemical extraction as a complement or alternative to remediation.

Along with Tier I results, data from the Tier II tests can be used to select bench-scale test equipment for conducting remediation tests of contaminated soils. The initiation of bench-scale testing is based on the preliminary information provided by soil characterization which assesses the differences in physical properties between the waste form and host materials. For example, for physical volume reduction the applicable information relating to the differences in the waste form from the host material may be classified as follows:

- Relationship of radioactivity to particle sizes.
- Relationship of radioactivity to particle densities.
- Relationship of radioactivity to particle wettabilities.
- Relationship of radioactivity to particle shapes.
- Relationship of radioactivity to particle magnetic properties.
- Relationship of radioactivity to friability of particles or of particle coatings.
- Solubility of contaminants.

The most important information is the relationship of radioactivity to particle sizes. The information on the other physical properties such as density is obtained by identifying the waste form and host matrix using petrographic techniques. It is important to develop this petrographic information for various ranges of particle size. And, based on a careful analysis of this information, a preliminary bench-scale test can be designed using batch applications of physical methods if a difference in the physical properties stated exists between the radioactive contamination and the host materials.

## Tier II Report

The Tier II report consists of the test data generated in the categories depicted in Figure I. In most cases, except for the chemical extraction tests, the Tier I recommendations provided focus on amplification of specific objectives that appear in tables and graphs in the report. Tier II tests results, just like Tier I tests results, are evaluated to assess the feasibility of using volume reduction, and if so, to what degree. The evaluation has focus on the physical differences previously cited between the waste form and host materials for design of bench-scale tests that will provide more realistic quantification of degree of separation possible by volume reduction equipment. The nature of the site specific soil drives the testing performed so that, while no standard format is presented, it is assumed that the test objectives will be governed by qualified personnel skilled in the state of the art of quality benefication testing. The report data can thus generate preliminary cost and time assessments that relate to the feasibility of volume reduction for the particular site.

## SUMMARY

The characterization protocol described above for radioactive contaminated soils depends mainly upon the physical, chemical, and mineralogical characteristics of the soil and radioactive particles with respect to grain size. The intent is to return the "clean" soil fractions, which can be a major portion of the soil (by volume), to the ground, preferrably on-site.

Supplemental information concerning this protocol may be obtained from James Neiheisel or Mike Eagle at (202) 260-9630, ANR 461, U.S. Environmental Protection Agency, 401 M Street SW, Washington, D.C. 20460.

## REFERENCES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10. Neiheisel, James, *Characterization of Contaminated Soil from the Montclair/Glen Ridge, New Jersey Superfund Sites,* U.S. EPA Office of Radiation Programs, EPA/500/1-89-012, 1989.

ORISE
OAK RIDGE INSTITUTE FOR SCIENCE AND EDUCATION
ENERGY/ENVIRONMENT SYSTEMS DIVISION

January 27, 1993

Mr. Chad Glen, Project Manager
U.S. Nuclear Regulatory Commission
Decommissioning and Regulatory Issues Branch
Division of Low-Level Waste Management and Decommissioning
11555 Rockville Pike
Rockville, MD 20852

SUBJECT: JUSTIFICATION OF THE CALIBRATION FACTOR USED FOR BOREHOLE MEASUREMENTS OF UNDERGROUND RADIATION EXPOSURE RATES AND AVERAGE $^{232}$TH CONCENTRATION AND RESPONSE TO NRC COMMENTS DATED OCTOBER 29, 1992, RADIATION SURVEILLANCE ASSOCIATES, INC. DECEMBER 30, 1992.

Dear Mr. Glen:

ESSAP has reviewed the subject document and offers the attached comments for your consideration. Contact me at (615) 576-2908 if you have any questions regarding this information.

Sincerely,

Michele R. Landis
Project Manager
Environmental Survey and
Site Assessment Program

MRL:kew

Attachment

cc: D. Tiktinsky, NRC/6E6
T. Mo, NRC/6H3
J. Hickey, NRC/6H3
J. Swift/F. Brown, NRC/6H3
NRC/PMDA, 6E6
J. Berger, ORISE/ESSAP
File/212

Attachment 2

to the capabilities of the instrumentation and technique, there is not adequate information provided to evaluate the detection sensitivity under the various situations anticipated, and thus review the use of the in-situ measurements to complement or replace sampling.

**Molycorp's Reply to the NRC Comments, Dated Feb. 25, 1993, on the Site Characterization Plan for the Washington, PA, Plant Site**

**General Comments**

✓ (1) Review and Analysis of the Previous Characterization Work: The NRC comments state that the "SCP does not discuss how the results of past site characterization efforts have been used in planning future characterization work."

Molycorp's reply: The SCP has been rewritten to clarify this. These studies are now cited throughout the SCP. On page 5 of the SCP we state that existing site characterization work constitutes an existing base of knowledge and that the site characterization study will expand upon this knowledge base. Throughout the SCP, we discuss the ways in which the complete data base on the site (which will include results from the site characterization study and data from previous studies) will be used to develop a site decommissioning plan. For example, in section 3, we describe how the results of the site characterization study will be used in dose assessment. All data, from previous and current studies will be used to do this.

Section 2.3 states that past characterization work will be used to make a preliminary evaluation of contamination. In section 5.1 (page 31) we cite the ORAU report, the Applied Health Physics report, and the RSA report. We point out that the inventory of the slag pile is available from the Applied Health Physics report and that gamma exposure rates are available from the ORAU and RSA reports. On page 36 we state the existing data has been used to divide the site into affected and unaffected areas (to the extent currently possible), and on page 37 we state the borehole coverage reported in the RSA report will be extended to include all affected areas. Section 5.2.2 on page 39 also cites the RSA report. Section 2.1.2 on page 7 of the SCP states that the SCR will include a section that summarizes and explains historical facts and records, including past characterization work.

(2) Location of Boreholes and Selection of Samples: The NRC comment states: "The SCP should discuss the rationale for the number and selection of borehole locations, types and quantities of samples collected during site characterization, and clarify how these data will be used in planning site decommissioning or conducting a termination survey."

Molycorp's reply: The SCP has been rewritten to expand and clarify the rationale for selecting borehole locations and types and quantities of samples.

(3) Decommissioning Criterion: The NRC staff states that: "A dose criterion should not be used in place of NRC's existing decommissioning criteria. ...Recent discussions with Molycorp consultants also indicate that Molycorp may propose a remediation guideline value based on dose rate in place of NRC's existing soil concentration guidelines in the Branch Technical Position (BTP) entitled *Disposal or Onsite Storage of*

*Thorium or Uranium Wastes from Past Operations.* It is important to note, that the decommissioning guidelines for residual soil concentrations ... are the soil concentration limits in Options 1 and 2 of NRC's 1981 BTP."

Molycorp's reply: Molycorp has not committed or agreed to adhere to the established cleanup criteria given in the 1981 Branch Technical Position. Molycorp reserves the option to pursue alternative cleanup criteria for the Molycorp Washington, PA, plant site. However, Molycorp may propose to clean up the site under Option 2 of the 1981 BTP, which is described in the Branch Technical Position as "Disposal of certain low concentrations of natural thorium with daughters in secular equilibrium and depleted or enriched uranium with no daughters present when buried under prescribed conditions with no subsequent land use restrictions and no continuing NRC licensing of the material."

In order to qualify for Option 2, a licensee must demonstrate that it meets the prescribed conditions. Option 2 states that there are three prescribed conditions:

(a) No member of the public will receive a radiation dose exceeding those in Option 1 in the absence of intrusion into the burial grounds.

(b) The residual contamination must be stabilized in place and not transported away from the site.

(c) In the event of intrusion into the burial ground, the doses must be limited to the levels given in Option 2.

In order to demonstrate the first and third of these prescribed conditions, Molycorp must provide dose calculations.

We quote the pertinent sections of Option 2 from the BTP (bold face type added for emphasis):

"Under this option the concentrations of natural thorium and uranium are set sufficiently low so that no member of the public will receive **a radiation dose** exceeding those discussed under option 1 when the wastes are buried in an approved manner absent intrusion into the burial grounds. This option will require establishing prescribed conditions for disposal in the license, such as depth and distribution of material, to minimize the likelihood of intrusion. Burial will be permitted only if it can be demonstrated that the buried materials will be stabilized in place and not be transported away from the site. Acceptability of the site for disposal will depend on topographical, geological, hydrological and meteorological characteristics of the site. At a minimum, burial depth will be at least four feet below the surface. In the event that there is an intrusion into the burial ground, no member of the public will likely receive **a dose in excess of 170 millirems** to a critical organ. An average **dose not exceeding 170 millirems** to the whole body for all members of a general population is recommended by international and national radiation expert bodies to limit **population doses**. With respect to limiting **doses** to individual body organs, the concentrations are sufficiently low that no individual will receive **a dose in excess of 170 millirems** to any organ from exposure to natural thorium, depleted uranium or enriched uranium.

"The average activity concentration of radioactive material that may be buried under this option in the case of natural thorium

(Th-232 plus Th-228) is 50 pCi/g, if all daughters are present and in equilibrium."

The boldfaced phrases in the preceding quotation indicate that dose calculations are essential in evaluating Option 2.

The NRC has provided Molycorp with a document entitled "Calculation of Allowable Concentrations for Four Disposal Options," which provides the dose calculations upon which the soil concentration limits stated in the BTP are based. Table 4 of that document has a footnote that reads: "The ground is modeled as a plane area with uniform distribution of radioactivity. Assume a soil density of 2.5 g/cc." At the Molycorp, Washington, PA, plant site, the radioactivity is *not* distributed uniformly in the soil. For this reason, the soil concentration limit of 25 pCi/g of $^{232}$Th will need to be an average applied over dosimetrically reasonable volumes of soil.

One of the best procedure for demonstrating compliance with the Option 2 cleanup criteria would be as follows. (Please note that the following is presented as an example. It does not imply that Molycorp will necessarily propose to adhere to Option 2 in its decommissioning plan.) (1) Future land use scenarios are modeled at the site, including both a scenario that assumes the absence of intrusion into the burial site, and a scenario that assumes intrusion. (2) Dose calculations are provided for each scenario, demonstrating that the residual thorium bearing material buried at the site is not likely to produce doses in excess of the dose limits given in Option 2. If the dose calculations demonstrate that the residual contamination at the site is at or below a level that is *equivalent* to the dose from 25 pCi/g of $^{232}Th$ that is uniformly distributed in soil, then the cleanup criteria are satisfied. Demonstration of equivalency between the level of residual contamination and the soil concentration limits in Option 2 would be based on dose estimates and calculations. As a part of the site decommissioning plan based on the above procedure, we would request that the NRC approve the scenario modeling proposed for the site, prior to the start of decommissioning. These scenarios would be part of the decommissioning plan sent to the NRC for evaluation.

Additionally, due to the non-homogeneous nature of the site with respect to radioactivity, relying solely on soil sampling may not provide an accurate picture of the contamination.

(4) Radiological Characterization of Site: The NRC states: "The primary objectives of Molycorp's radiological characterization efforts should be to assess the extent of contamination above background levels, and to identify locations and distributions of highly contaminated areas that may propose special handling concerns during decommissioning." The comment also says that site characterization should be "based on gamma screening coupled with direct measurement of thorium concentration."

Molycorp's reply: Molycorp agrees that the primary objective of the Site Characterization Study described in the SCP is to assess the extent of contamination. The NRC has also acknowledged that gamma logging is an appropriate technique for identifying the general zone of contamination. Meeting the primary objective of the SCP can be accomplished satisfactorily by a combination of gamma logging and soil sampling. In the Site Characterization Report, we will identify the general zones of contamination based on gamma logging and approximately 440 soil samples. (Please see our reply to comment 5, below, for a further discussion of the relationship between the site characterization plan, the site characterization study, and the site decommissioning plan.)

(5) Characterization to Evaluate Volume Reduction Technology: The NRC suggests that Molycorp "consider an alternative approach of characterizing and remediating the site simultaneously." The NRC also states that the SCP does not "discuss the collection of information needed to evaluate the feasibility of using volume reduction technologies."

Molycorp's reply: Our view of the purpose of each step in the decommissioning process is as follows:

(a) The Site Characterization Study. The purpose of the Site Characterization Study is to characterize the site as it exists prior to remediation and thereby obtain sufficient information to develop a decommissioning plan. It is not the objective of this study to demonstrate compliance. However, much of the information collected for this study will be useful for demonstrating compliance at a later stage in the decommissioning process. The primary objectives of the study are to identify the chemical and radiological properties of contaminants on site, identify the depth and extent of distribution of contaminants on-site, and document the geological and hydrological properties of the site that will affect the stability and mobility of residual contaminants. This information will be used to develop decommissioning alternatives.

(b) The Site Characterization Plan. The purpose of the SCP is to describe the Site Characterization Study, before the study is carried out. The SCP serves as a guide and a protocol to be followed during the conduction of the Site Characterization Study. In addition, part of the study will consist of excavation of limited areas to investigate the suitability of soil segregating techniques and volume reduction technologies.

(c) The Site Characterization Report: This report will present and interpret the results of the Site Characterization Study. It will not discuss the ways in which those results will be applied toward decommissioning of the site.

(d) The Site Decommissioning Plan. The Site Decommissioning Plan will describe the methodology that Molycorp will employ to reduce the residual contamination at the site, and will describe the methodology that Molycorp will employ to demonstrate compliance. The plan will include simultaneous remediation and characterization. It will also include the use of volume reduction technologies if such are found to be useful and appropriate for the site.

(e) Site Decommissioning. The Site Decommissioning phase consists of the execution of the decommissioning plan.

(f) Closure Survey. The closure survey will be conducted to demonstrate compliance. The data presented in the closure survey will be collected during the decommissioning phase. It will be supplemented by data from the Site Characterization Study and from previous characterization work, whenever this is appropriate.

Molycorp is presently investigating and evaluating current volume reduction technologies. It is the role of the contractors who offer such services to demonstrate their feasibility. The scope of the SCP is limited to site characterization. It does not include the demonstration of technologies. The site decommissioning plan will contain information demonstrating the utility of any volume reduction technology to be employed in decommissioning.

(6) Surface/Subsurface Contamination and Affected/Unaffected Areas: The NRC comment says that "Surface gamma exposure rates should not be used as the sole indicator of potential subsurface contamination in determining 'affected' and 'unaffected' areas. The SCP indicates (Section 5.2.1, pp. 36-38) that surface gamma exposure data, below background levels, are indicative of uncontaminated subsurface soils and may be useful in dividing the site into affected and unaffected areas." The NRC also suggests that "the boundary of the affected area outlined in Figure 5-2 should be extended in the 'active plant area' north of Caldwell

Avenue. ...The SCP should also identify any affected areas outside the site boundary resulting from past operations at the facility."

Molycorp's reply: Molycorp does not intend to use surface gamma exposure rates as the sole indicator of subsurface contamination. Section 5.2.1 is entitled "Surface Gamma Survey." It deals only with surface soils. Section 5.2.2 deals with subsurface soils. These sections have been rewritten to explicitly state that surface readings do not detect the presence of sufficiently deep subsurface contamination.

Figure 5.2 in the SCP is only meant to show areas that are currently classified as affected areas, based on past site characterization work. The status of other areas in the plant is not presently known because in-depth characterization work has not been completed there. These areas will be completely surveyed for both surface and, where historical operations indicate there is any possibility of past burial of material, for subsurface radiological contamination, as part of the site characterization study. Final classification of all potentially affected areas will be provided in the site characterization report, which will be submitted to the NRC after the site characterization study is completed.

Because the status of the areas not shown as affected in Figure 5.2 of the SCP is presently not known, we are unwilling to classify them as affected. The site characterization study will determine what portion of these areas are unaffected. In particular, the soil underneath buildings that were constructed before the processing of FeCb ore began can be assumed to be unaffected. Also, areas that have been under pavement prior to and during the processing of FeCb are unaffected. For the purposes of the SCP, we will divide the site into areas that are known to be affected, and areas whose status is unknown. Under this classification system, Figure 5.2 will be unaltered. In the SCP, we made several ambiguous statements which suggested that areas not shown as affected in Figure 5.2 are thought to be unaffected. These statements are unwarranted and have been deleted from the SCP.

(7) Use of NUREG/CR-5849 for Guidance on Sampling and Hot-Spot Characteristics: The NRC comment states that "if Molycorp plans to use site characterization data to support a final termination survey, then Molycorp needs to ensure that the information is collected under a rigorous QA/QC program and in accordance with the procedures discussed in NUREG/CR-5849."

Molycorp's reply: The SCP lacked an adequate QA/QC plan. An outline of the QA/QC program that will be developed and implemented during the site characterization study has been included as an Appendix to the SCP. The complete QA/QC plan will be submitted as part of the site decommissioning plan.

We wish to also make a general observation concerning the applicability of the procedures in NUREG/CR-5849. NUREG/CR-5849 provides detailed guidance concerning the methodology for averaging over surfaces. The methodology covers surfaces in buildings, on equipment and fixtures, and in open land areas. The document does not, however, address the problem of averaging over volumes of contaminated soil. The guidance is stated in terms of activity per unit surface area. There is no guidance for extending the averaging methodology to averages taken in terms of activity per unit volume of soil. The contamination present at the Molycorp Washington, PA, site is largely subsurface and, therefore, averages must be taken over some volume, rather than a surface area. Since the existing guidance does not address this situation, a site specific averaging methodology must be included as part of the site decommissioning plan and approved by the NRC . Molycorp intends to propose an averaging method based on dose modeling, gamma logging, and subsurface and surface soil sampling.

(8) Use of the Gamma Logging Technique to Derive $^{232}Th$ Concentration: In this comment, the NRC raises specific concerns and objections regarding the use of gamma logging for the purpose of dose assessment and demonstration of compliance.

Molycorp's reply: We have reviewed the specific concerns and objections regarding the gamma logging technique provided by both the NRC and ORISE. Accordingly, we intend to conduct further experiments and develop further refinements aimed at providing sufficient information to answer these objections to the satisfaction of the NRC staff. The NRC has acknowledged that gamma logging is adequate for identifying general zones and extent of contamination. The SCP, as written, utilizes soil sampling and gamma logging. This will provide sufficient information to develop a decommissioning plan.

(9) Establishment of Less Restrictive Cleanup Criteria: The NRC staff refers to section 3 of the SCP, which states that, due to the insolubility of the slag, a less restrictive cleanup criteria is indicated for the site.

Molycorp's reply: Section 3 of the SCP was too vague. It should have been phrased with specific reference to Options 1 and 2 of the 1981 BTP. One of the prescribed conditions for burial of material less than or equal to 25 pCi/g given in Option 2 is that the material be stabilized in place and not transported away form the site. The insolubility of the slag makes the Molycorp site a candidate for Option 2, which is less restrictive than Option 1. Section 3 of the SCP has been amended to remove this overly vague language.

(10) Insufficient Information in the Hydrogeology Section: The sections on hydrogeology have been extensively revised and rewritten to provide additional information.

(11) Evaluation of Mixed Waste Contamination: The NRC comment states: "The NRC favors a single characterization plan dealing with both radiological and hazardous chemical wastes if possible."

Molycorp's reply: Our present understanding of the Molycorp Washington site indicates the potential for hazardous or mixed waste at the site is largely confined to the area of the eight surface impoundments located at the west side of the plant area. Molycorp has prepared a plan for the closure of these impoundments, which has been reviewed by both the NRC and the Pennsylvania Department of Environmental Resources. This plan contains a detailed program for evaluating hazardous and mixed wastes that may be present in the impoundment area. In the interest of expediency, Molycorp intends to implement the impoundment closure plan and the site characterization plan simultaneously or sequentially, during the summer and fall of 1993. The implementation of the impoundment closure plan will have a significant impact on the hazardous and mixed waste characteristics of the site. In light of this fact, Molycorp intends to delay the development of a final plan to characterize the hazardous waste potential of the remainder of the site until after the impoundment closure activities are completed. The information collected during impoundment closure, coupled with data from past characterization work at the site, will constitute the majority of effort needed to characterize the site for hazardous material. After the impoundment closure work is completed, we will review all available data and develop a plan to collect any additional information that might be needed to completely characterize the site for hazardous material. An attempt to include the characterization for hazardous waste in the SCP would be premature and would lead to unnecessary delay in the implementation of the SCP.

(12) Hot Spot Definition and Guideline Limits: The NRC comment states that, "In accordance with NUREG/CR-5849, contamination levels above 3 times the NRC guideline levels are considered hot spots. ...Molycorp

should use NRC's guidance in NUREG/CR-5849 for identifying hot spots in the termination survey or justify an alternative hot spot criterion."

Molycorp's reply: The following is quoted from NUREG/CR-5849, p. 2.4:

This Manual assumes the following conditions for application of guideline values to decommissioning...

**Soil Activity**

Average radionuclide concentrations are at or below guideline values, established as acceptable by the NRC. For your land areas, averaging is based on a 100 $m^2$ (10 m x 10 m) grid area.

Reasonable efforts have been made to identify, evaluate, and remove, if necessary, areas of residual activity exceeding the guideline values. This Manual assumes that areas of residual activity exceeding the guideline value, known as elevated areas, are acceptable, provided that they do not exceed the guideline value by greater than a factor of $(100/A)^{1/2}$, where A is the area of residual activity in $m^2$, and provided the activity level at any location does not exceed three times the guideline value.

This quote again demonstrates that the guidance in NUREG/CR-5849 is directed toward averaging over areas. It does not address averaging over volumes of subsurface contaminated soil. The formula $(100/A)^{1/2}$ is a function of area. The methodology to be employed in applying this formula to soil that is located a number of feet, or even inches, below the surface is not specified, nor does it appear that the intent of NUREG/CR-

5849 as written is to give guidance about volumetric distributions of buried activity.

We again note that Option 2 of 1981 BTP permits the retention of buried material up to 50 pCi/g of total thorium, given that certain prescribed conditions are met. Those prescribed conditions are based on the principle of limiting the dose to populations that might utilize the site in the future. Under the conditions of Option 2, a quantity of thorium bearing FeCb slag is permitted to be left buried on site after unrestricted release. Given that some slag will remain on site, it will always be possible to take some small subsurface soil samples that exceed the limit in Option 2 by more than a factor of three. The slag has been shown to contain 1250 pCi/g of $^{232}$Th (2500 pCi/g $^{232}$Th + $^{228}$Th). If a 100 gram soil sample happens to contain a piece of slag of mass greater than 6 grams, and the whole sample is homogenized, then the sample will analyze to greater than 150 pCi/g total thorium, which is over three times the limit. Applying the criterion that no sample taken on site can exceed the limit by more than a factor of three is untenable at this site because soil samples, as they are collected in practice, average over a volume that is much too small to be meaningful in terms of potential dose to populations. It is Molycorp's position that subsurface concentrations should be averaged over a volume that *is* meaningful in terms of potential dose to populations.

In the decommissioning plan, we will state that all exposed soil surfaces onsite will meet the conditions for application of guidelines given in NUREG/CR-5849.

(13) Information on Regional Characteristics of Site: The NRC recommends that Molycorp refer to the FEIS from the Vitro Rare Metals Plant Site, Canonsburg, PA for information on regional characteristics.

Molycorp's reply: We wish to thank the NRC staff for drawing our attention to this valuable source of information.

(14) Determination of Background Soil Concentrations: The NRC comment states that "The determination of background soil concentrations should be based on measurement of both direct radiation measurements (gamma exposure rates) and laboratory analysis of soil samples. ...The SCP should also describe the methodology that will be used to select representative areas for determining background concentrations of $^{232}Th$ and other radionuclides in subsurface media.

Molycorp's reply: Molycorp agrees that it is appropriate to analyze soil samples from background boreholes. Since naturally occurring radionuclides are well homogenized in soil, the problem of averaging over a small volume is minimized in the case of background holes. The SCP has been rewritten to add a soil sampling program for the background boreholes.

## Specific Comments

| Page No. | Paragraph | Line | NRC Comment |
|---|---|---|---|
| 6 | 2nd | 1 | The SCP should include a "Legal Land Description" of the site. |

Molycorp's Reply: Appendix F has been added to the SCP providing a legal land description of the site.

| Page No. | Paragraph | Line | NRC Comment |
|---|---|---|---|
| 13 | 2nd | 1 | In using the MILDOS code to evaluate dose from airborne exposure, the SCP should indicate what values will be used for the "Dust Mass Loading Factor" and should present or describe plans to collect adequate wind and population data |

Molycorp's Reply: In Section 4.2 of the SCP, we state that data on the direction and magnitude of wind will be collected from the national weather service stations at the nearest airports to the Washington, Pennsylvania Facility. In section 4.5.1, we describe the demographic data that will be collected.

In section 3, Dose Assessment, we state that we will evaluate the MILDOS code for its utility in dose assessment for airborne exposure. Our evaluation of the utility of the code is not complete at this time. We will not complete this evaluation prior to the submission of the revised SCP. To do so would introduce a lengthy delay in the completion of the revised SCP, and this, in turn, would delay the start of the site characterization study. We are not prepared, at this point, to either commit to the use of the MILDOS code, nor to state values for specific input parameters, such as "dust mass loading factor." These decisions will be made after the evaluation is completed. If we employ the MILDOS code in the dose assessment part of the site characterization, we will include careful documentation of all input parameters in the Site Characterization Report.

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| 13 | 1st | 12 | Molycorp should use the sensitivity analysis in the RESRAD code to assess effects of uncertainties estimates of certain parameters on projected doses |

Molycorp's Reply: The SCP has been revised to indicate that the RESRAD code will be used to asses the affects of uncertainties estimates of certain parameters on projected doses.

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| 14 | 4th | 12 | The SCP should also include soil ingestion as one of the potential exposure pathways, or justify why exposure from this pathway is highly unlikely. |

Molycorp's Reply: The SCP has been amended to include soil ingestion as a potential exposure pathway.

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| 18 | 3rd | 8 | If Molycorp is considering onsite stabilization/disposal of large volumes of contaminated material, above the 1981 BTP Option 1 levels, the SCP should describe what additional characterization will be performed to |

evaluate suitability of the site if such an alternative is selected.

Molycorp's Reply: We have included a new section, 5.1.5, in the SCP which provides for an analysis of the distribution of thorium bearing slag with respect to particle size in soil samples from several areas of the plant. The data collected in this experiment will serve as an input to models of leaching under normal and saturated conditions, and to models of erosion under conditions of flooding.

In our reply to the General Comments by the NRC staff, particularly to General Comment number 3, we talk extensively about how the SCP includes the additional characterization needed to justify treatment of the facility under Option 2 of the 1981 BTP rather than Option 1. In addition, Molycorp may propose, as part of its Site Decommissioning Plan, that some amount of thorium bearing material be placed in engineered disposal cells. However the engineering specifications, the placement, and the relationship to the local hydrogeology of such cells is presently completely unknown. It is therefore impossible to include specific characterization plans aimed at justifying such disposal cells at this time.

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| 21 | 3rd | 4 | The SCP indicated that various other materials are present in layers between 0 and 10-12 feet thick. The SCP should elaborate on the characteristics of these materials or describe plans to characterize them. |

Molycorp's Reply: Chapter 4, entitled Physical Characteristics of Site, and, in particular, Section 4.6, on the hydrogeology of the site, have been extensively revised. Section 4.6 provides the outline of a study plan that, among other things, includes the characterization of the fill zone. Please refer to our reply to NRC General Comment #11 for a discussion of Molycorp's plans to characterize the site for hazardous and mixed waste.

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| 25 | 1st | 7 | The SCP indicates that the cinder slag deposit will have a major influence on the overall conductance of the aquifer. Molycorp should explain how this observation or phenomenon will affect selection of groundwater modeling codes and input parameters for such codes. |

Molycorp's Reply: At the present time, data is insufficient for a reliable determination of the nature, extent and distribution of the cinder, slag and other debris deposits in the fill zone. In the hydrgeological study plan, it is proposed that open trench excavation be made to ascertain these fill zone characteristics. At the present time it is anticipated that specific consideration will be needed in the selection of modeling codes and input parameters to accurately reflect the influence of the slag, cinder and debris deposits. It is anticipated that the field investigations during the site characterization study will be particularly conducted for characterization of the aquifer relative to such codes and parameters.

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| 26 | 1st & 2nd | 2 & 5 | The soil and vadose zone characterizations did not include determinations of the distribution coefficients ($K_d$'s) for each radionuclide using non-contaminated local soil. These parameters may be needed to assess transport properties of local soil if significant quantities of |

radionuclides, above the 1981 BTP Option 1 levels, will remain after remediation.

Molycorp's Reply: Whether or not it is necessary to determine the distribution coefficients for each radionuclide in the thorium series using non contaminated local soil depends upon the results of the leachability studies. Early studies show that the thorium and its daughter products are not leachable from slag under normal conditions and, therefore, is it reasonable to believe that these distribution coefficients will be irrelevant for this site. However if it turns out that the slag is more leachable than we have current reason to believe, the ($K_d$'s) will be determined for thorium and radium using non contaminated local soils found adjacent to Chartiers Creek. A sentence has been added to the section on soil characterization (4.6.12.1) which states that $K_d$'s will be measured if the leaching studies so indicate.

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| 27 | 1st | 4 | The SCP should indicate whether fracture-flow codes are necessary for simulation of groundwater flow conditions, and if so, which codes will be used. |

Molycorp's Reply: No predetermination has been made relative to the codes that will best simulate the characteristics of the fill zone. It may be that the fill zone should be simulated as an non-homogeneous mixed media rather than fracture flow. It is anticipated that the aquifer will be depicted as three zones, i.e., fill zone, clay zone and lower moderately permeable zone overlying the bedrock. The clay and lower zones are homogeneous, anisotropic, fine grained soils. The clay zone probably should be treated as an aquitard between the fill zone and the lower zone.

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| 32 | 1st | 2 | The SCP should provide data on the mineralogical, chemical and radiological characteristics of the ore imported from Araxa, Brazil. |

Molycorp's Reply: Molycorp has not been able to locate this information at the time of this writing. In order to prevent further delay in the submittal of the SCP to the NRC, we will not include data on the mineralogical, chemical and radiological characteristics of the ore imported from Araxa, Brazil. We will continue to search through 30 years of records to locate this information, and it will be included in the SCR, if possible.

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| 32 | 4th | 2 | The SCP indicates that chemical analysis will be performed on a sample of FeCb slag. Will this sample represent the chemical composition of the bulk slag? Is the slag chemically, physically and radiologically homogeneous? Molycorp will need to justify the number of samples and frequency of sampling considering the NRC guidance document NUREG/CR-5849 |

Molycorp's Reply: The NRC asks about the homogeneity of the chemical, physical and radiological properties of the slag. The homogeneity of the thorium content has been investigated in the past by Applied Health Physics. In a data set consisting of 19 samples taken from the slag pile, the standard deviation of the thorium content among these samples was 22% of a mean of 11.8 mg of thorium per gram of sample. The standard error of the mean was 5.2%. This indicates that the sampling program does not need to be to extensive to obtain results that are representative of the bulk slag present on site.

Following a careful perusal, we have concluded that NUREG/CR-5849 contains no guidance concerning the sampling of bulk contaminant for the purpose of determining its chemical composition. The guidance contained in that document on the subject of sampling is limited to soil samples in exterior areas, and sampling of surfaces in building interiors and on equipment. The only indirect guidance in NUREG/CR-5849 that seems applicable to the chemical analysis of slag is located in section 8.2, entitled "Measurement Uncertainty." We quote the pertinent section (page 8.4):

> The total uncertainty associated with a particular type of measurement can be determined empirically by performing repeat (6 to 10 recommended) measurements of several selected locations and determining the average and standard deviation of the data. This will provide an estimate of the upper bound on the magnitude of systematic uncertainties.

We have increased the number of samples to be analyzed from one to six, in order to comply with the recommendations of NUREG/CR-5849. Section 5.1.1.3 of the SCP has been rewritten to reflect these changes.

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| 33 | 5th | 2 & 3 | The SCP indicates that slag sampling will comprise six samples: three samples to be collected from the slag pile, two samples from the crushed slag which was pumped to a settling basin, and one slag sample from an undefined area at the site. The issue of sampling representation needs to addressed in this regard. As a minimum, approximately 30 samples from |

each type of slag should be collected and analyzed.

Molycorp's Reply: We disagree with the NRC's suggestion that 30 samples of each type of slag should be collected and analyzed. All FeCb slag present at the facility was produced by the same process so there is, in fact, only one type of FeCb slag present onsite. Except for minor variations in grade from batch to batch, the only variation found in the slag relates to its physical characteristics, in particular, the particle size, which is important for its effect on leachability. We will measure the thorium content in the slag samples taken from the pile so that their relationship to the mean established in previous studies (see previous section for data from prior Applied Health Physics Study) can be determined.

We also refer to our reply to the previous NRC comment, in which we quote from NUREG/CR-5849, Section 8.2, entitled "Measurement Uncertainty." That section of NUREG/CR-5849 states that 6 repeat samples are sufficient to empirically determine measurement uncertainties.

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| 35 | 3rd | 1-15 | The licensee indicated that leachability studies will be conducted on slag samples. The number of samples was not identified. The applicant stated that one of the methods to be adopted for determination of leachability is EPA's Toxicity Characteristics Leaching Procedure (TCLP) test. Molycorp did not indicate in the SCP any plans to determine the host soil distribution coefficient for thorium. Molycorp should provide the specific number of leachability tests to be conducted and the basis for selecting such a |

number. The applicant should use ANSI/ANS-16.1-1986 leachability test in addition to EPA's TCLP test. Molycorp should also determine the distribution coefficient of the host soil for thorium and decay products, and other possible radionuclides that may be present in the soil (e.g. $^{238}U$ and decay products).

Molycorp's Reply: In section 5.1.2.4 of the SCP, "Sampling of Slag," we stated that six samples of slag would be collected from the slag pile. From the wording in section 5.1.4, "Leachability of Slag," it was not clear that these samples would be used in the leachability study, which was our intention. We have reworded that section to clarify this point. We changed and clarified the sampling procedure described in section 5.1.2.4 somewhat since we think bulk slag is much less likely to be leachable than finely ground slag. Of the six samples described in section 5.1.2.4, four will be of crushed slag, and two will consist of discrete pieces of slag. The crushed slag will be distributed in a host matrix of soil and other fill material.

We have addressed the issue of determining the host soil distribution coefficient for thorium in our reply to a previous NRC specific comment (this specific comment was referenced to page 26 of the first SCP draft).

Section 5.1.4 of the SCP states that the leachability studies will be based on both the EPA TCLP parameters and the ANI/ANS.16 - 1986 leachability test.

We have indicated in past presentations to the NRC that the uranium content of the source material appears to be sufficiently small compared to the thorium that it can be neglected. However, if our radiological assays indicate evidence to the contrary, uranium and its daughter products will be included in the experimental protocols.

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| 38 | 2nd | 1-9 | The SCP indicates that the external gamma survey will be useful in quantifying concentrations of thorium within a radius of 10 meters of the measurements. This has not been demonstrated. The applicant needs to consider all comments discussed above associated with this issue. |

Molycorp's Reply: Please refer to our replies to NRC General Comments 3, 4, and 8 for a discussion of the use of gamma measurements to derive thorium concentrations in soil. In those replies, we state that Molycorp will conduct further studies in order to demonstrate the utility of these techniques. The results of these studies will be furnished to the NRC, relating average thorium concentration in soil to gamma exposure rates, both above and below the ground surface.

We also wish to point out that the practice of relating gamma exposure rates to average radionuclide concentrations in soil is well accepted and reported in the literature. The NRC can find the relationship between thorium content of uniformly contaminated ground and external exposure rate in NCRP Report #50. There are also a number of standard text books which provide information on this issue.

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| 38 | 2 | 4-9 | Based on the 1981 BTP, Option 1 soil concentrations are sufficiently low so that no individual will receive a direct exposure rate in |

excess of 10 μR/hr. Therefore, 10 μR/hr should be used in place of 14 μR/hr for 5 pCi/g of $^{232}$Th (in equilibrium with its daughters). Also, the NRC meaning of background radiation includes radiation from cosmic sources and naturally occurring radioactive materials.

Molycorp's Reply: The NRC 1981 BTP Option 1 states that: "...no individual may receive an **external dose** in excess of 10 microroentgens per hour above background" (bold face added for emphasis). The NRC BTP refers to dose rate, not to exposure rate. Exposure rate is a measure of the rate of free charge formation in air at a given point due to ionizing radiation. Dose rate is a measure of the rate of energy deposition in the tissue of living humans and animals due to the presence of ionizing radiation. Dose rate takes into account modifying factors such as occupancy. The BTP does *not* say that 5 pCi/g of $^{232}$Th, in equilibrium with its daughters and distributed uniformly in soil, will produce an exposure rate of 10 μR/hr. 5 pCi/g of $^{232}$Th, in equilibrium with its daughters and distributed uniformly in soil will produce an exposure rate of 14 μR/hr (according to the NCRP 50). This number is determined by the physics of the radiation involved.

In this section of the SCP, we point out that 5 pCi/g thorium distributed uniformly in soil produces 14 μR/hr exposure rate. In our decommissioning plan, we may adhere to Option 2, which states that no member of the public shall receive a dose rate above 10 μR/hr in the absence of intrusion into the burial ground. It is entirely possible to have exposure rates of 14 μR/hr present on site while keeping dose rates within the 10 μR/hr limit given in the 1981 BTP. We will leave the value of 14 μR/hr as it stands in the SCP, because this is the correct value for the exposure rate produced by 5 pCi/g of thorium in secular equilibrium and distributed uniformly in soil.

The definition a background radiation is determined by the instrumentation being employed to take the measurements. If the instrument responds to the cosmic radiation (e.g., a pressurized ionization chamber), then the background value must include the cosmic component. If the instrument does *not* respond to the cosmic radiation (e.g., a scintillometer), then the background value refers only to the gamma component, and the cosmic component must be omitted. The background measured is determined by the physics of the instrumentation being used. In the interest of technical accuracy, Molycorp will continue to use the correct definition of background for a given instrument.

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| 38 | 4 | 1-4 | In conducting the surface survey in unaffected areas, it is not clear why readings will not be recorded below 20 μR/h. Readings should be documented in all areas surveyed. |

Molycorp's Reply: It is Molycorp's intent to conduct a scanning survey of the type described in NUREG/CR-5849, Section 6.5.2 (page 6.7), which states that "Locations of direct radiation, discernible above the ambient level, are marked on facility maps and identified for further measurements and/or sampling." NUREG/CR-5849 does not recommend that measurements be recorded in areas where the direct radiation is not discernible above background levels. Section 6.4.2 of NUREG/CR-5849 document states that the minimum discernible increase in count rate for such a scanning survey is 2 to 3 times the ambient count rate. Since the background exposure rate is 8 to 10 μR/hr in the vicinity of the plant, 20 μR/hr corresponds approximately to the minimum discernible increase in count rate. This section of the SCP has been rewritten to reference NUREG/CR-5849.

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| 41 | 2nd | 1-4 | Molycorp is planning to collect 200 soil samples from the cores and is planning to conduct $^{232}Th$ analysis by ICP. Molycorp should describe its sampling procedures to insure that samples are representative and collected using appropriate methods. |

Molycorp's Reply: Section 5.2.3 has been rewritten to clarify the sampling procedures. An additional 200 soil samples to be taken by split spoon sampling of boreholes and analyzed by ICP have been added to the soil sampling program.

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| 45 | 3rd | 1-10 | The SCP states that 21 wells have been drilled from which groundwater samples can be and have been taken. The licensee needs to explain and illustrate the following: i) locations of these wells, ii) hydraulic gradient based on water level measurements, iii) construction of the wells and their ability to yield water levels and samples that are representative of in-situ conditions, and iv) techniques used to analyze water samples and results of such analyses. |

Molycorp's Reply: Section 5.5 has been rewritten to explicitly state that the 21 wells consist of the 17 wells drilled by Remcor in 1991 and the 4 previously existing water wells. i) The locations of the wells are included on Drawing MCWA-1 in Appendix E, which has been added to the SCP. ii) Section 5.5 deals with the analysis of groundwater samples for radioactivity. The hydraulic gradient of the shallow aquifer is best addressed in section 4.6, Hydrogeology. Section 4.6 has been extensively rewritten and expanded. In particular, please refer to section 4.6.3, Characteristics Of The Shallow Ground Water Aquifer. iii) The driller's logs for the water wells have been added to the SCP as Appendix G. These logs provide details of well construction. Please refer to section 4.6 for an extensive discussion of the groundwater conditions, including the wells and their ability to represent in situ conditions. iv) We are not prepared at this point to provide a synopsis of the results of water samples at the site. The SCP states that such information will be presented in the Site Characterization Report. Molycorp wishes to avoid any further delays that would be required to have this included in the SCP.

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| 57 | 2nd | 1-10 | Appendix A of the SCP describes an approach for selecting input data for leach rate and distribution coefficients. This approach is not acceptable because it relies on the leach rate of slag in bulk form. If significant quantities of radionuclides above the 1981 BTP Option 1 levels will remain after remediation, the licensee needs to also assess the leach rate for the finely ground slag which would have a much larger surface area and could be expected to exhibit increased leachability. |

Molycorp's Reply: In section 5.1.4, which has been rewritten to clarify the number and type of samples to be analyzed, we state that leachability tests will be performed on six samples. Four of these samples will be finely ground.

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| 57 | 3rd | 1-3 | The applicant stated that the default values are presented in Appendix E. There is no such appendix attached to the SCP document. The default values should be incorporated in the SCP. |

Molycorp's Reply: The SCP should have read "Appendix E of the RESRAD manual." This deficiency has been corrected.

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| Figure 5-2 | Add building numbers to figure. |

Molycorp's Reply: Building numbers have been added to the figure.

**Appendices to**

**Plan for Site Characterization in Support of Decommissioning of the Molycorp Inc. Washington, Pa Facility**

**Appendix I: 1990 Report by RSA, Inc., Entitled "A Sub-surface Survey for Thorium Content at the Molycorp Plant Site in Washington, Pa"**

**Appendix J: 1992 Report by RSA, Inc., Entitled "Justification of the Calibration Factor Used for Borehole Measurements of Underground Radiation Exposure Rates and Average Th-232 Concentration"**

**Appendix K: 1975 Report by Applied Health Physics, Inc., Entitled "Summary of Actions Taken During 1972-1974 to Comply with Requirements of the Nuclear Regulatory Commission"**

RSA, Inc. 8/4/93

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**Plan for Site Characterization in Support of Decommissioning of the Molycorp Inc. Washington, Pa Facility**

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**Appendix I: 1990 Report by RSA, Inc., Entitled "A Sub-surface Survey for Thorium Content at the Molycorp Plant Site in Washington, Pa"**

# A Sub-surface Survey for Thorium Content at The Molycorp Plant Site in Washington, Pa

Radiation Surveillance Associates, Inc.,
1230 Princeton Avenue
Salt Lake City, Utah  84105

Survey dates:  7/26/90 through 8/24/90
Report date:  December 27, 1990

Survey field personnel:

McDonald E. Wrenn, PhD, CHP
Bill Delaney, M.S., Physics
James G. Prather, PhD

Reviewed and approved by McDonald E. Wrenn, PhD, Certified Health Physicist, Chief Scientist, RSA, Inc.

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## A. Abstract

Radiation levels were measured on the surface and subsurface of the western portion of the Molycorp Washington, Pa., site in July and August of 1990. Subsurface measurements were made in 32 bore holes drilled expressly for that purpose to a depth of 19 feet or to bedrock, and in 5 already existing water wells. Each bore hole was cased with 2 inch PVC pipe. A small sodium iodide probe was lowered into each hole, protected from water by a one inch diameter sealed (waterproof) PVC pipe. Measurements of radiation levels were made every 6 inches. The vertical profiles found were distinctive for each hole. Subsurface radiation levels exceeded the surface levels at some depth in each hole. Below a depth of about 1 foot, the geometry is such that the radiation levels are directly proportional to the average thorium concentration in the locally surrounding soil, aggregate, rock, or slag, provided only that the thorium series is in radioactive equilibrium. Based on an assumption of radioactive equilibrium between $^{232}$Th and its gamma emitting daughter products, the Th concentration exceeded 0.01% at some depth in 27 of the 32 bore holes. The largest vertical distance exceeding 0.01% Th was 10 feet, although for most holes the thickness of that layer was much less. Usually, but not always, the radiation levels decreased to background by a depth of 9 feet. The distribution of underground activity determined from logging some replicate bore holes was quite patchy. This suggests that, if excavations are to be undertaken to remove contamination at the site, the material to be removed should be identified by concurrent measurements of radiation levels with a NaI survey meter, since the local content of Th underground at the excavation site varies significantly not only with depth but

also laterally over short distances, on the order of feet. Also, because of the spatial non-continuity in underground radiation levels, the results of subsurface measurements can not be used to make accurate estimates of the volume of material to be excavated, for example with a concentration exceeding 0.01% of Th.

## B. Executive Summary.

The objective of the radiation survey reported herein was to measure the subsurface concentration of thorium in the western part of the Molycorp site, particularly in the pond areas and immediately to the north, west, and northwest thereof. Information on subsurface radiation levels is needed for planning for future construction purposes on the site, and for planning with respect to long-term site management.

Radiation levels were measured with several instruments. Absolute radiation measurements were made on the surface of the site with a pressurized ionization chamber whose calibration is referenceable to the U.S. government's National Standards Testing Institute (NSTI), formerly known as the National Bureau of Standards. The calibration of the pressurized ionization chamber (PIC) formed the primary reference from which the concentrations of thorium in soil were determined.

Approximately 400 surface radiation measurements were made with a sodium iodide survey meter, cross calibrated against the pressurized ionization chamber. Surface radiation exposure rates are indicated on Site Map 3 in Appendix A of this report. Radiation measurements immediately above the surface of the ground, normally made at a height of 3 feet, reflect the average concentration of radioactive material in the top 6 inches of the soil. The radiation exposure rates 3 feet above the ground at the Molycorp site are predominantly the result of naturally occurring radioactive materials. However, in several regions of the study area, the measurements indicate elevated levels of radiation above background and therefor thorium in the soils, sediments, and aggregate near or on the surface.

Subsurface radiation measurements were made by drilling bore holes at 32 different locations (the locations are indicated on site maps 1 and 2), casing the holes with 2 inch polyvinyl chloride pipe, and lowering a NaI well logging instrument down each hole. The NaI probe had a diameter of approximately 3/4 inch, and it was encased inside a 1 inch i.d. PVC pipe to preserve a moisture free environment. Radiation measurements were made every 6 inches in these 32 holes from the surface until the bedrock was reached. Many measurements were made below ground water level and the balance above. Since the calibration of the instrument varied only slightly when the soil was saturated versus completely dry (a maximum change in response of about 6%), an average calibration factor equivalent to 80% soil saturation was used for all measurements to convert the count rate indicated by the instrument into thorium content of the surrounding soils and aggregate.

Multiplying the calibration factor times the measured count rate at each measurement location provided an average value for thorium in the soils in the vicinity of the probe. Because gamma rays are attenuated in soil over a relatively short distance, generally on the order of a foot or less, the measurements every 6 inches reflect the local average concentrations of thorium in the material at that depth.

In Appendix B, the radiation levels, as well as the average percent by mass of thorium in the material in the hole, are given in a tabular form as a function of depth. This appendix also shows the depth of the water table for each hole bored. Appendix C contains this data in graphs. The count rate equivalent to 0.01% thorium and normal background count rates are shown in the graphs for each hole.

Experiments were performed to determine the effect of soil moisture on our calibrations and also the effect of the two PVC pipes, within which the detector was housed, upon the calibration. An effective attenuation of about 5% was found under these geometric conditions. We conducted several experiments to determine the effect of the variation of the soil moisture upon the calibration conversion coefficient, which relates counts per minute (cpm) to thorium concentration. By taking calibration information at several different radiation intensities above ground, we determined the influence of the variation of the gamma spectral energies upon this coefficient. We concluded that the maximum possible systematic error of our measurements was approximately +12% and -11%, although it is likely that this error does not exceed 6% in either direction. The random counting error (i.e., precision) for individual measurements, wherever the underground radiation levels exceeded background, was always less than 2.2% (at one standard deviation) and at 0.01% Th this counting error was ±1.4%.

Core samples were taken in several holes, and, upon analysis of the thorium content thereof, it will be possible to provide a confirmation of the calibration by directly comparing the analytical work in the laboratory with the field measurements. Laboratory analyses of these cores will be done using radiochemical extractions and alpha spectrometric measurements of the $^{232}Th$ isotope. These results are not part of this report.

Although we had originally thought that it might be possible to provide a three dimensional underground map of the thorium concentration over the portion of the site surveyed, we found that there was considerable variation in radiation levels within a horizontal distance of 5 feet from hole to hole. We therefor concluded that such a map would not be accurate, since it would require extrapolations of dubious validity between the results from adjacent holes in order to construct it.

In general, the subsurface concentrations of thorium were above those found in the surface soils in almost every hole drilled. In 27 of the 32 holes drilled, the thorium concentration exceeded 0.01% at at least one depth, and sometimes for several feet. The largest thickness exceeding 0.01% thorium was 10 feet, although for most holes the thickness of the layer exceeding 0.01% thorium was usually much less. A general pattern, which was not always the case but which occurred often, was that the underground radiation levels decreased to background by a depth of about 9 feet.

Since the distribution of underground activity determined from logging replicate bore holes was quite patchy, during any future excavations, measurements should be made of the radiation levels with a sodium iodide survey meter as the excavation progresses. This will make it possible to assess the local content of thorium of the material being excavated at the excavation site and also to guide the depth of the excavation as well as to sort out materials exceeding 0.01% from those below 0.01%.Th.

Uniformly contaminated soil on the surface over a large area with a concentration of 0.01% thorium in equilibrium with its daughter products would give rise to an external exposure rate of 31 μR/hr.

In only a few holes did the thorium content exceed an average of 0.05% thorium at some point below the surface of the ground.

## C. Introduction.

During July and August 1990, RSA Inc. conducted a radiation survey at the request of the Molycorp Corporation at their Washington, Pa., plant in order to determine the levels of thorium on site in the vicinity of the ponds, as a function of depth below the surface. In order to do this survey, 32 logging holes were drilled on the site and radiation measurements were made at every 6 inches of depth from the surface down to bedrock, both above and below the water table. Radiation levels were also logged in water wells previously drilled on the site. The instrumentation and the calibration techniques are described in section F.

In addition to the subsurface measurements, RSA personnel conducted a scintillometer survey of the radiation exposure rates inside the study area. The surface study consisted of approximately 400 measurements of the gamma radiation field at a height of 1 meter above ground level.

This report presents the results of the survey. Appendices A through E contain the data collected over the course of the study. The data is presented in tabular form, graphical form, and on site maps. We have presented the "raw data" collected in the field along with the final results, in order to facilitate independent analysis.

D. Assessment of the Amount and Distribution of Subsurface Radionuclides in the Study Area.

The vertical distribution of radiation levels, and the inferred $^{232}Th$ content, expressed both as pCi/g average in the consolidated material in the bore hole at a given depth, and as percentage of Th per unit weight of this material, are listed for the 32 bore holes in Appendix B. This data is plotted as a function of depth in Appendix C so that it may be more readily examined by eye. In Appendix C, the count rate equivalent to 0.01% Th by weight is shown on each graph so that the depths between which the concentration of Th in the consolidated underground material exceeds 0.01% can be visually determined by inspection of each graph of the underground radiation profile. For example, in bore hole #1, the Th content only exceeds 0.01% for a depth of one foot, commencing at 1.25 below the surface of the ground, and thereafter drops rapidly to background levels at 3 feet below the surface of the ground. On the other hand, for bore hole #3, the concentration exceeds 0.01% from about 6 inches below the surface to a depth of almost 6 feet. In 16 of the bore holes, a layer more than 2 feet thick exceeding 0.01% Th was found. In the other 16 holes, although some of them exceeded 0.01% Th at some depth, there was no layer of 0.01% Th exceeding 2 feet in thickness.

Bore hole #28 was drilled off the site, and was chosen because of its profile, level, and location, as representative of normal background. By examining the profile, one can readily see there is very little fluctuation of radiation count rate with depth, which is unusual in the holes drilled on site, and that the average count rate was 2000 cpm. It is quite possible that true background varies above and below this value. In the water wells, there is additional attenuation of the gamma radiation because the diameter of the water wells was 4 inches whereas the bore holes were 2 inches in diameter. In view of the fact that in the water wells there is more water shielding the detector than in the bore holes, the response of the detector would be a lower number of counts per minute per microgram of Th per gram of consolidated material surrounding the detector. It would be possible to calibrate the detector for this situation, although that has not been done and was not within the workscope of this project. We have indicated 0.01% in the graphical profiles of the water wells, but it should be recognized that the equivalent concentration is above the 0.01% indicated. This is because an absolute calibration was not derived for the geometry present in the water wells. Water well #5, which was located off site, may be considered background for a water well. At no depth did the count rate in water well #5 exceed the background count rate of 2000 cpm in the 2 inch boreholes. Water well #1 shows that Th exceeding 0.01% is present at every depth down to 17 feet. In water well #2, on the other hand, the count rate exceeds 0.01% Th from about 1.5 to 4 feet in depth, and below 5 feet, the radiation levels clearly drop to background. Water well #3 has a different pattern. Below 6.5 feet radiation levels are clearly at background. Between 1.5 and 3 feet, and between 5 feet and 7 feet, there appears to be strata of increased radiation background. Water well #4 also shows count rates above background down to a depth of about 6 feet. The radiation levels in these wells do not come from the water itself, but from the surrounding soil and consolidated material outside of the 4 inch PVC pipe.

The conclusion relating gamma radiation levels to thorium content depends upon equilibrium being present between thorium and its radioactive daughters. Although this is probably a reasonable assumption, it will have to await confirmation from the radiochemical analyses of samples from several of the bore holes. Even if there were chemical fractionization between thorium and its daughter $^{228}Ra$, with time radioactive equilibrium would be reestablished. In the thorium series, it may require as long as 30 years to return to a large percentage of equilibrium. Nevertheless, 50% of equilibrium is established within 6 years, and, since this material has been underground for a considerable amount of time, the assumption of equilibrium, if untrue, should not introduce a large error into the conclusions.

## E. Conclusions and Recommendations.

The quantitative description of surface radiation levels is given in Site Map 3. The locations of the bore holes in which subsurface radiation measurements were made are given in Site Maps 1 and 2.

The quantitative data on vertical distribution of radiation levels and thorium content underground are given in Appendix B and plotted in Appendix C. The data for each hole establishes the vertical profile of thorium content within that hole. The depths containing thorium in excess of 0.01% by weight are indicated in the plots of the vertical distribution of the count rate in Appendix C.

The results of the subsurface survey indicate that there is considerable activity present within the study area examined at the Molycorp plant site. If the levels of activity found underground in large parts of the site were on the surface, the radiation exposure would be substantially elevated. In general, external gamma radiation levels above a source containing concentrations exceeding 0.01% Th would be about 31 μR/hr, or roughly double the natural background in the vicinity of the site.

The surface survey of the study area, in contrast to the subsurface survey, reveals only limited regions where the levels of activity are elevated above twice the natural background. Specifically, there are only two regions in the study area where the surface exposure rates greatly exceed twice background. The first is along the north fence in the vicinity of bore hole #16, and the second is east of the Lanthanide Building, around water well #1.

The external exposure rates in these two regions could be readily reduced to near background by excavating the top two feet of soil, removing it to the slag pile south of the plant site, and refilling the excavated area with a two foot thick layer of fill material imported from off site. We also noted that there is a pile of dirt around a power pole in the northeast section of the study area that contains elevated levels of activity. (PIC reading #3, which is marked on Site Map I in Appendix A, was taken on top of this pile.) This pile of dirt should be moved to the slag pile south of the plant. There may also be isolated pieces of slag or ore which contribute substantially to the radiation background in these areas.

Two bore holes in the pond area (BH#6 and BH#29) were drilled 5 feet apart to provide information about the variation of radiation profiles in the bore holes over a small distance. A second pair of holes (BH#16 and BH#32, located in the northeast corner of the study area) were also drilled 5 feet apart. For both of these pairs of holes, the radiation profile varied markedly over a short distance. These results demonstrate that it is probably not feasible to accurately model the subsurface activity levels by extrapolating between holes. A much higher density of bore hole data than is presently available, or even practical to make, would be necessary for such a model to be useful.

Since it is not possible to provide an accurate three dimensional map of the subsurface distribution of Th, an excavation undertaken to remove contaminated material might reasonably proceed as follows: (1) Using a hand held scintillometer, identify regions where the surface exposure rate at 1 meter above the ground exceeds 30 µR/hr. (2) Excavate these regions to a depth of 1 foot and remove the material to the slag pile south of the plant. (3) Excavate the remaining areas, where the exposure rate is below 30 μR/hr, to a depth of one foot, and place the material in a holding pile. (4) Repeat the above steps for subsequent one foot thick layers until the area has been excavated to a depth below the regions of elevated activity. The depth of the excavation can be estimated prior to the start of the excavation by examining the bore hole data. For most of the study area, the depth of excavation necessary appears to be less than 10 feet. The actual depth of excavation needed to decontaminate a particular region can be determined by making scintillometer measurements as the excavation proceeds. (5) Refill the excavation using material from the holding pile and fill material imported from off site. It is desirable that a buffer zone of at least 3 feet of uncontaminated fill be provided under and adjacent to any new building.

The present condition of the study area is such that the potential for harmful levels of exposure to humans is quite low. The regions of elevated activity are nearly all subsurface, so that the radiation emitted therefrom is absorbed by the intervening soil and aggregate. The two regions of elevated activity at the surface can be reduced to near background in the manner described above.

Prior to the construction of buildings on the site, it would be prudent to excavate and remove subsurface contamination under and adjacent to the proposed building, using the procedures described above. In particular, the bore hole data from the storage yard in the northeast portion of the study area (bore holes #15, 16, 18, 19, 20, 21, 22, 23, and 32) indicate that subsurface layers of elevated activity are present throughout most of this yard area.

## F. Collection and Analysis of Data.

### I. Calibration of the NaI Probe and Scintillometer against the Pressurized Ionization Chamber.

Purpose

During the course of the survey at the Molycorp plant site, two portable survey instruments were used to measure surface and subsurface gamma radiation exposure rates: a Ludlum model 19 scintillometer (which contains a 1" diameter by 1" long cylindrical NaI crystal), and a Ludlum NaI model 44-62 probe (containing a 1/2" diameter by 1" long crystal). The scintillometer was used in the surface study, and the NaI probe was the primary instrument used in the subsurface study.

Since both of these instruments are count rate meters, it is necessary to calibrate them against a pressurized ionization chamber (PIC) in order to express the results in terms of absolute exposure rate. The need to calibrate the scintillometer against the PIC arises from the fact that a scintillometer calibrated against a point source does not indicate true gamma exposure rate when it is used over a source distributed in the ground. For a distributed source, a scintillometer which has been previously calibrated against a point source generally indicates a reading that is higher than true gamma exposure rate. The discrepancy results from the fact that the reading from a count rate meter is proportional to the number of gamma events detected, without taking into account the energy spectrum of the gammas rays. The mean energy of gammas from a distributed source is lower than the mean energy from a point source of the same radionuclide because many of the gammas from the distributed source lose a portion of their energy in the process of Compton scattering. The PIC, on the other hand, integrates total gamma energy, so it produces readings in true exposure rate for both point sources and distributed sources. However, the PIC is heavy, unwieldy, barely portable, and quite time consuming to operate. We therefore calibrated the scintillometer against the PIC, which permitted the derivation of a compensation factor for the scintillometer that is appropriate for the gamma energy spectrum found at this particular site. We then used the scintillometer to make most of the surface measurements.

The scintillometer was calibrated by taking simultaneous PIC and scintillometer readings at several locations within the Molycorp plant site. The gamma exposure rates at the calibration locations ranged from about 10 to about 250 μR/hr. The data collected consisted of a series of paired scintillometer and PIC results. The cosmic ray contribution to the PIC readings was subtracted and then the paired readings were used as data points to calculate the least squares fit to line constrained to pass through the origin. The slope of the line derived by this procedure is the compensation factor for the scintillometer, (μR/hr true)/(μR/hr indicated). Multiplying the scintillometer reading by this compensation factor gives true exposure rate.

The NaI probe, which was used to log bore holes and water wells in the subsurface study, operates in the scaler mode, and therefore produces readings in units of counts per minute (cpm). The calibration of the probe against the PIC produced a calibration constant, (μR/hr true)/(cpm), that converts counts per minute to absolute exposure rate (μR/hr). Knowing the absolute exposure rate permitted the calculation of the absolute activity of the soil (expressed in units of µg/g and pCi/g).

The NaI probe calibration was similar to the calibration of the scintillometer. Simultaneous PIC and NaI probe readings were taken at the same time that scintillometer calibration data points were obtained. A least squares fit to a line constrained to pass through zero produced the calibration factor for the probe (expressed in units of $\mu R \cdot hr^{-1}/cpm$). Finally, the calibration factor was converted to units of $cpm/\mu g g^{-1}$ and $cpm/pCi g^{-1}$ using published conversion factors. (See the "Results" section, below, for a more detailed description of the calculations of the calibration factors.)

The PVC casing in the bore holes was taken into account in the calibration of the probe because the PVC can slightly modify the gamma energy distribution incident on the NaI detector. The bore holes were cased with 2 inch schedule 40 PVC pipe and the water wells were cased with 4 inch schedule 40 PVC pipe. The holes extended below the water table, and since the probe was not immersible, a 1 inch piece of schedule 40 PVC pipe with the end capped was placed in each hole, and the probe was lowered down the 1 inch pipe. To account for the varying thicknesses of PVC, the calibration procedure was carried out for each of the following configurations: probe in free air; probe inside 1 inch PVC pipe (1" i.d., 1/8" wall thickness); probe inside 2 inch PVC pipe (2" i.d., 5/32" wall thickness); probe inside 1 inch and 2 inch PVC pipe; probe inside 1 inch and 4 inch PVC pipe (4" i.d., 1/4" wall thickness).

Equipment and Material

(1) Reuter Stokes Pressurized Ionization Chamber, model RSS-111, serial number C6008, with tripod.

(2) Ludlum model 19 scintillometer, serial number 22527.

(3) Stopwatch.

(4) Ludlum model 44-62 NaI probe, serial number PR069085.

(5) Ludlum model 2000 scaler.

(6) 30 feet coaxial cable.

(7) PVC schedule 40 pipe: one 1 inch i.d. piece, 5 ft. long; one 2 inch i.d. piece, 5 ft. long; one 4 inch i.d. piece, 4 ft. long.

Procedure

This section presents the procedures followed for the collection and analysis of calibration data. The procedures are written in the form of instructions to be followed if the calibration were to be replicated.

(1) Selection of PIC locations: Select a series of PIC locations according to the following criteria. (Note In the following, and throughout this report, "PIC location" refers to a location where simultaneous PIC, scintillometer, and NaI(Tl) probe readings were taken.)

   (a) Choose a series of PIC locations such that as large a range of gamma exposure rates as possible is represented.

(b) The exposure rate at each location should be relatively constant inside a radius of several meters around the PIC to insure that the location approximates a $2\pi$ geometry (that is, the location should approximate a gamma source that is an infinite plane of constant activity).

(c) The area inside a radius of several meters around the PIC should be free of structures, vehicles, debris, or other material that might shield gamma radiation.

(2) Procedure for taking data at each PIC location:

(a) Assign a number to the location and record a description of the location in the field notebook.

(b) Set up the PIC on the tripod so that the center line is 1 meter above ground level, then turn on the power.

(c) Press the dose integrator reset button and simultaneously start the stop watch. Allow the PIC to integrate at least 2 μR and allow it to integrate at least 5 minutes. The stop watch should be stopped precisely when the dose integrator has integrated a whole number (that is, when the readout clicks to the next number). Record the time and the dose integrated in the field notebook.

(d) Take several scintillometer readings at the PIC location and record the average in the field notebook. The recorded reading should be the average of five to ten readings of the scintillometer taken at 1 meter above the ground.

(e) Take six NaI probe readings at the PIC location. Set the scaler to count for 1 minute. For each reading, hold the probe at a height of 1 meter above the ground. Press the count button on the scaler and, after the count period is over, record the number of counts integrated in the field notebook.

The six NaI probe readings should be taken in the following configurations

i. Hold the probe in free air.

ii. Center the probe inside a 5 foot length of 1 inch schedule 40 PVC pipe.

iii. Center the probe inside a 5 foot length of 2 inch schedule 40 PVC pipe.

iv. Center the probe inside a 5 foot length of 4 inch schedule PVC pipe.

v. Insert a 5 foot length of 1 inch schedule 40 PVC pipe inside a 5 foot length of 2 inch schedule 40 PVC pipe and center the probe inside the 1 inch piece of pipe.

vi. Insert a 5 foot length of 1 inch schedule 40 PVC pipe inside a 5 length of 4 inch schedule 40 PVC pipe and center the probe inside the 1 inch piece of pipe.

In each case, hold the pipe and the probe in the vertical position and record the number of counts in the field notebook.

## Results

Scintillometer Calibration:

The calibration of the NaI probe and of the scintillometer for the Molycorp Washington, Pa, plant site survey was based on PIC versus NaI probe data and PIC versus scintillometer data taken at nine different locations within the study area. Table 1 presents a list that assigns each PIC location a number and gives a brief description of the location. Site Map I in Appendix A is a map of the study area on which the PIC locations are indicated.

Table 2 gives the calibration data taken at each of the PIC locations. The top section of the table contains the PIC readings and the scintillometer readings. The second column of the top section, labeled "μR," is the integrated exposure for the time period given in the "minutes" and "seconds" columns. The next column, labeled "μR/hr," is the corresponding exposure rate calculated using the time period and the integrated exposure from the preceding three columns. The "scintillometer readings" column gives the uncompensated (i.e. indicated) scintillometer readings taken at each PIC location. The units for this column are "μR/hr indicated," meaning that these are the values indicated by the scintillometer, which reads uncorrected gamma exposure rate rather than true gamma exposure rate.

In calibrating the scintillometer against the PIC, the contribution of cosmic rays to the total exposure rate must be accounted for. Cosmic rays have higher energies than that of gamma rays. Since the PIC integrates the energy of (or more precisely, the charge produced by) the radiation that it detects, whereas the scintillometer integrates number of events, the PIC responds to cosmic rays while the scintillometer's response to cosmic rays is negligible. Therefore, we must subtract the cosmic ray contribution from the PIC readings to obtain true gamma exposure rate prior to comparing them to the readings from the scintillometer.

The National Council on Radiation Protection has published data showing the cosmic ray absorbed dose rate as a function of elevation above sea level [Ref. #1]. The Molycorp Washington, Pa, plant site is 1025 feet above sea level, which corresponds to a cosmic ray dose rate of 3.4 μR/hr. The final column in the upper table in Table 2 is the PIC reading minus the 3.4 μR/hr cosmic component.

The final step in the scintillometer calibration is the computation of the least squares fit to a line forced through the origin using the scintillometer readings as the independent variable and the PIC minus cosmic column as the dependent variable. Figure 1 shows the results of the computation. The compensation factor for the scintillometer at the Molycorp site was 0.728 ± 0.018.

NaI probe Calibration:

The lower section of Table 2 gives the calibration data for the NaI probe used for the subsurface gamma measurements. The "PIC minus cosmic" column in this table is a repetition of the column from the upper table. This is because the scintillometer calibration data and the NaI probe calibration data were all taken at the same time and at the same PIC locations. The six "NaI probe readings" columns present data

.ken using the NaI probe inside various combinations of PVC pipe.

Once again, we used a least squares fit to a line forced through the origin to compute the calibration factor for the probe. The "PIC minus cosmic" column serves as the dependent variable and the "NaI probe readings" columns serve as the independent variables. The six graphs in Figure 2 depict the computation of six different calibration factors for the probe. The appropriate calibration factor to use depends on how the probe is configured. For probe readings taken down a bore hole that is not cased at all, the free air factor (graph 1 in Figure 2) is appropriate. For probe readings in a bore hole cased with 2" schedule 40 PVC pipe, the factor from graph 3 is appropriate. And so on.

The six compensation factors shown in Figure 2 'emonstrate that the PVC casing in the bore hole has a relatively minor effect on the gamma field inside the hole. The various combinations of PVC pipe produce, at most, a 7.5% variation in the calibration factor. And even this small source of error can be minimized by choosing the proper calibration factor from Figure 2.

The final step in the NaI probe calibration is the conversion of the calibration factors from units of $\mu Rhr^{-1}/cpm$ to $cpm/\mu gg^{-1}$ and $cpm/pCig^{-1}$. The National Council on Radiation Protection publishes a table giving the calculated total exposure rate at 1 meter above the ground for natural emmitters uniformly distributed in the soil [Ref. #4]. The exposure rate for $^{232}Th$ + daughters is 2.82 $\mu Rhr^{-1}/pCig^{-1}$, and the specific activity is 9.1 µg/pCi. The calibration was complicated by the fact that the probe was to be used to log holes in the ground. The NCRP tabulated data refers to surface exposure rates measured at 1 meter above a source distributed in soil (also called a $2\pi$ geometry). In the bore les, the source completely surrounds the probe (a $4\pi$ geometry). Fortunately, these two geometries are related in a simple way. They differ by a factor of two, so doubling the $2\pi$ calibration factor gives the $4\pi$ calibration factor. To express the calibration factor in terms of cpm/$\mu g g^{-1}$, divide the calibration factor by the specific activity.

Table 3 presents a summary of the calibration factor calculations for the NaI probe. The uncertainties associated with the calibration factors were calculated using the propagation of errors formula. (Note this formula is used to calculate all propagated random errors quoted throughout this report.)

$$\sigma_u^2 = \left(\frac{\partial u}{\partial x}\right)^2 \sigma_x^2 + \left(\frac{\partial u}{\partial y}\right)^2 \sigma_y^2$$

In order to derive the propagation of errors formula for two values multiplied together, we take u=xy, which implies that

$$\left(\frac{\partial u}{\partial x}\right)^2 = y^2$$

$$\left(\frac{\partial u}{\partial y}\right)^2 = x^2$$

$$\sigma_u^2 = y^2\,\sigma_x^2 + x^2\,\sigma_y^2$$

| Location Number | Description of Location |
|---|---|
| 1 | 23', 7" north of bore hole #20, in the southern end of the storage yard. |
| 2 | Directly over bore hole #16, in the north east corner of the storage yard. |
| 3 | 7' 6" north of the power pole in the north east corner of the storage yard. |
| 4 | 5' north of the north end of the ammonia tank. |
| 5 | 10' north north west of water well #1. |
| 6 | 22' north west of water well #3 in the middle of the road between the fence and the creek. |
| 7 | Between pond #8 and the fence, about halfway between the ends of the ponds. |
| 8 | Directly over bore hole #27, located on Molycorp property ≈ 200 yards south west of study area. |
| 9 | Center of the slag pile in the south yard. |

**Table 1: PIC Locations**

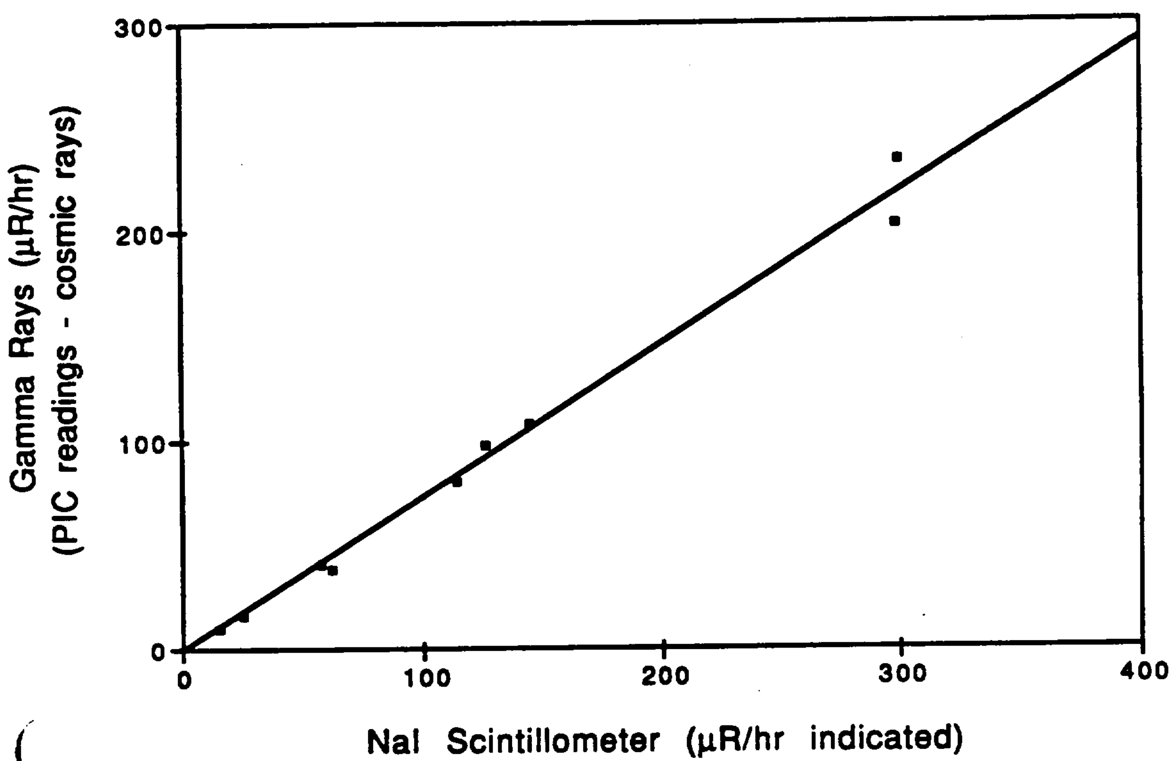
| PIC Location Number | PIC Readings | | | | Scintillometer Readings | PIC minus cosmic |
|---|---|---|---|---|---|---|
| | μR | minutes | seconds | μR/hr | μR/hr, indicated | (μR/hr) |
| 1 | 2 | 6 | 5 | 19.73 | 25.6 | 16.33 |
| 2 | 10 | 5 | 25 | 110.77 | 145.4 | 107.37 |
| 3 | 20 | 5 | 4 | 236.84 | 300.0 | 233.44 |
| 4 | 6 | 8 | 5 | 44.54 | 57.8 | 41.14 |
| 5 | 9 | 5 | 20 | 101.25 | 126.2 | 97.85 |
| 6 | 8 | 5 | 46 | 83.24 | 114.4 | 79.84 |
| 7 | 4 | 5 | 46 | 41.62 | 61.6 | 38.22 |
| 8 | 8 | 37 | 43 | 12.73 | 15.2 | 9.33 |
| 9 | 46 | 13 | 23 | 206.23 | 299.0 | 202.83 |

Note: The exposure rate at the Washighton PA site due to cosmic radiation is 3.4 μR/hr.

| PIC Location Number | PIC minus cosmic (μR/hr) | NaI probe readings (# of counts, one min. count time) | | | | | |
|---|---|---|---|---|---|---|---|
| | | graph 1* free air | graph 2* 1" PVC | graph 3* 2" PVC | graph 4* 4" PVC | graph 5* 1" & 2" PVC | graph 6* 1" & 4" PVC |
| 1 | 16.33 | 1717 | 1673 | 1637 | 1689 | 1647 | 1682 |
| 2 | 107.37 | 8875 | 8663 | 8511 | 8539 | 8430 | 8321 |
| 3 | 233.44 | 17920 | 17284 | 17448 | 17980 | 17572 | 17157 |
| 4 | 41.14 | 3589 | 3649 | 3509 | 3463 | 3548 | 3606 |
| 5 | 97.85 | 7025 | 7117 | 7136 | 7046 | 6882 | 7119 |
| 6 | 79.84 | 7084 | 6855 | 6779 | 6792 | 6565 | 6295 |
| 7 | 38.22 | 3798 | 3725 | 3645 | 3598 | 3526 | 3450 |
| 8 | 9.33 | 1089 | 1018 | 1019 | 980 | 1014 | 907 |
| 9 | 202.83 | 18326 | 17590 | 17560 | 17605 | 17092 | 16589 |

*refers to the calibration factor graphs in Figure 4

Table 2: Calibration data; PIC vs. scintillometer and PIC vs. NaI probe



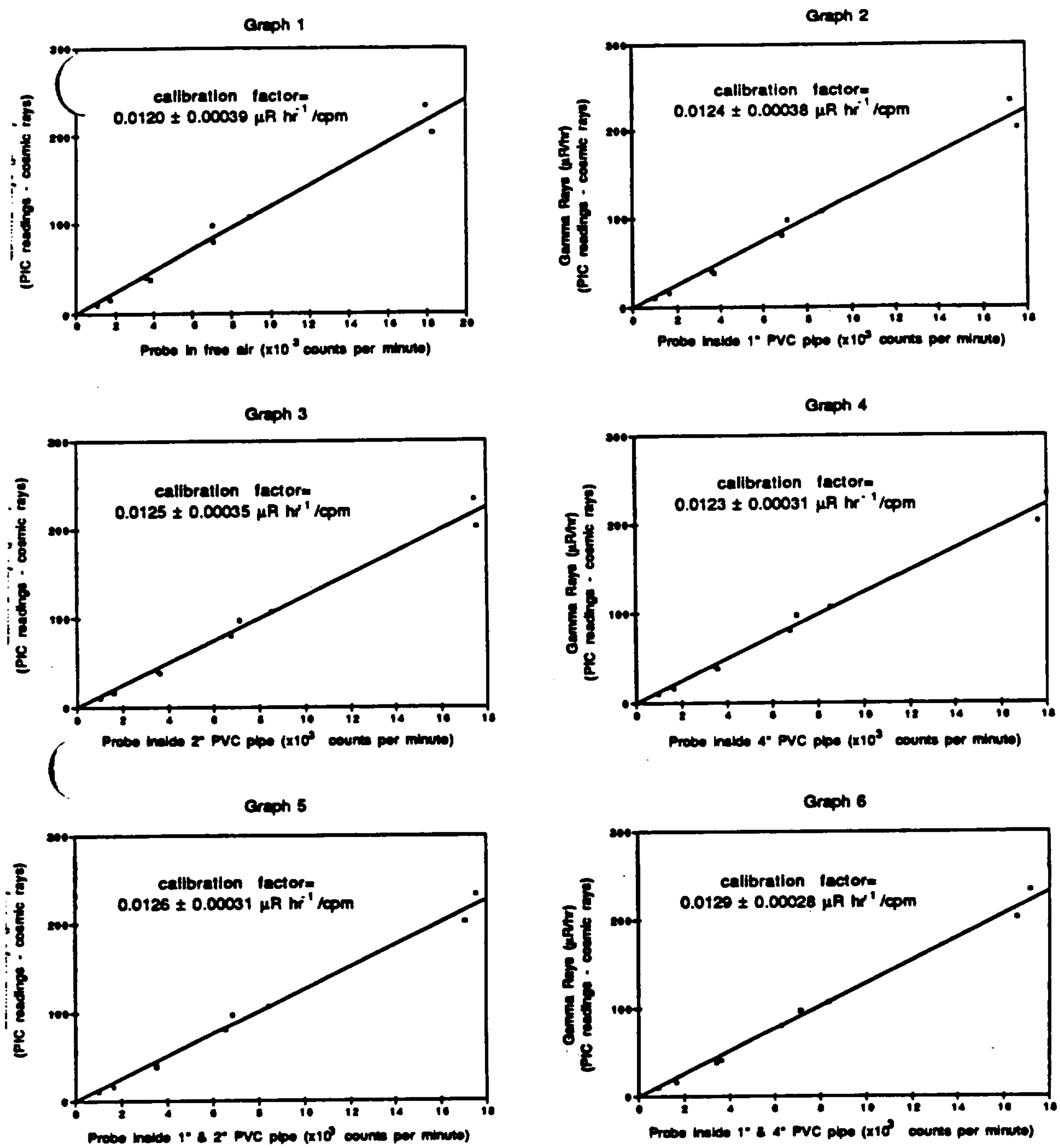

Least Squares Fit to a Line Forced Through Zero:

Slope (compensation factor): 0.728 ± 0.018

y intercept = 0

(Computed using the statistical software package StatWorks on a Macintosh computer.)

**Figure 1: Least squares fit computation of the compensation factor for the NaI scintillometer gamma measurements.**




Note: Multiply the $2\pi$ calibration factors given above by 2 to obtain the calibration factor for the $4\pi$ geometry present in sub-surface measurements

**Figure 2: Least squares fit computation of the compensation factors for the NaI probe over a $2\pi$ geometry with various combinations of PVC pipe around the probe.**

Calibration factors for NaI probe:

| PVC pipe configuration | Least squares fit to calibration data<br>(μR/hr)/cpm (2π geometry) | Derived calibration factors<br>cpm/(pCi/g) (2π geometry) | cpm/(pCi/g) (4π geometry) | cpm/(μg/g) (4π geometry) |
|---|---|---|---|---|
| Probe in free air | 0.0120 ± 0.00039 | 235 ± 0.092 | 470 ± 0.183 | 51.6 ± 0.020 |
| Probe inside 1" PVC pipe | 0.0124 ± 0.00038 | 227 ± 0.086 | 455 ± 0.173 | 50.0 ± 0.019 |
| Probe inside 2" PVC pipe | 0.0125 ± 0.00035 | 226 ± 0.079 | 451 ± 0.158 | 49.6 ± 0.017 |
| Probe inside 4" PVC pipe | 0.0123 ± 0.00031 | 229 ± 0.071 | 459 ± 0.142 | 50.4 ± 0.016 |
| Probe inside 1" & 2" PVC pipe | 0.0126 ± 0.00031 | 224 ± 0.069 | 448 ± 0.139 | 49.2 ± 0.015 |
| Probe inside 1" & 4" PVC pipe | 0.0129 ± 0.00028 | 219 ± 0.061 | 437 ± 0.122 | 48.0 ± 0.013 |

**Table 3: Calibration factors for NaI probe**

## II. Supplementary Calibration Data.

Purpose.

The supplementary calibration data presented in this section were collected in order to confirm the results of the primary calibration experiment and to investigate additional sources of variability in the calibration.

(A) Attenuation of Gamma Response vs. PVC Pipe Thickness: The results of the PIC vs. NaI probe calibration experiment suggested that several readings using longer count times would be useful in order to help characterize the effect of the PVC pipe on the gamma field. The long count times (ten minutes) reduce the statistical counting error to negligible values. The purpose of these readings was to measure the attenuation of the gamma field as a function of the wall thickness of the PVC pipe. We took long count time measurements in the both the horizontal and the vertical position, in order to observe the effect of altering the geometry.

(B) Effect of Soil Water Content: The water content of the soil in the material adjacent to the wells and the bore holes could potentially vary from dry to saturated. The soil water content experiment was designed to determine whether or not the attenuation of the gamma field due to water in the soil would necessitate a correction factor. A 5 foot length of 2 inch PVC pipe was inserted into a 55 gallon drum filled with dry, relatively active soil, in order to simulate conditions in a bore hole. Water was slowly added to the soil and measurements were taken inside the pipe, until the soil became saturated.

## Equipment and Material

(1) Reuter Stokes Pressurized Ionization Chamber, model RSS-111, serial number C6008, with tripod.

(2) Ludlum model 19 scintillometer, serial number 22527.

(3) Stopwatch.

(4) Ludlum model 44-62 NaI probe, serial number PR069085.

(5) Ludlum model 2000 scaler.

(6) 30 feet coaxial cable.

(7) PVC schedule 40 pipe one 1 inch i.d. piece, 20 ft. long, capped at on end; one 1 inch i.d. piece, 5 ft. long; one 2 inch i.d. piece, 5 ft. long; one 4 inch i.d. piece, 4 ft. long.

(8) Tripod.

(9) 55 gal drum containing relatively active, dry soil.

## Procedure

(1) Surface measurements using long count times. (These procedures are written in the form of instructions to be followed if the experiment were to be replicated.)

(A) Select a number of PIC locations such that a large range of exposure rates (i.e., between 10 and 250 μR/hr) are represented.

(B) At each location, set up the PIC and obtain an integrated exposure for a period of 10 minutes or longer, using the method described in the calibration data procedure (section F-I).

(C) Take a scintillometer reading using the method described in the calibration data procedure (section F-I).

(D) Take NaI probe readings in the following manner

i. Four probe readings should be made with the probe in the vertical position. Place the length of 1 inch PVC pipe in the vertical position with one end on the ground at the PIC location. Place the transit tripod next to the pipe and strap the pipe to the tripod to prevent it from falling over. Insert the detector into the pipe from the top so that the end of the detector is 1 meter above ground level and take a 10 minute reading. Repeat the above procedure two more times, once with the 1 inch pipe inside the 2 inch pipe and once with the 1 inch pipe inside the 2 inch pipe inside the 4 inch pipe. Finally, remove all three pipes and take a reading in free air, holding the detector in the same position, 1 meter above the ground. For each of these readings, the detector should be spatially located at the point where the PIC readings were taken. Record the results in the field notebook.

ii. Repeat the above four measurements with the pipe and the detector in the horizontal position. To hold the pipes in the horizontal position at a height of one meter above the ground, position the transit tripod at a height of one meter and strap the pipe to the tripod so that the pipe is parallel to the ground. The detector should be centered inside the pipe and the center of the pipe should be offset so that the detector is not over the tripod. For the free air reading, run the detector cable through the pipe so that the detector is sticking out one end in the horizontal position. For each of these readings, the detector should be spatially located at the point where the PIC readings were taken. Record the results in the field notebook.

2) Effect of soil water content: For this experiment, center a 5 foot length of 2 inch schedule 40 PVC pipe in the 55 gallon drum and fill the drum with dry, thorium bearing soil. The soil should come from a location where surface exposure rates are relatively high. Insert a length of 1 inch schedule 40 PVC pipe, capped at the bottom, into the 2 inch piece of pipe. The 1 inch pipe protects the detector from immersion in water. Insert the NaI probe into the 1 inch pipe and lower it until the end of the probe is centered in the 55 gallon drum. Take a 2 minute reading. Next, add 1 gallon of water to the soil and take another 2 minute reading. Continue adding water and taking readings after each gallon is added until the soil becomes saturated. At 5 gallon increments, stop and check the level of the water in the 2 inch pipe. Record the results in the field notebook as data is taken.

## esults

Attenuation of Gamma Response: PVC Pipe Experiment.

Table 4 shows the data obtained by this experiment. Table 5 gives the same data rearranged to display the measured values as a function wall thickness of the PVC pipe surrounding the NaI probe. The upper half of the table gives the values measured in the field and the lower half gives the same data normalized to the value measured in free air. The normalization makes it possible to compare data taken at different locations over a range of exposure rates.

Figure 3 gives graphs of the data plotted as a function of PVC wall thickness. Graph (a) in that figure shows the results measured with the probe and the pipe held in the horizontal position and graph (b) presents the results for the vertical orientation. Each of the three lines shown on the graphs represents data taken at a single location (i.e., a single exposure rate). These graphs (Figure 3) do not include the data taken at the location where the exposure rate was 9.33 μR/hr (see Table 5), because that data represents the natural background in the area. Thorium is not the sole contributor to the natural background, so that data taken at 9 μR/hr is not appropriate to derive a calibration for the response of the instrument to thorium. The other data in Table 5 represent areas of elevated gamma radiation due mostly to thorium.

It is evident from these graphs that the count rate varies slightly with wall thickness and orientation. For the probe held in a horizontal position, the count rate increases as the thickness of PVC increases. For the probe held in the vertical position the count rate decreases generally with increasing PVC thickness.

The graphs in Figure 3 indicate that, for the PVC thickness that is of concern in the measurements taken in the Molycorp study (0.28 inches), the range of the variations is only about 10%. We can conclude, therefore, that the uncertainties in the bore hole measurements due to degradation of the spectrum by the PVC are less than ± 10%.

Soil Water Content Experiment:

Table 6 contains the results from the soil water content study. The first six columns present the data as it was taken in the field. Column 7 gives the water content of the soil in the barrel expressed as "percent of saturation." At the beginning of the experiment, the soil in the barrel was dry, and after 19 gallons of water were added, the soil was saturated to the point that there was standing water on the surface. The formula for "percent of saturation" is, therefore,

100x(number of gallons added)/19.

This produces a scale that takes the dry soil as 0% and saturated soil as 100%.

The final column in Table 6 gives the count rate normalized to the value measured when the soil was dry. This column can therefore be viewed as "percent attenuation," that is, the percent by which the gamma field was attenuated by the addition of water to the soil.

The graph in Figure 4 is a least squares fit to a line using the "percent of saturation" column from Table 6 as the independent variable and the normalized count rate as dependent variable. The least squares fit is justified by ıe fact that the gamma field attenuation as a function of saturation is evidently quite linear.

The field work at the Molycorp site did not include any attempt to measure the water content of the soil at the time that the holes were logged. Such measurements were deemed unnecessary. We can, however, make a reasonable estimate of the average soil water content and of the range of soil water content variation. The average depth to the water table in the bore holes and water wells was 5.5 feet. The average depth of the holes was 17.5 feet. This means that about 70% of the readings were taken below the water table, where the soil was 100% saturated. Although some dry soil was found near the surface, below the 1 to 2 foot level, the drill auger tended to bring up very muddy soil. (Western Pennsylvania had experienced an unusually wet period in the six months prior to the study.) A good approximation of the average soil water content, then, is about 80%, with variations ranging from about 25% to 100%.

The results from this experiment allow us to use a single correction factor to account for soil water content. Figure 4 demonstrates that 80% saturation corresponds to an attenuation factor 0.95. A water content range of 25% to 100% saturation translates to a range of +0.017 to -0.012 in this factor. Hence, using an average attenuation factor of

$$C = 0.95 \begin{array}{l} +\,0.017. \\ -\,0.012 \end{array}$$

(where C = attenuation due to water)

will give a very small error; at most, for dry soil, the error is about 6%. In the field under the measuring conditions extant during our survey, the error from using a single attenuation factor was probably less than 2%.

o correct for this attenuation, we must multiply the readings taken in the field by 1/C, that is,

$$\text{correction factor for soil water content} = 1/C = 1.053 \begin{array}{l} +\ 0.019 \\ -\ 0.013 \end{array}$$

The uncertainties come from applying the propagation of errors formula to u = 1/C, which produces the equation $\sigma_u = (1/C^2)\sigma_c$.

Combined correction factor:

The final step in the calibration of the probe is to derive a single correction factor that accounts for variations in the soil water content and variations due to the PVC pipe. Although the PVC pipe does not reduce the count rate in the holes, the presence of the PVC does contribute to the uncertainty in the measurements. The uncertainty due to the PVC pipe is about 10%. We can not use the propagation of errors formula to combine the uncertainty due to the PVC pipe with the uncertainty associated with the soil water content correction factor because the errors are systematic. The propagation formula only applies to random error. To estimate the maximum systematic error, we add the estimates of errors from soil moisture and the PVC pipe attenuation. Thus,

$$\text{Combined correction factor} = 1.053 \begin{array}{l} +\ 0.12 \\ -\ 0.11 \end{array}$$

The significance of this correction lies not so much in it's value, but in the fact that it is a relatively minor correction. It demonstrates that the water in the soil and the presence of PVC casing has little effect on the gamma esponse of the probe in the hole, and attenuates the response relative to air by about 5% on the average.

| Date/Time | PIC Location Number | PIC readings | | | PIC minus cosmic | Scintillometer readings |
|---|---|---|---|---|---|---|
| | | μR | minutes | μR/hr | (μR/hr) | μR/hr |
| 11:00 a.m., 8/6 | 5 | 27 | 16.1 | 100.62 | 97.22 | 127.6 |
| 11:30 a.m., 8/6 | 3 | 70 | 17.98 | 233.59 | 230.19 | 288 |
| 10:30 a.m., 8/7 | 8 | 8 | 37.72 | 12.73 | 9.33 | 15.2 |
| 3:15 p.m., 8/7 | 9 | 46 | 13.38 | 206.28 | 202.88 | 299 |

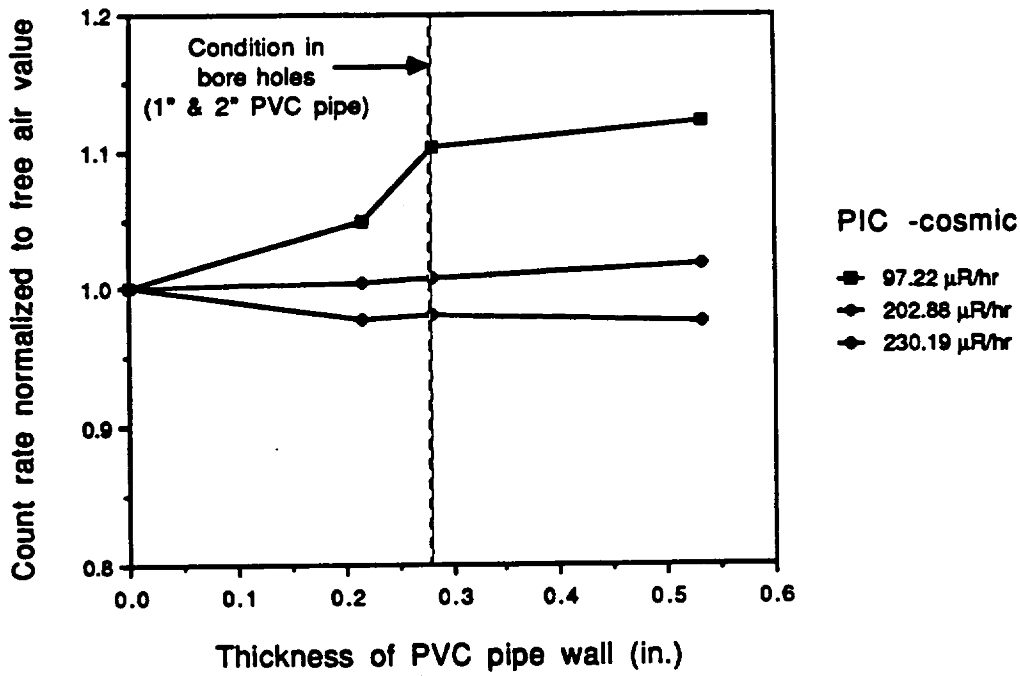
| PIC Location Number | NaI probe readings (# of counts) | | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|
| | Count Time | Horizontal free air | Vertical free air | Horizontal 1" PVC | Vertical 1" PVC | Horizontal 1" & 2" PVC | Vertical 1" & 2" PVC | Horizontal 1", 2" & 4" PVC | Vertical 1", 2" & 4" PVC |
| 5 | 10 min. | 72634 | 71458 | 76169 | 69918 | 80080 | 68905 | 81440 | 64202 |
| 3 | 10 min. | 175265 | 174346 | 176056 | 158962 | 176690 | 157358 | 178363 | 163666 |
| 8 | 10 min. | 11191 | 109448 | 10697 | 9782 | 10140 | 9611 | 9417 | 9331 |
| 9 | 10 min. | 194514 | 182730 | 190076 | 180779 | 190865 | 170100 | 189778 | 164923 |

**Table 4: Experimental data: PVC Pipe Attenuation**

| Thickness of PVC walls (inches) | 97.22 μR/hr (PIC-cosmic) horizontal | 97.22 μR/hr (PIC-cosmic) vertical | 230.19 μR/hr (PIC-cosmic) horizontal | 230.19 μR/hr (PIC-cosmic) vertical | 9.33 μR/hr (PIC-cosmic) horizontal | 9.33 μR/hr (PIC-cosmic) vertical | 202.88 μR/hr (PIC-cosmic) horizontal | 202.88 μR/hr (PIC-cosmic) vertical |
|---|---|---|---|---|---|---|---|---|
| **Data (cpm):** | | | | | | | | |
| 0.0000 | 72,634 | 71,458 | 175,265 | 174,346 | 11,191 | 10,948 | 194,514 | 182,730 |
| 0.2150 | 76,169 | 69,918 | 176,056 | 158,962 | 10,697 | 9,782 | 190,076 | 180,779 |
| 0.2813 | 80,080 | 68,905 | 176,690 | 157,358 | 10,140 | 9,611 | 190,865 | 170,100 |
| 0.5313 | 81,440 | 64,202 | 178,363 | 163,666 | 9,417 | 9,331 | 189,778 | 164,923 |
| **Data normalized to free air value:** | | | | | | | | |
| 0.0000 | 1.0000 | 1.0000 | 1.0000 | 1.0000 | 1.0000 | 1.0000 | 1.0000 | 1.0000 |
| 0.2150 | 1.0487 | 0.9784 | 1.0045 | 0.9118 | 0.9559 | 0.8935 | 0.9772 | 0.9893 |
| 0.2813 | 1.1025 | 0.9643 | 1.0081 | 0.9026 | 0.9061 | 0.8779 | 0.9812 | 0.9309 |
| 0.5313 | 1.1212 | 0.8985 | 1.0177 | 0.9387 | 0.8415 | 0.8523 | 0.9757 | 0.9026 |

**Table 5: Normalized response of NaI probe as a function of PVC wall thickness**

(a). Pipe and probe held in the horizontal position




(b). Pipe and probe held in the vertical position

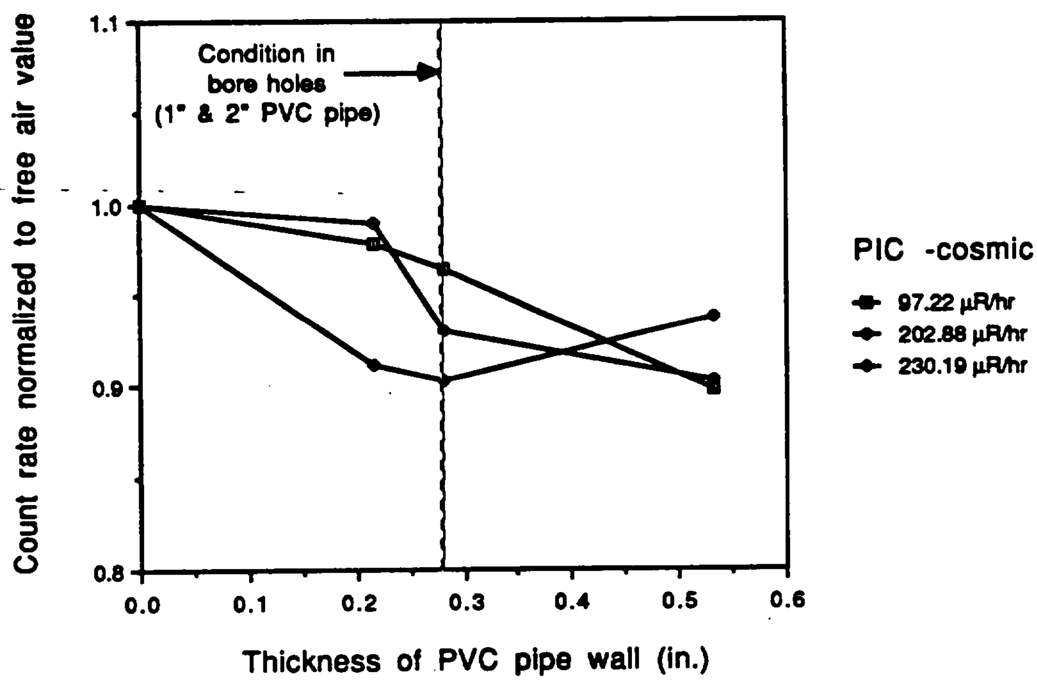



Figure 3: Effect of varying orientaion, PVC pipe wall thickness, and free air exposure rate

Diameter of barrel: 22 inches
Depth of soil in barrel: 28 inches
Volume of soil in barrel: 6.16 cubic feet
Detector depth (from bottom): 14 inches

| Date/Time | Gallons Water added | Water Depth in Pipe | NaI Probe Count Time | NaI Probe 1" & 2"PVC (counts) | NaI Probe counts/min. | Percent of saturation | Normalized exposure rate* |
|---|---|---|---|---|---|---|---|
| 8/8, 5:35 p.m. | 0 | | 2 min. | 98423 | 49,211 | 0 | 1.000 |
| 8/8, 5:28 p.m. | 1 | | 2 min. | 98577 | 49,288 | 5.3 | 1.002 |
| 8/8, 5:31 p.m. | 2 | | 2 min. | 98299 | 49,149 | 10.5 | 0.999 |
| 8/8, 5:35 p.m. | 3 | | 2 min. | 98199 | 49,099 | 15.8 | 0.998 |
| 8/8, 5:38 p.m. | 4 | | 2 min. | 97439 | 48,719 | 21.1 | 0.990 |
| 8/8, 5:42 p.m. | 5 | 0 in. | 2 min. | 96464 | 48,232 | 26.3 | 0.980 |
| 8/8, 5:45 p.m. | 6 | | 2 min. | 96740 | 48,370 | 31.6 | 0.983 |
| 8/8, 5:48 p.m. | 7 | | 2 min. | 96408 | 48,204 | 36.8 | 0.980 |
| 8/8, 5:52 p.m. | 8 | | 2 min. | 95361 | 47,680 | 42.1 | 0.969 |
| 8/8, 5:56 p.m. | 9 | | 2 min. | 95319 | 47,659 | 47.4 | 0.968 |
| 8/8, 5:58 p.m. | 10 | 0 in. | 2 min. | 95008 | 47,504 | 52.6 | 0.965 |
| 8/8, 6:03 p.m. | 11 | | 2 min. | 94914 | 47,457 | 57.9 | 0.964 |
| 8/8, 6:07 p.m. | 12 | | 2 min. | 94687 | 47,343 | 63.2 | 0.962 |
| 8/8, 6:11 p.m. | 13 | | 2 min. | 94791 | 47,395 | 68.4 | 0.963 |
| 8/8, 6:15 p.m. | 14 | | 2 min. | 93461 | 46,730 | 73.7 | 0.950 |
| 8/8, 6:19 p.m. | 15 | 1 ft. 2 in. | 2 min. | 94178 | 47,089 | 78.9 | 0.957 |
| 8/8, 6:24 p.m. | 16 | | 2 min. | 93353 | 46,676 | 84.2 | 0.949 |
| 8/8, 6:26 p.m. | 17 | | 2 min. | 93305 | 46,652 | 89.5 | 0.948 |
| 8/8, 6:30 p.m. | 18 | | 2 min. | 93275 | 46,637 | 94.7 | 0.948 |
| 8/8, 6:32 p.m. | 19 | 2 ft. 4 in. | 2 min. | 93112 | 46,556 | 100.0 | 0.946 |

Note: Soil reached saturation after 19 gallons.

*Count rate normalized to the exposure rate for dry soil.

## Table 6: Data from the soil water content experiment

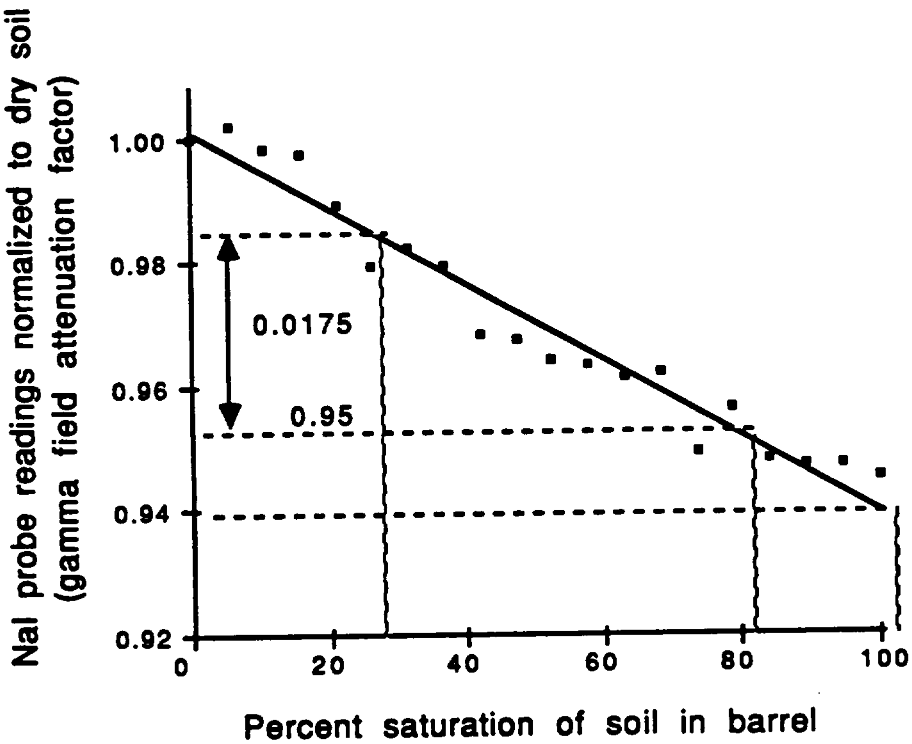



**Figure 4: Least squares fit to a line of percent saturation of soil with water versus normalized NaI probe readings**

## III. Measurement of Gamma Radiation Field in Bore Holes and Ground Water Wells

### Purpose

The purpose of this procedure was to measure the gamma radiation field below the surface of the study area at the Molycorp facility, and then to use those gamma readings to calculate the concentration of thorium in equilibrium with its daughters in the subsurface soil. The soil and fill material in the pond area along the western boundary of the plant site and in the storage yard in the northwest corner of the site are known to contain thorium bearing slag produced as a by-product from past operations at the site. The radionuclide concentrations and the gamma exposure rates at the surface have been well characterized in a study conducted by the Associated Universities of Oak Ridge in 1985 [Ref. #2] and in a Health Physics survey conducted by Dr. McDonald E. Wrenn in 1986 [Ref #3]. The present study was undertaken to extend the soils study to a depth of 20 feet below the surface, over a limited area of the site.

In order to measure the thorium content of the soil in the pond area and the storage yard, a series of bore holes were drilled to depths ranging from 16 to 20 feet. The gamma fields in the holes were then logged using an NaI probe. Four ground water sampling wells were present in the study area. These were also logged. The ground water wells were cased with 4 inch PVC pipe, which extends approximately 2 feet above the surface of the ground and the bore holes were cased with 2 inch schedule 40 PVC pipe. The top several feet of the ground water wells were also cased with 6 inch steel pipe, which protruded approximately 2 feet above the surface. (The 4 inch PVC pipe was inside the steel pipe.)

Two control bore holes were drilled on Molycorp property outside of the study area in a location that was known to be free of thorium bearing slag. One of these control holes was drilled on a pile of ferro-molybdenum slag that does not contain elevated levels of thorium. The second was drilled in virgin soil in an area that has never been used for slag storage. A control ground water well was available outside of the study area at a location that was also free of thorium bearing slag.

The procedure for measuring the gamma radiation field below the surface consisted of lowering a NaI probe down each of the bore holes and each of the ground water wells. One minute counts of scintillation events in the probe were taken at 6 inch intervals down each of the holes. Multiplying these readings by the calibration factors obtained using the PIC yielded values expressed in units of µg/g, % thorium by mass, and pCi/g.

Two of the bore holes drilled for the study were cored, and soil samples from the cores were taken at 18 inch intervals from the cores. Radiochemical analysis on the soil samples from these cores will be made to verify the calibration obtained here.

Equipment and Material

(1) A mobile drilling rig and other drilling equipment, 2 inch schedule 40 PVC casing pipe, and drilling crew, all supplied by Terra Testing Inc. of Washington, Pa., a drilling company under contact to Molycorp.

2) Ludlum model 44-62 NaI scintillation probe, serial # PR069085.

(3) Two 30 ft. coaxial cables.

(4) Ludlum model 2000 scaler (scaler A).

(5) 20 feet of 1 inch schedule 40 PVC pipe, capped at one end.

(6) 100 ft. surveyor's measuring tape.

(7) Electrical tape.

Procedure

(1) The drilling locations were chosen using the following criteria

(a) The study area was defined to consist of the eight settling ponds on the western side of the plant, the land west of the ponds between the ponds and Chartier's Creek, and the storage yard in the north west corner of the plant site. Site Map I in Appendix A shows the perimeter of the study area. The R & D parking lot south of the ponds was excluded from the study area because the presence of overhead powerlines prevented drilling in the parking lot.

(b) Eight bore holes were drilled around the perimeter of the study area. These holes, in conjunction with four ground water wells that were already available on the site, established data points on the boundary of the study area. A pattern of eighteen bore holes served as data points in the interior of the study area. The locations of the interior holes produced an approximately uniform density of holes throughout the study area, although the presence of obstacles such as ponds, buried pipes, and overhead power lines forced some constraints on the uniformity of the distribution of bore holes.

(c) Two bore hole locations on Molycorp property south west of the study area served to establish the natural background radiation typical of the site. One of these locations was over virgin soil that had not been disturbed by operations at the site, and the other was over ferro molybdenum slag. A ground water well was also available outside the study area. We logged this water well as part of our collection of data on the natural gamma background in the area surrounding the plant site.

(d) After the original 28 bore holes and 5 water wells had been drilled and logged, the drilling crew returned to drill five more holes. Two of these additional holes were drilled five feet from two previously drilled holes that were found to be relatively active. Core samples were taken from these two holes. These two pairs of holes provide a measure of the amount of variation in the gamma field that might be expected over a short distance. The radiochemical analysis of the cores will provide a check on the calibration constant measured in the field. Three additional bore holes in the vicinity of ponds 7 and 8 had the effect of increasing the density of data points in that region.

2) Procedure for logging bore holes and water wells: (These procedures are written in the form of instructions to be followed if the measurements were to be replicated.)

(a) Set up the Ludlum scaler as follows: Dial the "minutes" thumbwheel to 1 minute and set the time scale switch to X1. Make certain that the high voltage adjustment potentiometer is set to 3.84 (approximately 950 V).

(b) Attach the cable to the scaler and the probe and waterproof the probe by wrapping it in plastic.

(c) Insert the 20 foot length of PVC pipe into the hole, capped end first. Push the pipe into the hole as far as possible and secure it to prevent it from floating. (Taping the pipe to the hole's casing using electrical tape is a good way to secure it.) The purpose of the 1 inch pipe is to keep the probe dry.

(d) Use electrical tape to attach the end of the measuring tape to the probe cable. The distance from the flat end of the probe to the end of the measuring tape should equal the length of pipe protruding above ground level. When the tape is read at the top of the pipe, the reading gives the depth of the probe below ground level.

(e) Lower the probe into the 1 inch pipe and begin taking readings. Take the first reading at ground level, the second at a depth of 6 inches, the third at 1 foot, and so on, until the bottom is reached. The procedure for each reading is as follows Press the "count" button; wait while the instrument integrates 1 minute of counts (counting stops automatically after 1 minute); record the number of counts on the log record sheet; lower the probe 6 inches and begin the next reading.

(f) Measure and record the distance from the surface to the level of the ground water and record the measured value on the log sheet.

(3) Procedure for collecting and analyzing core samples The drilling crew, from Terra Testing, Inc., collected the core samples using a split spoon technique. Figure 5 shows how the cores were divided into samples. The samples were each placed in separate bottles and were labeled according to the numbering scheme shown in Figure 5.

## Results

Data from Bore Holes and Water Wells:

Appendix B presents the data taken in the bore holes and water wells. Each page in that appendix gives the results from a single hole. The pages are labeled BH#1 through BH#32, referring to the thirty-two bore holes drilled by Terra Testing, and WW#1 through WW#5, referring to the ground water sampling wells that were drilled prior to the start of the present study. Site Map I in Appendix A shows the locations of the bore holes and water wells that were situated within the study area. Locations of background bore holes and water wells situated outside the study area are shown on Site Map II in Appendix A.

The last column on each page of the bore hole data in Appendix B is the data taken in each hole, in units of counts per minute (cpm). The other three data columns on each page give the concentrations of thorium as a function of depth, expressed in units of µg/g, % by mass, and pCi/g. These derived values were calculated using the calibration constants developed in sections F-I ("Calibration of NaI Probe and Scintillometer versus Pressurized Ionization Chamber") and F-II ("Supplementary Calibration Data"). The data given in tabular form in Appendix B appears in Appendix C in graphical form. That appendix contains a graph for each hole giving counts per minute as a function of depth. We did not calculate thorium concentrations for the top 1 foot of the bore holes because the conditions there do not justify an assumption of a $4\pi$ geometry. Near the surface, the geometry is somewhere between $2\pi$ and $4\pi$. The calibration factors are only valid for a true $4\pi$ geometry.

The tables in Appendix B give the data for the water wells in units of counts per minute, but we did not calculate thorium levels for the wells. The calibration factors for the bore holes were based on the soil water content experiment, which employed 2" schedule 40 PVC pipe. The calibration was valid for the bore holes because they were cased with 2" PVC pipe. The water wells, however, were cased with 4" PVC pipe, so the soil water content experiment does not apply. For the section of the water wells below the water table, the increased diameter of the casing means that there is increased shielding due to water in the pipe. Therefore, the calibration factors do not strictly apply to the water wells.

Appendix D contains the drillers logs from the bore holes. These logs provide information concerning the type of material the auger encountered during drilling.

Background Data:

Two bore holes (BH#27 and BH#28) and one water well (WW#5) were situated outside of the study area at locations that were known to be free from thorium bearing slag. These three locations were selected to be representative of the subsurface background radiation levels that might typically be found in the vicinity of the Molycorp plant site. Site Map II in Appendix A shows the locations of these background holes. BH#27 was drilled on Molycorp property in an area of virgin soil that had not been disturbed by plant operations. The drillers encountered bedrock at eight feet in BH#27, so this is a short hole. BH#28 was drilled at a dumping site for ferro-molybdenum slag that was thought to have a low thorium content. WW#5, which was drilled prior to the start of the present study, was located near Chartier's Creek in a wooded area. The readings taken in these holes are summarized in the following table.

| | Conditions | Mean Value | Depth of Hole |
|---|---|---|---|
| BH#27 | virgin soil | 1640 cpm | 7.5 ft. |
| BH#28 | ferro molybdenum slag | 1969 cpm | 18 ft. |
| WW#5 | near Chartier's Creek | 1003 cpm | 13 ft |

BH#27, which was drilled in virgin soil, is the best indicator of the natural background in the study area. The data from this bore hole indicates that the maximum response of the NaI probe to the background radiation is approximately 2000 cpm.

Variations in soil thorium content over small distances:

We drilled two pairs of bore holes close together in order to assess the amount of variation in soil thorium ontent over small distances. Bore hole #29 was drilled 5 feet north of bore hole #6, and bore hole #32 was drilled 5 feet east of bore hole #16. An examination of the graphs of these pairs of holes (see Appendix C) demonstrates that the thorium content at a given depth can vary by as much as a factor of 10 over a distance of 5 feet. This result suggests that the thorium bearing material was deposited in an irregular manner at the site, and large variations exist over small distances. It might not be appropriate at this site, therefore, to draw conclusions based on extrapolation between holes.

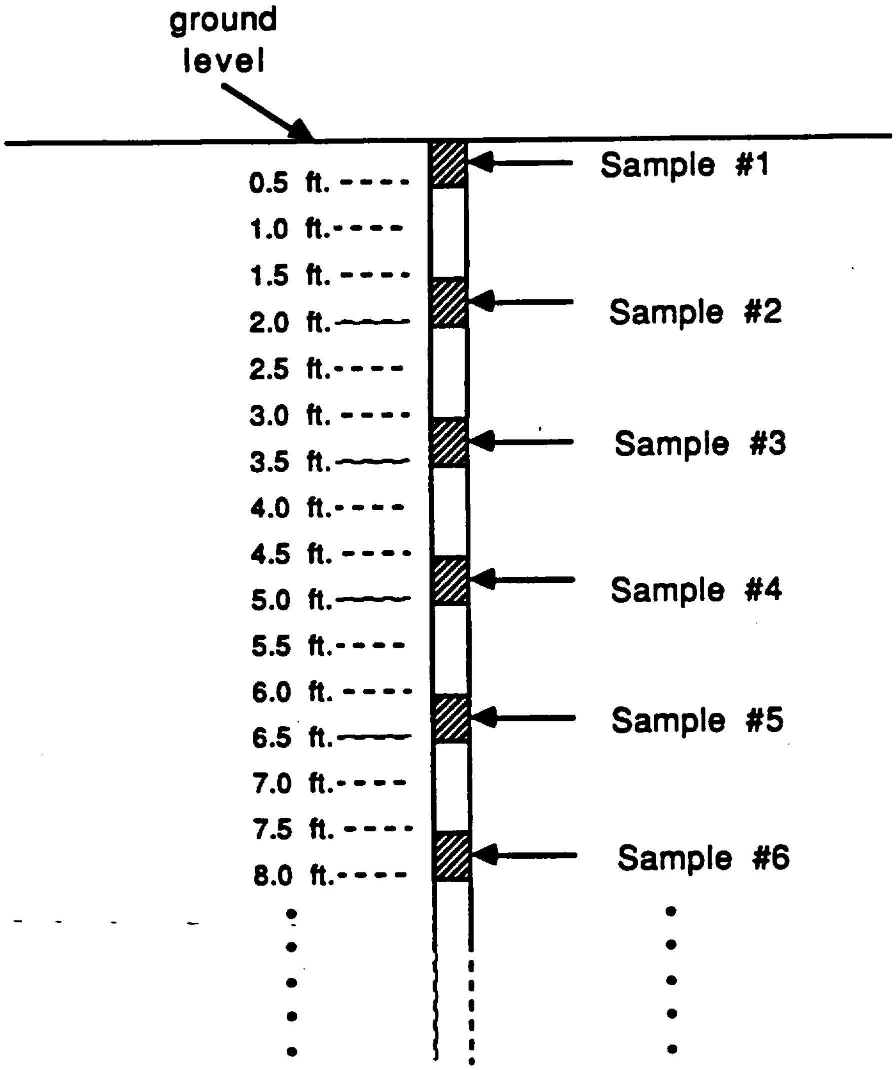



**Figure 5: Numbering system for soil samples taken from cores**

## IV. Surface Scintillometer Survey

### Purpose

A survey of the surface gamma exposure rates at the Molycorp Washington Pa. site was conducted to provide data for determining the relationship between subsurface concentrations of radionuclides and the surface gamma exposure rates. The gamma survey consisted of laying out a 20 foot grid imposed upon the entire study area and taking scintillometer readings at the grid intersections.

### Equipment and Material

(1) Ludlum model 19 scintillometer, serial number 22527.

(2) 100 ft. surveyor's tape.

(3) 100 surveyor's flags.

(4) The field notebook and a comfortable pair of walking shoes.

### Procedure

We established the twenty foot grid pattern on the study area in the following manner. A Cartesian co-ordinate system was established by taking a line co-incident with the north side of the Lanthanide Building as the X-axis and a line co-incident with the west side of the Lanthanide Building as the

:-axis. The northwest corner of the Lanthanide Building, therefore, was the origin of the Cartesian co-ordinates; the Y axis ran north-south with north as the positive direction; and the X-axis ran east-west with east as the positive direction. (Note: The sides of the Lanthanide Building are laid out to run north-south, east-west, so the co-ordinate system also runs north-south, east-west.) Site Map I in Appendix A shows how the co-ordinate system was laid out.

The twenty foot grid pattern consisted of several lines of red surveyor's flags laid out along the axes and along lines parallel to the axes. The flags were positioned so that all of the grid line intersections could be located by sighting down the flags.

The gamma radiation measurements were made using the Ludlum model 19 scintillometer. One reading was taken at each grid line intersection, with the meter held at waist level.

## Results

Site Map III in Appendix A presents the results of the scintillometer survey. The map shows the study area and the 20 foot grid pattern. The values shown at the grid intersections have been multiplied by the compensation factor derived in section F-I ("Calibration of NaI Probe and Scintillometer versus Pressurized Ionization Chamber") and are therefore true gamma. Appendix E gives the uncorrected scintillometer readings taken in the field.

## V. Survey and Mapping of Site

### Purpose

The complete characterization of the subsurface concentrations of radionuclides within the study area necessitated a careful survey of the site to obtain the location and elevation of the bore holes and the ground water wells. We used a rod and transit to find the locations of the holes in terms of the same Cartesian co-ordinate system employed in the scintillometer survey of the surface gamma field. The survey also included measurements of the positions of each of the PIC locations used in the calibration of the scintillometer and the NaI probe.

### Equipment and Material

(1) Transit, with tripod and plumb bob.

(2) 15 foot surveying rod.

(3) 100 ft. surveyor's tape.

(4) 100 surveyor's flags.

### Procedure

The locations and elevations of each of the bore holes, water wells, and PIC locations were measured using standard surveying techniques. The locations were recorded in terms

›f a co-ordinate system that was established by taking a line co-incident with the north side of the Lanthanide Building as the X-axis and a line co-incident with the west side of the Lanthanide Building as the Y-axis. The northwest corner of the Lanthanide Building, therefore, was the origin of the Cartesian co-ordinates, the Y axis ran north-south with north as the positive direction, and the X-axis ran east-west with east as the positive direction. (Note The sides of the Lanthanide Building are laid out to run north-south, east-west, so the co-ordinate system also runs north-south, east-west.) Site Map I in Appendix A shows how the co-ordinate system was laid out.

The elevations were all measured relative to a single reference point. The reference point was the top of the westernmost retaining wall of the loading dock on the west side of the Lanthanide Building. The point was five feet north of the building's northwest corner (i.e., five feet north of the origin of the X-Y co-ordinate system). Site Map I in Appendix A shows the location of the reference point.

## Results

Table 7 gives the X and Y co-ordinates of the boreholes, water wells, and PIC locations within the study area. All of the points listed in this table are also plotted on Site Map I in Appendix A.

| | x-coordinate (feet) | y-coordinate (feet) | Elevations (feet) |
|---|---|---|---|
| BH#1 | -48.024 | -254.423 | -6.11 |
| BH#2 | -154.729 | -276.524 | Data not available |
| BH#3 | -129.919 | -260.124 | -5.58 |
| BH#4 | -86.107 | -208.159 | -5.55 |
| BH#5 | -45.797 | -157.136 | -5.36 |
| BH#6 | -153.558 | -123.697 | -5.31 |
| BH#7 | -91.004 | -107.822 | -5.01 |
| BH#8 | -75.689 | -61.091 | -5.57 |
| BH#9 | -145.937 | -30.625 | -4.89 |
| BH#10 | -94.542 | -15.714 | -5 |
| BH#11 | -47.224 | 32.557 | -4.62 |
| BH#12 | -100.574 | 83.62 | -5.66 |
| BH#13 | -61.662 | 138.158 | -5.82 |
| BH#14 | -3.667 | 22.167 | -1.56 |
| BH#15 | 155.602 | 40.23 | -0.92 |
| BH#16 | 174.702 | 262.437 | 0.01 |
| BH#17 | -2.5 | 270.62 | -5.51 |
| BH#18 | 76.715 | 148.092 | -3.94 |
| BH#19 | 12.583 | 109.75 | -4.36 |
| BH#20 | 69.337 | 66.804 | -2.72 |
| BH#21 | 147.227 | 146.656 | -1.83 |
| BH#22 | 87.652 | 209.213 | -2.67 |
| BH#23 | 12.583 | 172.75 | -5.49 |
| BH#24 | -225.943 | -139.788 | -5.49 |
| BH#25 | -202.5 | 11.203 | -5.35 |
| BH#26 | -52.391 | 224.43 | -5.77 |
| BH#27 | | Outside of study area | |
| BH#28 | | Outside of study area | |
| BH#29 | -153.558 | -118.697 | Data not available |
| BH#30 | -172.413 | -145.16 | Data not available |
| BH#31 | -178.435 | -238.789 | Data not available |
| BH#32 | 179.702 | 262.437 | Data not available |
| WW#1 | 104.69 | -41.25 | 0.033 |
| WW#2 | -172.413 | -190.16 | -5.73 |
| WW#3 | -203.842 | -58.34 | -4.71 |
| WW#4 | -150.534 | 38.095 | -5.17 |
| WW#5 | | Outside of study area | |
| PIC#1 | 70.466 | 90.097 | -3.3 |
| PIC#2 | 174.702 | 262.437 | 0.01 |
| PIC#3 | 118.664 | 238.938 | 0.6 |
| PIC#4 | 154.687 | 111.875 | -1.82 |
| PIC#5 | 99.375 | -33.75 | 0.14 |
| PIC#6 | -217.812 | -41.875 | -5.48 |
| PIC#7 | -82.812 | -253.75 | -6.31 |

*Elevations are relative to the top of the retaining wall at the northwest corner of the Lanthanide building

**`ble 7: Co-ordinates and reletive elevations of Bore Holes, Water Wells and Pic Locations**

## Appendix A: Site Maps

Site Map I: Study area boundaries, the Cartesian co-ordinate system, the reference point for the elevation measurements, locations of boreholes and water wells, and PIC locations.

Site Map II: Locations of background bore holes and water wells situated outside the study area

Site Map III: Scintillometer survey of the surface gamma field.

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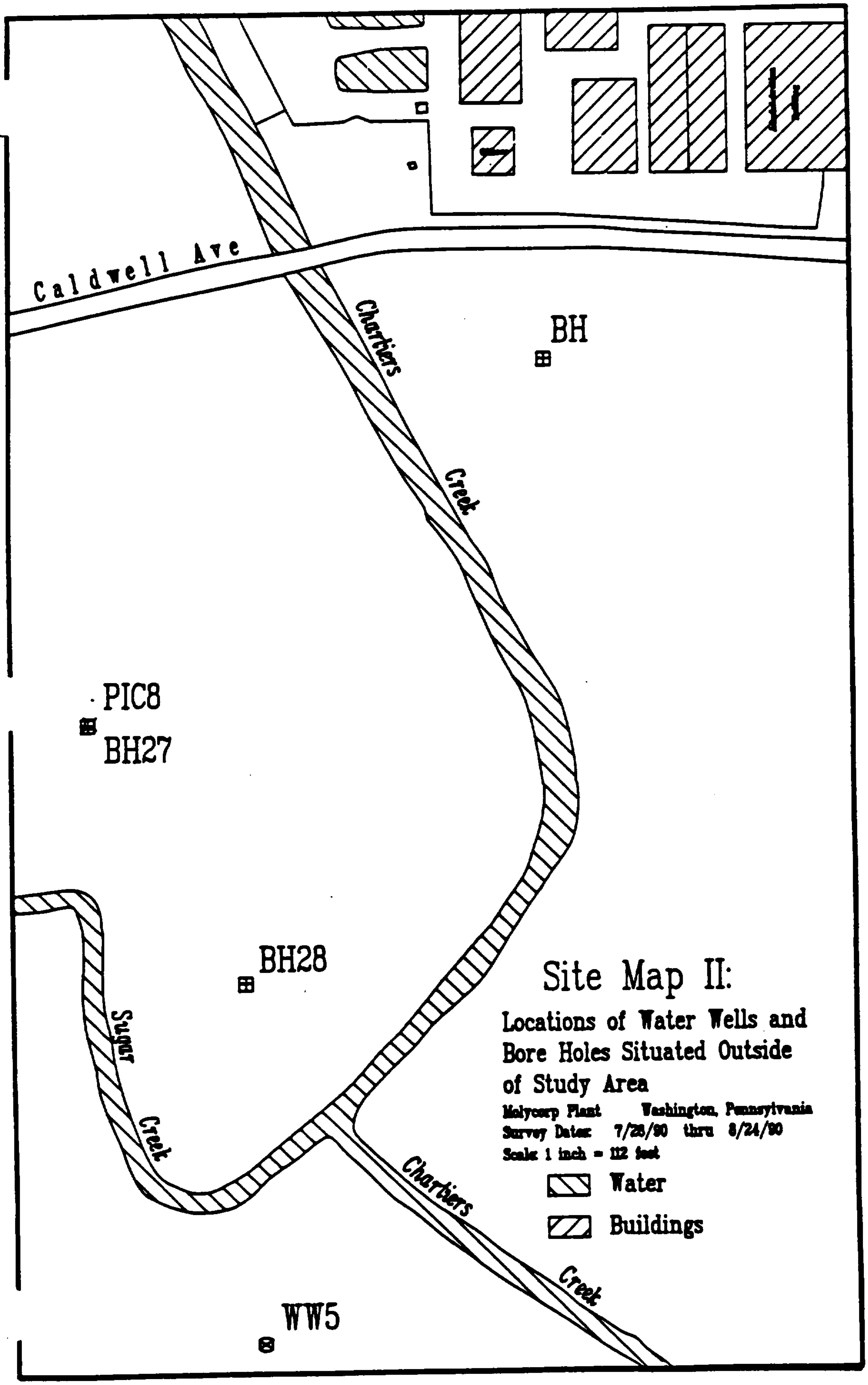



Site Map II:
Locations of Water Wells and Bore Holes Situated Outside of Study Area
Molycorp Plant Washington, Pennsylvania
Survey Dates: 7/28/90 thru 8/24/90
Scale: 1 inch = 112 feet

## Appendix B: Data from Bore Holes and Water Wells.

Formulas:

C = compensation factor ($\mu R \cdot hr^{-1}/cpm$). The compensation factor was derived by doing a least squares fit to a line constrained to pass through the origin using PIC readings - cosmic ray exposure vs. NaI probe readings. (See Figure 2.)

N = NaI probe readings (cpm).

(1) conversion from cpm to pCi/g:

$$^{232}Th\ (pCi/g) = 2(N \cdot cpm)(C \cdot \mu R \cdot hr{-}1/cpm)/(2.82\ \mu R \cdot hr{-}1/pCi \cdot g^{-1})$$

(2) conversion from pCi/g to µg/g:

$$^{232}Th\ (\mu g/g) = [^{232}Th\ (pCi/g)][9.1\ \mu g/pCi]$$

(3) conversion from µg/g to % by mass:

$$^{232}Th\ (\mu g/g) \cdot 0.0001 = {}^{232}Th\ (\%\ by\ mass)$$

(note: Data in this appendix include background; no background subtraction has been carried out.)

BH#[illegible]

| Depth (feet) | Level of water table | µg/g | % by n. | pCi/g | raw data (cpm) |
|---|---|---|---|---|---|
| 0 | | not calibrated* | not calibrated* | not calibrated* | 2886 ± 54 |
| 0.5 | | not calibrated* | not calibrated* | not calibrated* | 2958 ± 54 |
| 1 | | not calibrated* | not calibrated* | not calibrated* | 3798 ± 62 |
| 1.5 | | 133.1 | 0.01331 | 14.62 | 6221 ± 79 |
| 2 | | 114.0 | 0.01140 | 12.52 | 5327 ± 73 |
| 2.5 | 2' 9" | 71.8 | 0.00718 | 7.89 | 3357 ± 58 |
| 3 | ← | 54.0 | 0.00540 | 5.93 | 2524 ± 50 |
| 3.5 | | 38.6 | 0.00386 | 4.24 | 1805 ± 42 |
| 4 | | 37.3 | 0.00373 | 4.09 | 1742 ± 42 |
| 4.5 | | 33.0 | 0.00330 | 3.62 | 1542 ± 39 |
| 5 | | 33.4 | 0.00334 | 3.67 | 1561 ± 40 |
| 5.5 | | 32.3 | 0.00323 | 3.54 | 1508 ± 39 |
| 6 | | 32.5 | 0.00325 | 3.57 | 1520 ± 39 |
| 6.5 | | 28.8 | 0.00288 | 3.17 | 1347 ± 37 |
| 7 | | 27.9 | 0.00279 | 3.06 | 1304 ± 36 |
| 7.5 | | 26.7 | 0.00267 | 2.94 | 1249 ± 35 |
| 8 | | 26.7 | 0.00267 | 2.93 | 1248 ± 35 |
| 8.5 | | 26.5 | 0.00265 | 2.91 | 1239 ± 35 |
| 9 | | 27.9 | 0.00279 | 3.06 | 1302 ± 36 |
| 9.5 | | 25.5 | 0.00255 | 2.80 | 1192 ± 35 |
| 10 | | 25.0 | 0.00250 | 2.75 | 1169 ± 34 |
| 10.5 | | 24.2 | 0.00242 | 2.66 | 1132 ± 34 |
| 11 | | 23.6 | 0.00236 | 2.59 | 1104 ± 33 |
| 11.5 | | 23.3 | 0.00233 | 2.55 | 1087 ± 33 |
| 12 | | 22.3 | 0.00223 | 2.45 | 1042 ± 32 |
| 12.5 | | 21.3 | 0.00213 | 2.34 | 996 ± 32 |
| 13 | | 22.6 | 0.00226 | 2.48 | 1056 ± 32 |
| 13.5 | | 23.0 | 0.00230 | 2.52 | 1074 ± 33 |
| 14 | | 25.4 | 0.00254 | 2.79 | 1185 ± 34 |
| 14.5 | | 23.3 | 0.00233 | 2.56 | 1090 ± 33 |
| 15 | | 25.0 | 0.00250 | 2.74 | 1166 ± 34 |
| 15.5 | | 27.4 | 0.00274 | 3.00 | 1278 ± 36 |
| 16 | | 28.3 | 0.00283 | 3.11 | 1322 ± 36 |
| 16.5 | | 30.1 | 0.00301 | 3.31 | 1407 ± 38 |
| 17 | | 31.7 | 0.00317 | 3.48 | 1482 ± 38 |
| 17.5 | | 35.6 | 0.00356 | 3.91 | 1665 ± 41 |
| 18 | | 38.0 | 0.00380 | 4.17 | 1776 ± 42 |
| 18.5 | | 40.1 | 0.00401 | 4.41 | 1875 ± 43 |
| 19 | | 42.8 | 0.00428 | 4.70 | 1998 ± 45 |

*The top 1 foot of the bore hole does not represent a true 4π geometery, so a valid calibration factor is not available.

BH# [illegible]

| Depth (feet) | Level of water table | μg/g | % by n[illegible] | pCi/g | raw data (cpm) |
|---|---|---|---|---|---|
| 0 | | not calibrated* | not calibrated* | not calibrated* | 2042 ± 45 |
| 0.5 | | not calibrated* | not calibrated* | not calibrated* | 3992 ± 63 |
| 1 | | not calibrated* | not calibrated* | not calibrated* | 5322 ± 73 |
| 1.5 | | 99.1 | 0.00991 | 10.89 | 4632 ± 68 |
| 2 | | 86.2 | 0.00862 | 9.47 | 4027 ± 63 |
| 2.5 | | 80.0 | 0.00800 | 8.78 | 3737 ± 61 |
| 3 | | 95.5 | 0.00955 | 10.49 | 4464 ± 67 |
| 3.5 | | 109.3 | 0.01093 | 12.01 | 5108 ± 71 |
| 4 | | 85.4 | 0.00854 | 9.38 | 3992 ± 63 |
| 4.5 | | 68.2 | 0.00682 | 7.49 | 3186 ± 56 |
| 5 | | 43.1 | 0.00431 | 4.73 | 2014 ± 45 |
| 5.5 | | 33.4 | 0.00334 | 3.67 | 1561 ± 40 |
| 6 | | 29.1 | 0.00291 | 3.19 | 1359 ± 37 |
| 6.5 | | 27.7 | 0.00277 | 3.04 | 1294 ± 36 |
| 7 | | 28.9 | 0.00289 | 3.17 | 1348 ± 37 |
| 7.5 | 8' 2" | 29.2 | 0.00292 | 3.21 | 1365 ± 37 |
| 8 | ← | 28.0 | 0.00280 | 3.07 | 1306 ± 36 |
| 8.5 | | 27.9 | 0.00279 | 3.06 | 1302 ± 36 |
| 9 | | 25.9 | 0.00259 | 2.85 | 1211 ± 35 |
| 9.5 | | 22.7 | 0.00227 | 2.49 | 1060 ± 33 |
| 10 | | 22.1 | 0.00221 | 2.43 | 1032 ± 32 |
| 10.5 | | 19.9 | 0.00199 | 2.19 | 932 ± 31 |
| 11 | | 19.3 | 0.00193 | 2.12 | 903 ± 30 |
| 11.5 | | 22.0 | 0.00220 | 2.42 | 1028 ± 32 |
| 12 | | 24.3 | 0.00243 | 2.67 | 1137 ± 34 |
| 12.5 | | 22.6 | 0.00226 | 2.49 | 1058 ± 33 |
| 13 | | 22.4 | 0.00224 | 2.46 | 1046 ± 32 |
| 13.5 | | 21.7 | 0.00217 | 2.39 | 1015 ± 32 |
| 14 | | 23.1 | 0.00231 | 2.54 | 1079 ± 33 |
| 14.5 | | 23.9 | 0.00239 | 2.63 | 1118 ± 33 |
| 15 | | 23.4 | 0.00234 | 2.57 | 1093 ± 33 |
| 15.5 | | 23.5 | 0.00235 | 2.59 | 1100 ± 33 |
| 16 | | 21.3 | 0.00213 | 2.33 | 993 ± 32 |
| 16.5 | | 21.6 | 0.00216 | 2.37 | 1007 ± 32 |
| 17 | | 21.7 | 0.00217 | 2.38 | 1014 ± 32 |

*The top 1 foot of the bore hole does not represent a true 4π geometery, so a valid calibration factor is not available.

BH#^~

| Depth (feet) | Level of water table | µg/g | % by m... | pCi/g | raw data (cpm) |
|---|---|---|---|---|---|
| 0 | | not calibrated* | not calibrated* | not calibrated* | 4370 ± 66 |
| 0.5 | | not calibrated* | not calibrated* | not calibrated* | 6163 ± 79 |
| 1 | | not calibrated* | not calibrated* | not calibrated* | 9930 ± 100 |
| 1.5 | | 311.5 | 0.03115 | 34.21 | 14553 ± 121 |
| 2 | | 815.5 | 0.08155 | 89.56 | 38102 ± 195 |
| 2.5 | | 1481.0 | 0.14810 | 162.64 | 69196 ± 263 |
| 3 | | 1368.3 | 0.13683 | 150.27 | 63932 ± 253 |
| 3.5 | | 1361.4 | 0.13614 | 149.51 | 63610 ± 252 |
| 4 | | 1319.3 | 0.13193 | 144.89 | 61644 ± 248 |
| 4.5 | | 937.3 | 0.09373 | 102.94 | 43795 ± 209 |
| 5 | | 406.6 | 0.04066 | 44.66 | 18999 ± 138 |
| 5.5 | 6' 2" | 152.1 | 0.01521 | 16.71 | 7109 ± 84 |
| 6 | ← | 82.6 | 0.00826 | 9.07 | 3859 ± 62 |
| 6.5 | | 59.9 | 0.00599 | 6.57 | 2797 ± 53 |
| 7 | | 48.3 | 0.00483 | 5.30 | 2257 ± 48 |
| 7.5 | | 47.7 | 0.00477 | 5.23 | 2227 ± 47 |
| 8 | | 45.2 | 0.00452 | 4.97 | 2113 ± 46 |
| 8.5 | | 44.3 | 0.00443 | 4.87 | 2071 ± 46 |
| 9 | | 40.4 | 0.00404 | 4.44 | 1887 ± 43 |
| 9.5 | | 51.5 | 0.00515 | 5.66 | 2407 ± 49 |
| 10 | | 60.5 | 0.00605 | 6.65 | 2829 ± 53 |
| 10.5 | | 55.1 | 0.00551 | 6.05 | 2575 ± 51 |
| 11 | | 58.8 | 0.00588 | 6.46 | 2747 ± 52 |
| 11.5 | | 55.4 | 0.00554 | 6.09 | 2590 ± 51 |
| 12 | | 52.6 | 0.00526 | 5.77 | 2456 ± 50 |
| 12.5 | | 52.6 | 0.00526 | 5.78 | 2458 ± 50 |
| 13 | | 41.6 | 0.00416 | 4.57 | 1945 ± 44 |
| 13.5 | | 35.8 | 0.00358 | 3.93 | 1672 ± 41 |
| 14 | | 35.1 | 0.00351 | 3.86 | 1641 ± 41 |
| 14.5 | | 29.4 | 0.00294 | 3.23 | 1373 ± 37 |
| 15 | | 29.3 | 0.00293 | 3.22 | 1370 ± 37 |
| 15.5 | | 27.7 | 0.00277 | 3.05 | 1296 ± 36 |
| 16 | | 26.4 | 0.00264 | 2.90 | 1235 ± 35 |
| 16.5 | | 27.1 | 0.00271 | 2.97 | 1265 ± 36 |
| 17 | | 25.9 | 0.00259 | 2.84 | 1208 ± 35 |

*The top 1 foot of the bore hole does not represent a true 4π geometery, so a valid calibration factor is not available.

## BH# [illegible]

| Depth (feet) | Level of water table | µg/g | % by ma[illegible] | pCi/g | raw data (cpm) |
|---|---|---|---|---|---|
| 0 | | not calibrated* | not calibrated* | not calibrated* | 2769 ± 53 |
| 0.5 | | not calibrated* | not calibrated* | not calibrated* | 3094 ± 56 |
| 1 | 1' 5" | not calibrated* | not calibrated* | not calibrated* | 3828 ± 62 |
| 1.5 | ← | 114.9 | 0.01149 | 12.62 | 5370 ± 73 |
| 2 | | 109.4 | 0.01094 | 12.01 | 5110 ± 71 |
| 2.5 | | 91.7 | 0.00917 | 10.07 | 4286 ± 65 |
| 3 | | 101.5 | 0.01015 | 11.15 | 4742 ± 69 |
| 3.5 | | 117.2 | 0.01172 | 12.87 | 5474 ± 74 |
| 4 | | 115.4 | 0.01154 | 12.68 | 5394 ± 73 |
| 4.5 | | 87.4 | 0.00874 | 9.59 | 4082 ± 64 |
| 5 | | 54.5 | 0.00545 | 5.98 | 2546 ± 50 |
| 5.5 | | 42.1 | 0.00421 | 4.62 | 1967 ± 44 |
| 6 | | 35.0 | 0.00350 | 3.84 | 1633 ± 40 |
| 6.5 | | 36.3 | 0.00363 | 3.98 | 1695 ± 41 |
| 7 | | 34.2 | 0.00342 | 3.75 | 1597 ± 40 |
| 7.5 | | 32.0 | 0.00320 | 3.52 | 1497 ± 39 |
| 8 | | 30.2 | 0.00302 | 3.32 | 1412 ± 38 |
| 8.5 | | 29.6 | 0.00296 | 3.25 | 1383 ± 37 |
| 9 | | 29.0 | 0.00290 | 3.19 | 1357 ± 37 |
| 9.5 | | 28.2 | 0.00282 | 3.10 | 1317 ± 36 |
| 10 | | 28.4 | 0.00284 | 3.12 | 1329 ± 36 |
| 10.5 | | 28.5 | 0.00285 | 3.13 | 1333 ± 37 |
| 11 | | 26.9 | 0.00269 | 2.95 | 1255 ± 35 |
| 11.5 | | 28.5 | 0.00285 | 3.13 | 1331 ± 36 |
| 12 | | 29.9 | 0.00299 | 3.28 | 1397 ± 37 |
| 12.5 | | 31.3 | 0.00313 | 3.44 | 1464 ± 38 |
| 13 | | 32.2 | 0.00322 | 3.54 | 1505 ± 39 |
| 13.5 | | 31.3 | 0.00313 | 3.44 | 1462 ± 38 |
| 14 | | 28.6 | 0.00286 | 3.14 | 1335 ± 37 |
| 14.5 | | 26.5 | 0.00265 | 2.91 | 1237 ± 35 |
| 15 | | 21.9 | 0.00219 | 2.41 | 1024 ± 32 |
| 15.5 | | 23.1 | 0.00231 | 2.54 | 1080 ± 33 |
| 16 | | 27.1 | 0.00271 | 2.98 | 1267 ± 36 |
| 16.5 | | 22.5 | 0.00225 | 2.48 | 1053 ± 32 |
| 17 | | 27.0 | 0.00270 | 2.96 | 1261 ± 36 |
| 17.5 | | 27.8 | 0.00278 | 3.06 | 1300 ± 36 |

*The top 1 foot of the bore hole does not represent a true 4π geometery, so a valid calibration factor is not available.

BH#[illegible]

| Depth (feet) | Level of water table | µg/g | % by ma[illegible] | pCi/g | raw data (cpm) |
|---|---|---|---|---|---|
| 0 | | not calibrated* | not calibrated* | not calibrated* | 1875 ± 43 |
| 0.5 | | not calibrated* | not calibrated* | not calibrated* | 2611 ± 51 |
| 1 | | not calibrated* | not calibrated* | not calibrated* | 4236 ± 65 |
| 1.5 | 2' 0" | 142.6 | 0.01426 | 15.66 | 6663 ± 82 |
| 2 | ← | 177.5 | 0.01775 | 19.49 | 8293 ± 91 |
| 2.5 | | 119.1 | 0.01191 | 13.08 | 5565 ± 75 |
| 3 | | 119.1 | 0.01191 | 13.08 | 5564 ± 75 |
| 3.5 | | 64.6 | 0.00646 | 7.10 | 3020 ± 55 |
| 4 | | 59.5 | 0.00595 | 6.54 | 2781 ± 53 |
| 4.5 | | 63.7 | 0.00637 | 6.99 | 2974 ± 55 |
| 5 | | 69.6 | 0.00696 | 7.64 | 3250 ± 57 |
| 5.5 | | 76.0 | 0.00760 | 8.34 | 3549 ± 60 |
| 6 | | 70.3 | 0.00703 | 7.72 | 3283 ± 57 |
| 6.5 | | 59.6 | 0.00596 | 6.55 | 2787 ± 53 |
| 7 | | 49.1 | 0.00491 | 5.39 | 2293 ± 48 |
| 7.5 | | 48.3 | 0.00483 | 5.30 | 2257 ± 48 |
| 8 | | 43.2 | 0.00432 | 4.75 | 2019 ± 45 |
| 8.5 | | 37.2 | 0.00372 | 4.09 | 1739 ± 42 |
| 9 | | 34.2 | 0.00342 | 3.76 | 1598 ± 40 |
| 9.5 | | 32.2 | 0.00322 | 3.54 | 1506 ± 39 |
| 10 | | 34.4 | 0.00344 | 3.77 | 1606 ± 40 |
| 10.5 | | 32.0 | 0.00320 | 3.51 | 1495 ± 39 |
| 11 | | 32.7 | 0.00327 | 3.59 | 1526 ± 39 |
| 11.5 | | 31.4 | 0.00314 | 3.45 | 1467 ± 38 |
| 12 | | 30.5 | 0.00305 | 3.35 | 1426 ± 38 |
| 12.5 | | 28.9 | 0.00289 | 3.18 | 1351 ± 37 |
| 13 | | 30.3 | 0.00303 | 3.33 | 1417 ± 38 |
| 13.5 | | 28.3 | 0.00283 | 3.10 | 1321 ± 36 |
| 14 | | 30.9 | 0.00309 | 3.39 | 1444 ± 38 |
| 14.5 | | 29.4 | 0.00294 | 3.23 | 1374 ± 37 |
| 15 | | 26.8 | 0.00268 | 2.94 | 1250 ± 35 |
| 15.5 | | 24.5 | 0.00245 | 2.69 | 1143 ± 34 |
| 16 | | 26.9 | 0.00269 | 2.96 | 1259 ± 35 |
| 16.5 | | 25.0 | 0.00250 | 2.74 | 1167 ± 34 |
| 17 | | 26.6 | 0.00266 | 2.93 | 1245 ± 35 |
| 17.5 | | 34.2 | 0.00342 | 3.75 | 1596 ± 40 |

*The top 1 foot of the bore hole does not represent a true 4π geometery, so a valid calibration factor is not available.

BH#

| Depth (feet) | Level of water table | µg/g | % by mass | pCi/g | raw data (cpm) |
|---|---|---|---|---|---|
| 0 | | not calibrated* | not calibrated* | not calibrated* | 2866 ± 54 |
| 0.5 | | not calibrated* | not calibrated* | not calibrated* | 3610 ± 60 |
| 1 | | not calibrated* | not calibrated* | not calibrated* | 4945 ± 70 |
| 1.5 | | 183.5 | 0.01835 | 20.16 | 8575 ± 93 |
| 2 | | 209.1 | 0.02091 | 22.97 | 9772 ± 99 |
| 2.5 | | 166.6 | 0.01666 | 18.29 | 7783 ± 88 |
| 3 | | 165.9 | 0.01659 | 18.22 | 7751 ± 88 |
| 3.5 | | 264.3 | 0.02643 | 29.03 | 12351 ± 111 |
| 4 | | 302.6 | 0.03026 | 33.23 | 14139 ± 119 |
| 4.5 | | 431.3 | 0.04313 | 47.36 | 20151 ± 142 |
| 5 | | 690.3 | 0.06903 | 75.81 | 32253 ± 180 |
| 5.5 | | 743.0 | 0.07430 | 81.60 | 34718 ± 186 |
| 6 | | 1109.5 | 0.11095 | 121.84 | 51839 ± 228 |
| 6.5 | 6' 10" | 758.6 | 0.07586 | 83.31 | 35444 ± 188 |
| 7 | ← | 214.0 | 0.02140 | 23.51 | 10001 ± 100 |
| 7.5 | | 76.2 | 0.00762 | 8.37 | 3561 ± 60 |
| 8 | | 37.9 | 0.00379 | 4.17 | 1773 ± 42 |
| 8.5 | | 31.6 | 0.00316 | 3.47 | 1477 ± 38 |
| 9 | | 29.9 | 0.00299 | 3.29 | 1398 ± 37 |
| 9.5 | | 29.1 | 0.00291 | 3.20 | 1360 ± 37 |
| 10 | | 31.7 | 0.00317 | 3.48 | 1481 ± 38 |
| 10.5 | | 34.9 | 0.00349 | 3.84 | 1632 ± 40 |
| 11 | | 42.2 | 0.00422 | 4.63 | 1970 ± 44 |
| 11.5 | | 46.4 | 0.00464 | 5.09 | 2167 ± 47 |
| 12 | | 43.2 | 0.00432 | 4.74 | 2018 ± 45 |
| 12.5 | | 40.0 | 0.00400 | 4.39 | 1869 ± 43 |
| 13 | | 38.0 | 0.00380 | 4.17 | 1775 ± 42 |
| 13.5 | | 34.5 | 0.00345 | 3.79 | 1614 ± 40 |
| 14 | | 31.9 | 0.00319 | 3.50 | 1490 ± 39 |
| 14.5 | | 30.4 | 0.00304 | 3.34 | 1421 ± 38 |
| 15 | | 28.4 | 0.00284 | 3.12 | 1329 ± 36 |
| 15.5 | | 23.9 | 0.00239 | 2.63 | 1119 ± 33 |
| 16 | | 25.0 | 0.00250 | 2.75 | 1169 ± 34 |
| 16.5 | | 25.6 | 0.00256 | 2.81 | 1196 ± 35 |
| 17 | | 26.1 | 0.00261 | 2.86 | 1218 ± 35 |
| 17.5 | | 26.6 | 0.00266 | 2.92 | 1243 ± 35 |
| 18 | | 26.2 | 0.00262 | 2.88 | 1225 ± 35 |
| 18.5 | | 24.8 | 0.00248 | 2.72 | 1157 ± 34 |
| 19 | | 25.9 | 0.00259 | 2.84 | 1208 ± 35 |

*The top 1 foot of the bore hole does not represent a true $4\pi$ geometery, so a valid calibration factor is not available.

BH#

| Depth (feet) | Level of water table | µg/g | % by mass | pCi/g | raw data (cpm) |
|---|---|---|---|---|---|
| 0 | | not calibrated* | not calibrated* | not calibrated* | 6430 ± 80 |
| 0.5 | | not calibrated* | not calibrated* | not calibrated* | 7345 ± 86 |
| 1 | | not calibrated* | not calibrated* | not calibrated* | 5265 ± 73 |
| 1.5 | | 160.7 | 0.01607 | 17.65 | 7510 ± 87 |
| 2 | 2' 7" | 223.3 | 0.02233 | 24.52 | 10433 ± 102 |
| 2.5 | ← | 397.8 | 0.03978 | 43.69 | 18589 ± 136 |
| 3 | | 1025.1 | 0.10251 | 112.58 | 47896 ± 219 |
| 3.5 | | 1562.2 | 0.15622 | 171.56 | 72992 ± 270 |
| 4 | | 1685.1 | 0.16851 | 185.06 | 78736 ± 281 |
| 4.5 | | 1526.9 | 0.15269 | 167.68 | 71340 ± 267 |
| 5 | | 1281.6 | 0.12816 | 140.74 | 59880 ± 245 |
| 5.5 | | 906.6 | 0.09066 | 99.56 | 42360 ± 206 |
| 6 | | 1012.0 | 0.10120 | 111.14 | 47286 ± 217 |
| 6.5 | | 1346.5 | 0.13465 | 147.88 | 62915 ± 251 |
| 7 | | 678.2 | 0.06782 | 74.48 | 31689 ± 178 |
| 7.5 | | 247.2 | 0.02472 | 27.15 | 11551 ± 107 |
| 8 | | 90.2 | 0.00902 | 9.90 | 4214 ± 65 |
| 8.5 | | 47.2 | 0.00472 | 5.18 | 2204 ± 47 |
| 9 | | 34.6 | 0.00346 | 3.80 | 1617 ± 40 |
| 9.5 | | 30.7 | 0.00307 | 3.37 | 1434 ± 38 |
| 10 | | 30.3 | 0.00303 | 3.33 | 1415 ± 38 |
| 10.5 | | 29.6 | 0.00296 | 3.26 | 1385 ± 37 |
| 11 | | 30.4 | 0.00304 | 3.34 | 1419 ± 38 |
| 11.5 | | 29.1 | 0.00291 | 3.19 | 1359 ± 37 |
| 12 | | 30.3 | 0.00303 | 3.33 | 1416 ± 38 |
| 12.5 | | 30.4 | 0.00304 | 3.34 | 1421 ± 38 |
| 13 | | 36.3 | 0.00363 | 3.98 | 1695 ± 41 |
| 13.5 | | 35.1 | 0.00351 | 3.86 | 1642 ± 41 |
| 14 | | 51.3 | 0.00513 | 5.63 | 2396 ± 49 |
| 14.5 | | 121.5 | 0.01215 | 13.34 | 5675 ± 75 |
| 15 | | 121.2 | 0.01212 | 13.31 | 5661 ± 75 |
| 15.5 | | 66.1 | 0.00661 | 7.26 | 3087 ± 56 |
| 16 | | 73.8 | 0.00738 | 8.11 | 3450 ± 59 |
| 16.5 | | 89.4 | 0.00894 | 9.82 | 4179 ± 65 |
| 17 | | 38.2 | 0.00382 | 4.19 | 1784 ± 42 |
| 17.5 | | 26.8 | 0.00268 | 2.94 | 1251 ± 35 |
| 18 | | 26.0 | 0.00260 | 2.86 | 1216 ± 35 |
| 18.5 | | 26.5 | 0.00265 | 2.91 | 1238 ± 35 |
| 19 | | 29.6 | 0.00296 | 3.25 | 1382 ± 37 |

*The top 1 foot of the bore hole does not represent a true 4π geometery, so a valid calibration factor is not available.

## BH#[illegible]

| Depth (feet) | Level of water table | µg/g | % by m[illegible] | pCi/g | raw data (cpm) |
|---|---|---|---|---|---|
| 0 | | not calibrated* | not calibrated* | not calibrated* | 1402 ± 37 |
| 0.5 | | not calibrated* | not calibrated* | not calibrated* | 1869 ± 43 |
| 1 | | not calibrated* | not calibrated* | not calibrated* | 2628 ± 51 |
| 1.5 | | 67.4 | 0.00674 | 7.40 | 3149 ± 56 |
| 2 | 2' 5" | 108.7 | 0.01087 | 11.94 | 5080 ± 71 |
| 2.5 | ← | 191.5 | 0.01915 | 21.03 | 8948 ± 95 |
| 3 | | 390.9 | 0.03909 | 42.93 | 18263 ± 135 |
| 3.5 | | 478.3 | 0.04783 | 52.53 | 22350 ± 149 |
| 4 | | 219.8 | 0.02198 | 24.14 | 10269 ± 101 |
| 4.5 | | 120.5 | 0.01205 | 13.24 | 5631 ± 75 |
| 5 | | 63.8 | 0.00638 | 7.01 | 2981 ± 55 |
| 5.5 | | 48.1 | 0.00481 | 5.28 | 2247 ± 47 |
| 6 | | 53.3 | 0.00533 | 5.86 | 2492 ± 50 |
| 6.5 | | 59.4 | 0.00594 | 6.52 | 2775 ± 53 |
| 7 | | 76.3 | 0.00763 | 8.38 | 3564 ± 60 |
| 7.5 | | 37.3 | 0.00373 | 4.09 | 1742 ± 42 |
| 8 | | 32.2 | 0.00322 | 3.54 | 1506 ± 39 |
| 8.5 | | 28.0 | 0.00280 | 3.07 | 1307 ± 36 |
| 9 | | 28.2 | 0.00282 | 3.10 | 1317 ± 36 |
| 9.5 | | 28.9 | 0.00289 | 3.17 | 1349 ± 37 |
| 10 | | 32.1 | 0.00321 | 3.53 | 1500 ± 39 |
| 10.5 | | 31.2 | 0.00312 | 3.42 | 1457 ± 38 |
| 11 | | 30.5 | 0.00305 | 3.34 | 1423 ± 38 |
| 11.5 | | 31.0 | 0.00310 | 3.40 | 1447 ± 38 |
| 12 | | 30.8 | 0.00308 | 3.38 | 1439 ± 38 |
| 12.5 | | 30.6 | 0.00306 | 3.36 | 1431 ± 38 |
| 13 | | 30.7 | 0.00307 | 3.37 | 1434 ± 38 |
| 13.5 | | 32.1 | 0.00321 | 3.52 | 1498 ± 39 |
| 14 | | 32.4 | 0.00324 | 3.55 | 1512 ± 39 |
| 14.5 | | 27.9 | 0.00279 | 3.07 | 1305 ± 36 |
| 15 | | 26.9 | 0.00269 | 2.95 | 1255 ± 35 |
| 15.5 | | 26.8 | 0.00268 | 2.94 | 1250 ± 35 |
| 16 | | 26.8 | 0.00268 | 2.94 | 1250 ± 35 |
| 16.5 | | 24.3 | 0.00243 | 2.67 | 1135 ± 34 |
| 17 | | 24.1 | 0.00241 | 2.65 | 1127 ± 34 |
| 17.5 | | 24.2 | 0.00242 | 2.66 | 1132 ± 34 |
| 18 | | 24.0 | 0.00240 | 2.64 | 1122 ± 33 |
| 18.5 | | 24.4 | 0.00244 | 2.68 | 1140 ± 34 |

*The top 1 foot of the bore hole does not represent a true 4π geometery, so a valid calibration factor is not available.

**BH#[illegible]**

| Depth (feet) | Level of water table | µg/g | % by [illegible] | pCi/g | raw data (cpm) |
|---|---|---|---|---|---|
| 0 | | not calibrated* | not calibrated* | not calibrated* | 1910 ± 44 |
| 0.5 | | not calibrated* | not calibrated* | not calibrated* | 2712 ± 52 |
| 1 | | not calibrated* | not calibrated* | not calibrated* | 4768 ± 69 |
| 1.5 | | 118.4 | 0.01184 | 13.00 | 5530 ± 74 |
| 2 | | 136.7 | 0.01367 | 15.01 | 6387 ± 80 |
| 2.5 | | 114.5 | 0.01145 | 12.57 | 5349 ± 73 |
| 3 | | 107.3 | 0.01073 | 11.78 | 5012 ± 71 |
| 3.5 | | 103.4 | 0.01034 | 11.36 | 4833 ± 70 |
| 4 | | 105.7 | 0.01057 | 11.61 | 4938 ± 70 |
| 4.5 | | 136.1 | 0.01361 | 14.95 | 6361 ± 80 |
| 5 | 5' 8" | 150.7 | 0.01507 | 16.55 | 7040 ± 84 |
| 5.5 | ← | 125.5 | 0.01255 | 13.78 | 5864 ± 77 |
| 6 | | 94.8 | 0.00948 | 10.41 | 4431 ± 67 |
| 6.5 | | 70.6 | 0.00706 | 7.76 | 3301 ± 57 |
| 7 | | 61.9 | 0.00619 | 6.80 | 2893 ± 54 |
| 7.5 | | 37.1 | 0.00371 | 4.08 | 1734 ± 42 |
| 8 | | 29.3 | 0.00293 | 3.22 | 1370 ± 37 |
| 8.5 | | 26.7 | 0.00267 | 2.93 | 1246 ± 35 |
| 9 | | 27.8 | 0.00278 | 3.05 | 1297 ± 36 |
| 9.5 | | 25.7 | 0.00257 | 2.83 | 1202 ± 35 |
| 10 | | 27.8 | 0.00278 | 3.06 | 1301 ± 36 |
| 10.5 | | 26.3 | 0.00263 | 2.89 | 1231 ± 35 |
| 11 | | 25.7 | 0.00257 | 2.83 | 1203 ± 35 |
| 11.5 | | 25.9 | 0.00259 | 2.84 | 1208 ± 35 |
| 12 | | 24.7 | 0.00247 | 2.71 | 1153 ± 34 |
| 12.5 | | 23.4 | 0.00234 | 2.57 | 1092 ± 33 |
| 13 | | 25.0 | 0.00250 | 2.75 | 1168 ± 34 |
| 13.5 | | 24.0 | 0.00240 | 2.63 | 1121 ± 33 |
| 14 | | 22.2 | 0.00222 | 2.44 | 1038 ± 32 |
| 14.5 | | 21.7 | 0.00217 | 2.38 | 1014 ± 32 |
| 15 | | 25.3 | 0.00253 | 2.78 | 1182 ± 34 |
| 15.5 | | 28.0 | 0.00280 | 3.07 | 1306 ± 36 |
| 16 | | 27.4 | 0.00274 | 3.01 | 1280 ± 36 |
| 16.5 | | 23.5 | 0.00235 | 2.58 | 1097 ± 33 |
| 17 | | 24.1 | 0.00241 | 2.65 | 1127 ± 34 |
| 17.5 | | 26.3 | 0.00263 | 2.89 | 1229 ± 35 |
| 18 | | 27.1 | 0.00271 | 2.98 | 1267 ± 36 |
| 18.5 | | 32.9 | 0.00329 | 3.61 | 1535 ± 39 |
| 19 | | 36.5 | 0.00365 | 4.01 | 1707 ± 41 |
| 19.5 | | 36.2 | 0.00362 | 3.97 | 1691 ± 41 |

*The top 1 foot of the bore hole does not represent a true 4π geometery, so a valid calibration factor is not available.

BH

| Depth (feet) | Level of water table | µg/g | % by mass | pCi/g | raw data (cpm) |
|---|---|---|---|---|---|
| 0 | | not calibrated* | not calibrated* | not calibrated* | 4451 ± 67 |
| 0.5 | 1' 2" | not calibrated* | not calibrated* | not calibrated* | 6551 ± 81 |
| 1 | ← | not calibrated* | not calibrated* | not calibrated* | 6574 ± 81 |
| 1.5 | | 129.9 | 0.01299 | 14.27 | 6071 ± 78 |
| 2 | | 64.7 | 0.00647 | 7.11 | 3023 ± 55 |
| 2.5 | | 46.2 | 0.00462 | 5.07 | 2157 ± 46 |
| 3 | | 40.9 | 0.00409 | 4.49 | 1909 ± 44 |
| 3.5 | | 41.6 | 0.00416 | 4.56 | 1942 ± 44 |
| 4 | | 40.4 | 0.00404 | 4.44 | 1887 ± 43 |
| 4.5 | | 40.7 | 0.00407 | 4.47 | 1900 ± 44 |
| 5 | | 38.8 | 0.00388 | 4.27 | 1815 ± 43 |
| 5.5 | | 39.7 | 0.00397 | 4.36 | 1853 ± 43 |
| 6 | | 39.9 | 0.00399 | 4.39 | 1866 ± 43 |
| 6.5 | | 39.9 | 0.00399 | 4.38 | 1862 ± 43 |
| 7 | | 37.5 | 0.00375 | 4.12 | 1752 ± 42 |
| 7.5 | | 38.1 | 0.00381 | 4.18 | 1780 ± 42 |
| 8 | | 36.6 | 0.00366 | 4.02 | 1712 ± 41 |
| 8.5 | | 36.7 | 0.00367 | 4.03 | 1713 ± 41 |
| 9 | | 38.0 | 0.00380 | 4.17 | 1776 ± 42 |
| 9.5 | | 33.4 | 0.00334 | 3.67 | 1560 ± 39 |
| 10 | | 32.1 | 0.00321 | 3.53 | 1502 ± 39 |
| 10.5 | | 32.6 | 0.00326 | 3.58 | 1521 ± 39 |
| 11 | | 26.6 | 0.00266 | 2.92 | 1242 ± 35 |
| 11.5 | | 25.2 | 0.00252 | 2.76 | 1176 ± 34 |
| 12 | | 21.7 | 0.00217 | 2.38 | 1012 ± 32 |
| 12.5 | | 21.5 | 0.00215 | 2.36 | 1003 ± 32 |
| 13 | | 21.3 | 0.00213 | 2.34 | 995 ± 32 |
| 13.5 | | 23.1 | 0.00231 | 2.54 | 1081 ± 33 |
| 14 | | 23.5 | 0.00235 | 2.58 | 1096 ± 33 |
| 14.5 | | 24.6 | 0.00246 | 2.70 | 1148 ± 34 |
| 15 | | 23.3 | 0.00233 | 2.55 | 1087 ± 33 |
| 15.5 | | 23.4 | 0.00234 | 2.57 | 1093 ± 33 |
| 16 | | 25.7 | 0.00257 | 2.82 | 1201 ± 35 |
| 16.5 | | 25.3 | 0.00253 | 2.78 | 1182 ± 34 |
| 17 | | 26.2 | 0.00262 | 2.88 | 1224 ± 35 |
| 17.5 | | 29.3 | 0.00293 | 3.22 | 1369 ± 37 |
| 18 | | 32.7 | 0.00327 | 3.60 | 1530 ± 39 |
| 18.5 | | 35.6 | 0.00356 | 3.91 | 1664 ± 41 |
| 19 | | 37.4 | 0.00374 | 4.11 | 1749 ± 42 |

*The top 1 foot of the bore hole does not represent a true 4π geometery, so a valid calibration factor is not available.

BH

| Depth (feet) | Level of water table | µg/g | % by mass | pCi/g | raw data (cpm) |
|---|---|---|---|---|---|
| 0 | | not calibrated* | not calibrated* | not calibrated* | 2397 ± 49 |
| 0.5 | | not calibrated* | not calibrated* | not calibrated* | 4211 ± 65 |
| 1 | | not calibrated* | not calibrated* | not calibrated* | 7784 ± 88 |
| 1.5 | | 273.8 | 0.02738 | 30.07 | 12792 ± 113 |
| 2 | 2' 4" | 181.4 | 0.01814 | 19.92 | 8477 ± 92 |
| 2.5 | ← | 92.8 | 0.00928 | 10.19 | 4334 ± 66 |
| 3 | | 64.9 | 0.00649 | 7.13 | 3033 ± 55 |
| 3.5 | | 77.0 | 0.00770 | 8.45 | 3597 ± 60 |
| 4 | | 90.1 | 0.00901 | 9.89 | 4208 ± 65 |
| 4.5 | | 83.4 | 0.00834 | 9.15 | 3895 ± 62 |
| 5 | | 63.6 | 0.00636 | 6.99 | 2973 ± 55 |
| 5.5 | | 51.2 | 0.00512 | 5.62 | 2390 ± 49 |
| 6 | | 47.7 | 0.00477 | 5.24 | 2231 ± 47 |
| 6.5 | | 45.4 | 0.00454 | 4.98 | 2120 ± 46 |
| 7 | | 50.4 | 0.00504 | 5.54 | 2356 ± 49 |
| 7.5 | | 67.0 | 0.00670 | 7.35 | 3129 ± 56 |
| 8 | | 77.2 | 0.00772 | 8.48 | 3609 ± 60 |
| 8.5 | | 49.7 | 0.00497 | 5.46 | 2323 ± 48 |
| 9 | | 38.6 | 0.00386 | 4.24 | 1802 ± 42 |
| 9.5 | | 35.2 | 0.00352 | 3.87 | 1647 ± 41 |
| 10 | | 33.3 | 0.00333 | 3.65 | 1555 ± 39 |
| 10.5 | | 32.2 | 0.00322 | 3.54 | 1505 ± 39 |
| 11 | | 30.4 | 0.00304 | 3.34 | 1422 ± 38 |
| 11.5 | | 32.6 | 0.00326 | 3.58 | 1525 ± 39 |
| 12 | | 32.9 | 0.00329 | 3.61 | 1537 ± 39 |
| 12.5 | | 32.0 | 0.00320 | 3.51 | 1495 ± 39 |
| 13 | | 29.9 | 0.00299 | 3.28 | 1397 ± 37 |
| 13.5 | | 33.5 | 0.00335 | 3.68 | 1564 ± 40 |
| 14 | | 31.1 | 0.00311 | 3.42 | 1455 ± 38 |
| 14.5 | | 31.9 | 0.00319 | 3.50 | 1491 ± 39 |
| 15 | | 33.1 | 0.00331 | 3.63 | 1545 ± 39 |
| 15.5 | | 28.4 | 0.00284 | 3.11 | 1325 ± 36 |
| 16 | | 26.3 | 0.00263 | 2.89 | 1229 ± 35 |
| 16.5 | | 25.7 | 0.00257 | 2.83 | 1203 ± 35 |
| 17 | | 27.8 | 0.00278 | 3.05 | 1297 ± 36 |
| 17.5 | | 31.1 | 0.00311 | 3.41 | 1451 ± 38 |
| 18 | | 30.6 | 0.00306 | 3.36 | 1430 ± 38 |

*The top 1 foot of the bore hole does not represent a true 4π geometery, so a valid calibration factor is not available.

BH#[illegible]

| Depth (feet) | Level of water table | µg/g | % by n... | pCi/g | raw data (cpm) |
|---|---|---|---|---|---|
| 0 | | not calibrated* | not calibrated* | not calibrated* | 4767 ± 69 |
| 0.5 | | not calibrated* | not calibrated* | not calibrated* | 9131 ± 96 |
| 1 | | not calibrated* | not calibrated* | not calibrated* | 11857 ± 109 |
| 1.5 | | 229.8 | 0.02298 | 25.23 | 10735 ± 104 |
| 2 | | 355.2 | 0.03552 | 39.01 | 16598 ± 129 |
| 2.5 | 2' 10" | 418.9 | 0.04189 | 46.01 | 19574 ± 140 |
| 3 | ← | 173.1 | 0.01731 | 19.02 | 8090 ± 90 |
| 3.5 | | 71.7 | 0.00717 | 7.87 | 3350 ± 58 |
| 4 | | 46.0 | 0.00460 | 5.05 | 2147 ± 46 |
| 4.5 | | 37.1 | 0.00371 | 4.08 | 1734 ± 42 |
| 5 | | 35.1 | 0.00351 | 3.85 | 1638 ± 40 |
| 5.5 | | 35.6 | 0.00356 | 3.91 | 1663 ± 41 |
| 6 | | 30.9 | 0.00309 | 3.39 | 1444 ± 38 |
| 6.5 | | 31.0 | 0.00310 | 3.41 | 1450 ± 38 |
| 7 | | 28.5 | 0.00285 | 3.13 | 1330 ± 36 |
| 7.5 | | 26.1 | 0.00261 | 2.87 | 1219 ± 35 |
| 8 | | 25.3 | 0.00253 | 2.78 | 1183 ± 34 |
| 8.5 | | 24.5 | 0.00245 | 2.69 | 1143 ± 34 |
| 9 | | 23.1 | 0.00231 | 2.54 | 1081 ± 33 |
| 9.5 | | 25.0 | 0.00250 | 2.74 | 1166 ± 34 |
| 10 | | 26.0 | 0.00260 | 2.86 | 1216 ± 35 |
| 10.5 | | 27.4 | 0.00274 | 3.00 | 1278 ± 36 |
| 11 | | 27.1 | 0.00271 | 2.98 | 1267 ± 36 |
| 11.5 | | 29.4 | 0.00294 | 3.23 | 1375 ± 37 |
| 12 | | 30.3 | 0.00303 | 3.33 | 1418 ± 38 |
| 12.5 | | 28.5 | 0.00285 | 3.13 | 1332 ± 36 |
| 13 | | 27.0 | 0.00270 | 2.96 | 1260 ± 35 |
| 13.5 | | 24.7 | 0.00247 | 2.71 | 1152 ± 34 |
| 14 | | 27.6 | 0.00276 | 3.03 | 1291 ± 36 |
| 14.5 | | 34.7 | 0.00347 | 3.81 | 1619 ± 40 |
| 15 | | 29.9 | 0.00299 | 3.28 | 1397 ± 37 |
| 15.5 | | 25.4 | 0.00254 | 2.79 | 1187 ± 34 |
| 16 | | 25.3 | 0.00253 | 2.78 | 1181 ± 34 |
| 16.5 | | 36.5 | 0.00365 | 4.01 | 1704 ± 41 |
| 17 | | 26.9 | 0.00269 | 2.96 | 1259 ± 35 |
| 17.5 | | 26.8 | 0.00268 | 2.94 | 1250 ± 35 |
| 18 | | 29.7 | 0.00297 | 3.27 | 1390 ± 37 |
| 18.5 | | 32.8 | 0.00328 | 3.60 | 1533 ± 39 |
| 19 | | 36.2 | 0.00362 | 3.97 | 1690 ± 41 |

*The top 1 foot of the bore hole does not represent a true 4π geometery, so a valid calibration factor is not available.

**BH#**

| Depth (feet) | Level of water table | µg/g | % by mass | pCi/g | raw data (cpm) |
|---|---|---|---|---|---|
| 0 | | not calibrated* | not calibrated* | not calibrated* | 1591 ± 40 |
| 0.5 | | not calibrated* | not calibrated* | not calibrated* | 2435 ± 49 |
| 1 | | not calibrated* | not calibrated* | not calibrated* | 3022 ± 55 |
| 1.5 | | 50.7 | 0.00507 | 5.57 | 2369 ± 49 |
| 2 | | 38.1 | 0.00381 | 4.19 | 1781 ± 42 |
| 2.5 | | 35.6 | 0.00356 | 3.91 | 1662 ± 41 |
| 3 | | 35.0 | 0.00350 | 3.84 | 1635 ± 40 |
| 3.5 | 4' 0" | 35.4 | 0.00354 | 3.88 | 1652 ± 41 |
| 4 | ← | 33.5 | 0.00335 | 3.67 | 1563 ± 40 |
| 4.5 | | 30.3 | 0.00303 | 3.33 | 1415 ± 38 |
| 5 | | 29.8 | 0.00298 | 3.27 | 1392 ± 37 |
| 5.5 | | 28.7 | 0.00287 | 3.15 | 1341 ± 37 |
| 6 | | 31.1 | 0.00311 | 3.42 | 1453 ± 38 |
| 6.5 | | 31.4 | 0.00314 | 3.44 | 1465 ± 38 |
| 7 | | 31.2 | 0.00312 | 3.43 | 1459 ± 38 |
| 7.5 | | 30.0 | 0.00300 | 3.29 | 1400 ± 37 |
| 8 | | 29.2 | 0.00292 | 3.21 | 1364 ± 37 |
| 8.5 | | 28.7 | 0.00287 | 3.15 | 1340 ± 37 |
| 9 | | 28.6 | 0.00286 | 3.14 | 1334 ± 37 |
| 9.5 | | 27.4 | 0.00274 | 3.01 | 1281 ± 36 |
| 10 | | 24.2 | 0.00242 | 2.66 | 1133 ± 34 |
| 10.5 | | 23.6 | 0.00236 | 2.59 | 1103 ± 33 |
| 11 | | 22.5 | 0.00225 | 2.47 | 1051 ± 32 |
| 11.5 | | 20.4 | 0.00204 | 2.24 | 952 ± 31 |
| 12 | | 19.7 | 0.00197 | 2.17 | 922 ± 30 |
| 12.5 | | 20.7 | 0.00207 | 2.27 | 967 ± 31 |
| 13 | | 20.8 | 0.00208 | 2.29 | 974 ± 31 |
| 13.5 | | 21.6 | 0.00216 | 2.37 | 1007 ± 32 |
| 14 | | 22.5 | 0.00225 | 2.47 | 1052 ± 32 |
| 14.5 | | 23.9 | 0.00239 | 2.63 | 1118 ± 33 |
| 15 | | 22.8 | 0.00228 | 2.50 | 1063 ± 33 |
| 15.5 | | 23.0 | 0.00230 | 2.52 | 1074 ± 33 |
| 16 | | 23.2 | 0.00232 | 2.54 | 1082 ± 33 |
| 16.5 | | 22.5 | 0.00225 | 2.48 | 1053 ± 32 |
| 17 | | 23.0 | 0.00230 | 2.53 | 1075 ± 33 |
| 17.5 | | 22.5 | 0.00225 | 2.48 | 1053 ± 32 |
| 18 | | 23.0 | 0.00230 | 2.53 | 1075 ± 33 |

*The top 1 foot of the bore hole does not represent a true 4π geometery, so a valid calibration factor is not available.

# BH#

| Depth (feet) | Level of water table | µg/g | % by mass | pCi/g | raw data (cpm) |
|---|---|---|---|---|---|
| 0 | | not calibrated* | not calibrated* | not calibrated* | 1703 ± 41 |
| 0.5 | | not calibrated* | not calibrated* | not calibrated* | 2196 ± 47 |
| 1 | | not calibrated* | not calibrated* | not calibrated* | 1971 ± 44 |
| 1.5 | | 39.9 | 0.00399 | 4.38 | 1863 ± 43 |
| 2 | | 43.6 | 0.00436 | 4.79 | 2038 ± 45 |
| 2.5 | | 61.5 | 0.00615 | 6.75 | 2873 ± 54 |
| 3 | | 89.3 | 0.00893 | 9.80 | 4171 ± 65 |
| 3.5 | | 68.4 | 0.00684 | 7.51 | 3196 ± 57 |
| 4 | | 52.3 | 0.00523 | 5.74 | 2443 ± 49 |
| 4.5 | | 61.1 | 0.00611 | 6.71 | 2856 ± 53 |
| 5 | 5' 6" | 91.3 | 0.00913 | 10.02 | 4265 ± 65 |
| 5.5 | ← | 100.1 | 0.01001 | 10.99 | 4677 ± 68 |
| 6 | | 91.7 | 0.00917 | 10.07 | 4283 ± 65 |
| 6.5 | | 134.0 | 0.01340 | 14.72 | 6261 ± 79 |
| 7 | | 183.2 | 0.01832 | 20.12 | 8558 ± 93 |
| 7.5 | | 161.6 | 0.01616 | 17.74 | 7549 ± 87 |
| 8 | | 122.1 | 0.01221 | 13.41 | 5706 ± 76 |
| 8.5 | | 111.6 | 0.01116 | 12.26 | 5215 ± 72 |
| 9 | | 109.8 | 0.01098 | 12.05 | 5128 ± 72 |
| 9.5 | | 101.1 | 0.01011 | 11.11 | 4726 ± 69 |
| 10 | | 88.8 | 0.00888 | 9.76 | 4151 ± 64 |
| 10.5 | | 73.6 | 0.00736 | 8.08 | 3439 ± 59 |
| 11 | | 73.0 | 0.00730 | 8.02 | 3412 ± 58 |
| 11.5 | | 76.7 | 0.00767 | 8.42 | 3584 ± 60 |
| 12 | | 58.9 | 0.00589 | 6.47 | 2754 ± 52 |
| 12.5 | | 50.7 | 0.00507 | 5.57 | 2371 ± 49 |
| 13 | | 41.0 | 0.00410 | 4.51 | 1917 ± 44 |
| 13.5 | | 40.6 | 0.00406 | 4.46 | 1899 ± 44 |
| 14 | | 43.6 | 0.00436 | 4.79 | 2037 ± 45 |
| 14.5 | | 42.0 | 0.00420 | 4.61 | 1962 ± 44 |
| 15 | | 40.8 | 0.00408 | 4.48 | 1907 ± 44 |
| 15.5 | | 37.9 | 0.00379 | 4.16 | 1771 ± 42 |
| 16 | | 35.5 | 0.00355 | 3.90 | 1661 ± 41 |
| 16.5 | | 32.2 | 0.00322 | 3.54 | 1506 ± 39 |
| 17 | | 32.9 | 0.00329 | 3.61 | 1536 ± 39 |
| 17.5 | | 35.0 | 0.00350 | 3.84 | 1635 ± 40 |
| 18 | | 33.6 | 0.00336 | 3.69 | 1572 ± 40 |
| 18.5 | | 31.2 | 0.00312 | 3.42 | 1457 ± 38 |
| 19 | | 30.0 | 0.00300 | 3.30 | 1404 ± 37 |
| 19.5 | | 31.1 | 0.00311 | 3.42 | 1455 ± 38 |

*The top 1 foot of the bore hole does not represent a true 4π geometery, so a valid calibration factor is not available.

## BH# [illegible]

| Depth (feet) | Level of water table | µg/g | % by [illegible] | pCi/g | raw data (cpm) |
|---|---|---|---|---|---|
| 0 | | not calibrated* | not calibrated* | not calibrated* | 1995 ± 45 |
| 0.5 | | not calibrated* | not calibrated* | not calibrated* | 2182 ± 47 |
| 1 | | not calibrated* | not calibrated* | not calibrated* | 2346 ± 48 |
| 1.5 | | 64.3 | 0.00643 | 7.07 | 3006 ± 55 |
| 2 | | 84.9 | 0.00849 | 9.33 | 3968 ± 63 |
| 2.5 | | 119.0 | 0.01190 | 13.07 | 5562 ± 75 |
| 3 | | 147.7 | 0.01477 | 16.22 | 6901 ± 83 |
| 3.5 | | 172.0 | 0.01720 | 18.89 | 8037 ± 90 |
| 4 | | 242.8 | 0.02428 | 26.66 | 11344 ± 107 |
| 4.5 | | 313.1 | 0.03131 | 34.38 | 14629 ± 121 |
| 5 | | 235.8 | 0.02358 | 25.90 | 11018 ± 105 |
| 5.5 | | 152.7 | 0.01527 | 16.77 | 7136 ± 84 |
| 6 | | 117.8 | 0.01178 | 12.94 | 5506 ± 74 |
| 6.5 | | 100.7 | 0.01007 | 11.06 | 4705 ± 69 |
| 7 | | 95.7 | 0.00957 | 10.51 | 4473 ± 67 |
| 7.5 | | 80.0 | 0.00800 | 8.79 | 3738 ± 61 |
| 8 | | 76.7 | 0.00767 | 8.42 | 3582 ± 60 |
| 8.5 | | 84.7 | 0.00847 | 9.30 | 3956 ± 63 |
| 9 | | 90.0 | 0.00900 | 9.88 | 4205 ± 65 |
| 9.5 | | 76.9 | 0.00769 | 8.44 | 3592 ± 60 |
| 10 | | 48.9 | 0.00489 | 5.37 | 2285 ± 48 |
| 10.5 | | 40.3 | 0.00403 | 4.43 | 1884 ± 43 |
| 11 | | 37.3 | 0.00373 | 4.10 | 1745 ± 42 |
| 11.5 | | 35.0 | 0.00350 | 3.84 | 1634 ± 40 |
| 12 | | 34.4 | 0.00344 | 3.77 | 1606 ± 40 |
| 12.5 | | 33.9 | 0.00339 | 3.72 | 1582 ± 40 |
| 13 | | 34.1 | 0.00341 | 3.74 | 1591 ± 40 |
| 13.5 | | 31.5 | 0.00315 | 3.46 | 1470 ± 38 |
| 14 | | 31.3 | 0.00313 | 3.44 | 1463 ± 38 |
| 14.5 | | 29.4 | 0.00294 | 3.23 | 1373 ± 37 |
| 15 | | 29.4 | 0.00294 | 3.22 | 1372 ± 37 |
| 15.5 | | 29.7 | 0.00297 | 3.26 | 1389 ± 37 |
| 16 | | 29.4 | 0.00294 | 3.23 | 1375 ± 37 |
| 16.5 | 17' 0" | 28.7 | 0.00287 | 3.16 | 1343 ± 37 |
| 17 | ← | 28.2 | 0.00282 | 3.09 | 1316 ± 36 |
| 17.5 | | 28.2 | 0.00282 | 3.10 | 1318 ± 36 |
| 18 | | 30.8 | 0.00308 | 3.38 | 1438 ± 38 |
| 18.5 | | 29.7 | 0.00297 | 3.27 | 1390 ± 37 |
| 19 | | 37.7 | 0.00377 | 4.14 | 1762 ± 42 |

*The top 1 foot of the bore hole does not represent a true 4π geometery, so a valid calibration factor is not available.

## BH#1

| Depth (feet) | Level of water table | µg/g | % by m | pCi/g | raw data (cpm) |
|---|---|---|---|---|---|
| 0 | | not calibrated* | not calibrated* | not calibrated* | 18396 ± 136 |
| 0.5 | | not calibrated* | not calibrated* | not calibrated* | 25461 ± 160 |
| 1 | | not calibrated* | not calibrated* | not calibrated* | 21943 ± 148 |
| 1.5 | | 503.4 | 0.05034 | 55.28 | 23520 ± 153 |
| 2 | | 841.3 | 0.08413 | 92.39 | 39308 ± 198 |
| 2.5 | | 1461.5 | 0.14615 | 160.50 | 68287 ± 261 |
| 3 | | 2364.8 | 0.23648 | 259.70 | 110490 ± 332 |
| 3.5 | | 2627.2 | 0.26272 | 288.53 | 122754 ± 350 |
| 4 | | 1630.9 | 0.16309 | 179.10 | 76200 ± 276 |
| 4.5 | | 640.7 | 0.06407 | 70.36 | 29934 ± 173 |
| 5 | | 345.9 | 0.03459 | 37.99 | 16162 ± 127 |
| 5.5 | | 219.9 | 0.02199 | 24.15 | 10276 ± 101 |
| 6 | | 166.6 | 0.01666 | 18.30 | 7784 ± 88 |
| 6.5 | | 126.3 | 0.01263 | 13.87 | 5903 ± 77 |
| 7 | | 90.8 | 0.00908 | 9.97 | 4242 ± 65 |
| 7.5 | | 68.9 | 0.00689 | 7.56 | 3217 ± 57 |
| 8 | 8' 4" | 64.5 | 0.00645 | 7.09 | 3015 ± 55 |
| 8.5 | ← | 72.6 | 0.00726 | 7.98 | 3394 ± 58 |
| 9 | | 88.9 | 0.00889 | 9.76 | 4153 ± 64 |
| 9.5 | | 77.1 | 0.00771 | 8.47 | 3604 ± 60 |
| 10 | | 61.1 | 0.00611 | 6.71 | 2853 ± 53 |
| 10.5 | | 46.0 | 0.00460 | 5.05 | 2148 ± 46 |
| 11 | | 42.0 | 0.00420 | 4.61 | 1961 ± 44 |
| 11.5 | | 40.6 | 0.00406 | 4.46 | 1899 ± 44 |
| 12 | | 42.1 | 0.00421 | 4.62 | 1967 ± 44 |
| 12.5 | | 43.4 | 0.00434 | 4.77 | 2030 ± 45 |
| 13 | | 35.1 | 0.00351 | 3.85 | 1638 ± 40 |
| 13.5 | | 33.4 | 0.00334 | 3.67 | 1560 ± 39 |
| 14 | | 33.7 | 0.00337 | 3.70 | 1574 ± 40 |
| 14.5 | | 33.9 | 0.00339 | 3.73 | 1586 ± 40 |
| 15 | | 32.6 | 0.00326 | 3.58 | 1525 ± 39 |
| 15.5 | | 32.4 | 0.00324 | 3.56 | 1516 ± 39 |
| 16 | | 34.1 | 0.00341 | 3.74 | 1592 ± 40 |
| 16.5 | | 33.5 | 0.00335 | 3.68 | 1567 ± 40 |
| 17 | | 34.1 | 0.00341 | 3.74 | 1592 ± 40 |
| 17.5 | | 34.1 | 0.00341 | 3.74 | 1591 ± 40 |
| 18 | | 34.0 | 0.00340 | 3.73 | 1588 ± 40 |
| 18.5 | | 33.7 | 0.00337 | 3.70 | 1575 ± 40 |

*The top 1 foot of the bore hole does not represent a true 4π geometery, so a valid calibration factor is not available.

## BH#1

| Depth (feet) | Level of water table | µg/g | % by mass | pCi/g | raw data (cpm) |
|---|---|---|---|---|---|
| 0 | | not calibrated* | not calibrated* | not calibrated* | 2033 ± 45 |
| 0.5 | | not calibrated* | not calibrated* | not calibrated* | 2512 ± 50 |
| 1 | | not calibrated* | not calibrated* | not calibrated* | 3723 ± 61 |
| 1.5 | | 115.1 | 0.01151 | 12.64 | 5376 ± 73 |
| 2 | | 125.1 | 0.01251 | 13.74 | 5844 ± 76 |
| 2.5 | | 121.7 | 0.01217 | 13.36 | 5685 ± 75 |
| 3 | | 123.4 | 0.01234 | 13.56 | 5768 ± 76 |
| 3.5 | | 111.6 | 0.01116 | 12.26 | 5215 ± 72 |
| 4 | | 106.1 | 0.01061 | 11.65 | 4956 ± 70 |
| 4.5 | | 84.9 | 0.00849 | 9.33 | 3968 ± 63 |
| 5 | | 57.9 | 0.00579 | 6.35 | 2703 ± 52 |
| 5.5 | 6' 2" | 40.2 | 0.00402 | 4.41 | 1876 ± 43 |
| 6 | ← | 33.3 | 0.00333 | 3.66 | 1556 ± 39 |
| 6.5 | | 30.1 | 0.00301 | 3.31 | 1407 ± 38 |
| 7 | | 28.4 | 0.00284 | 3.12 | 1329 ± 36 |
| 7.5 | | 27.1 | 0.00271 | 2.98 | 1268 ± 36 |
| 8 | | 25.1 | 0.00251 | 2.75 | 1172 ± 34 |
| 8.5 | | 24.5 | 0.00245 | 2.69 | 1143 ± 34 |
| 9 | | 23.5 | 0.00235 | 2.58 | 1099 ± 33 |
| 9.5 | | 24.1 | 0.00241 | 2.65 | 1126 ± 34 |
| 10 | | 25.6 | 0.00256 | 2.81 | 1197 ± 35 |
| 10.5 | | 28.2 | 0.00282 | 3.10 | 1317 ± 36 |
| 11 | | 29.6 | 0.00296 | 3.25 | 1383 ± 37 |
| 11.5 | | 29.2 | 0.00292 | 3.20 | 1362 ± 37 |
| 12 | | 27.1 | 0.00271 | 2.97 | 1265 ± 36 |
| 12.5 | | 26.7 | 0.00267 | 2.93 | 1248 ± 35 |
| 13 | | 25.8 | 0.00258 | 2.83 | 1206 ± 35 |
| 13.5 | | 25.4 | 0.00254 | 2.79 | 1188 ± 34 |
| 14 | | 25.1 | 0.00251 | 2.76 | 1174 ± 34 |
| 14.5 | | 25.3 | 0.00253 | 2.78 | 1181 ± 34 |
| 15 | | 26.6 | 0.00266 | 2.93 | 1245 ± 35 |
| 15.5 | | 26.0 | 0.00260 | 2.86 | 1215 ± 35 |
| 16 | | 26.4 | 0.00264 | 2.90 | 1234 ± 35 |
| 16.5 | | 29.8 | 0.00298 | 3.27 | 1391 ± 37 |
| 17 | | 28.4 | 0.00284 | 3.12 | 1329 ± 36 |
| 17.5 | | 33.0 | 0.00330 | 3.62 | 1541 ± 39 |
| 18 | | 32.6 | 0.00326 | 3.58 | 1525 ± 39 |
| 18.5 | | 33.3 | 0.00333 | 3.66 | 1557 ± 39 |
| 19 | | 36.9 | 0.00369 | 4.05 | 1722 ± 41 |

*The top 1 foot of the bore hole does not represent a true 4π geometery, so a valid calibration factor is not available.

BH#

| Depth (feet) | Level of water table | µg/g | % by mass | pCi/g | raw data (cpm) |
|---|---|---|---|---|---|
| 0 | | not calibrated* | not calibrated* | not calibrated* | 1083 ± 33 |
| 0.5 | | not calibrated* | not calibrated* | not calibrated* | 1154 ± 34 |
| 1 | | not calibrated* | not calibrated* | not calibrated* | 1257 ± 35 |
| 1.5 | | 27.4 | 0.00274 | 3.01 | 1282 ± 36 |
| 2 | | 28.3 | 0.00283 | 3.11 | 1323 ± 36 |
| 2.5 | | 30.3 | 0.00303 | 3.33 | 1416 ± 38 |
| 3 | | 37.4 | 0.00374 | 4.11 | 1749 ± 42 |
| 3.5 | 4' 0" | 49.5 | 0.00495 | 5.44 | 2315 ± 48 |
| 4 | ← | 55.8 | 0.00558 | 6.13 | 2609 ± 51 |
| 4.5 | | 43.8 | 0.00438 | 4.81 | 2046 ± 45 |
| 5 | | 39.0 | 0.00390 | 4.29 | 1824 ± 43 |
| 5.5 | | 38.7 | 0.00387 | 4.25 | 1807 ± 43 |
| 6 | | 39.7 | 0.00397 | 4.36 | 1855 ± 43 |
| 6.5 | | 51.5 | 0.00515 | 5.65 | 2404 ± 49 |
| 7 | | 84.0 | 0.00840 | 9.22 | 3924 ± 63 |
| 7.5 | | 139.5 | 0.01395 | 15.32 | 6520 ± 81 |
| 8 | | 147.1 | 0.01471 | 16.16 | 6874 ± 83 |
| 8.5 | | 106.2 | 0.01062 | 11.66 | 4962 ± 70 |
| 9 | | 67.9 | 0.00679 | 7.46 | 3174 ± 56 |
| 9.5 | | 48.0 | 0.00480 | 5.27 | 2242 ± 47 |
| 10 | | 41.3 | 0.00413 | 4.54 | 1930 ± 44 |
| 10.5 | | 37.5 | 0.00375 | 4.12 | 1751 ± 42 |
| 11 | | 33.9 | 0.00339 | 3.73 | 1585 ± 40 |
| 11.5 | | 32.7 | 0.00327 | 3.59 | 1526 ± 39 |
| 12 | | 31.6 | 0.00316 | 3.47 | 1477 ± 38 |
| 12.5 | | 33.5 | 0.00335 | 3.68 | 1564 ± 40 |
| 13 | | 37.7 | 0.00377 | 4.14 | 1763 ± 42 |
| 13.5 | | 38.7 | 0.00387 | 4.25 | 1807 ± 43 |
| 14 | | 38.5 | 0.00385 | 4.22 | 1797 ± 42 |
| 14.5 | | 38.1 | 0.00381 | 4.18 | 1779 ± 42 |
| 15 | | 35.4 | 0.00354 | 3.89 | 1653 ± 41 |
| 15.5 | | 36.0 | 0.00360 | 3.96 | 1684 ± 41 |
| 16 | | 35.5 | 0.00355 | 3.90 | 1661 ± 41 |
| 16.5 | | 37.9 | 0.00379 | 4.16 | 1770 ± 42 |

*The top 1 foot of the bore hole does not represent a true 4π geometery, so a valid calibration factor is not available.

BH

| Depth (feet) | Level of water table | µg/g | % by mass | pCi/g | raw data (cpm) |
|---|---|---|---|---|---|
| 0 | | not calibrated* | not calibrated* | not calibrated* | 1199 ± 35 |
| 0.5 | | not calibrated* | not calibrated* | not calibrated* | 1405 ± 37 |
| 1 | | not calibrated* | not calibrated* | not calibrated* | 1689 ± 41 |
| 1.5 | | 42.7 | 0.00427 | 4.68 | 1993 ± 45 |
| 2 | | 45.4 | 0.00454 | 4.99 | 2123 ± 46 |
| 2.5 | | 56.9 | 0.00569 | 6.25 | 2659 ± 52 |
| 3 | | 80.1 | 0.00801 | 8.80 | 3742 ± 61 |
| 3.5 | 3' 11" | 91.4 | 0.00914 | 10.03 | 4269 ± 65 |
| 4 | ← | 128.1 | 0.01281 | 14.07 | 5987 ± 77 |
| 4.5 | | 79.5 | 0.00795 | 8.73 | 3716 ± 61 |
| 5 | | 51.3 | 0.00513 | 5.63 | 2395 ± 49 |
| 5.5 | | 44.5 | 0.00445 | 4.89 | 2079 ± 46 |
| 6 | | 41.8 | 0.00418 | 4.60 | 1955 ± 44 |
| 6.5 | | 42.4 | 0.00424 | 4.66 | 1982 ± 45 |
| 7 | | 45.4 | 0.00454 | 4.98 | 2119 ± 46 |
| 7.5 | | 41.5 | 0.00415 | 4.56 | 1941 ± 44 |
| 8 | | 35.8 | 0.00358 | 3.93 | 1671 ± 41 |
| 8.5 | | 34.2 | 0.00342 | 3.76 | 1598 ± 40 |
| 9 | | 32.1 | 0.00321 | 3.53 | 1500 ± 39 |
| 9.5 | | 28.9 | 0.00289 | 3.18 | 1351 ± 37 |
| 10 | | 28.4 | 0.00284 | 3.12 | 1326 ± 36 |
| 10.5 | | 31.3 | 0.00313 | 3.44 | 1464 ± 38 |
| 11 | | 30.2 | 0.00302 | 3.31 | 1410 ± 38 |
| 11.5 | | 31.9 | 0.00319 | 3.50 | 1489 ± 39 |
| 12 | | 33.5 | 0.00335 | 3.68 | 1564 ± 40 |
| 12.5 | | 32.5 | 0.00325 | 3.57 | 1518 ± 39 |
| 13 | | 31.5 | 0.00315 | 3.46 | 1472 ± 38 |
| 13.5 | | 31.2 | 0.00312 | 3.42 | 1456 ± 38 |
| 14 | | 33.9 | 0.00339 | 3.72 | 1582 ± 40 |
| 14.5 | | 32.5 | 0.00325 | 3.57 | 1520 ± 39 |
| 15 | | 33.5 | 0.00335 | 3.68 | 1565 ± 40 |
| 15.5 | | 32.0 | 0.00320 | 3.52 | 1496 ± 39 |
| 16 | | 27.1 | 0.00271 | 2.97 | 1265 ± 36 |
| 16.5 | | 30.6 | 0.00306 | 3.36 | 1430 ± 38 |
| 17 | | 25.1 | 0.00251 | 2.75 | 1172 ± 34 |
| 17.5 | | 27.7 | 0.00277 | 3.05 | 1296 ± 36 |
| 18 | | 25.0 | 0.00250 | 2.75 | 1168 ± 34 |
| 18.5 | | 26.2 | 0.00262 | 2.87 | 1223 ± 35 |
| 19 | | 27.6 | 0.00276 | 3.03 | 1291 ± 36 |
| 19.5 | | 27.8 | 0.00278 | 3.05 | 1298 ± 36 |

*The top 1 foot of the bore hole does not represent a true 4π geometery, so a valid calibration factor is not available.

BH#[illegible]

| Depth (feet) | Level of water table | µg/g | % by m[illegible] | pCi/g | raw data (cpm) |
|---|---|---|---|---|---|
| 0 | | not calibrated* | not calibrated* | not calibrated* | 2442 ± 49 |
| 0.5 | | not calibrated* | not calibrated* | not calibrated* | 4145 ± 64 |
| 1 | | not calibrated* | not calibrated* | not calibrated* | 7355 ± 86 |
| 1.5 | | 199.6 | 0.01996 | 21.92 | 9328 ± 97 |
| 2 | | 222.2 | 0.02222 | 24.40 | 10380 ± 102 |
| 2.5 | | 224.7 | 0.02247 | 24.68 | 10499 ± 102 |
| 3 | | 216.4 | 0.02164 | 23.77 | 10112 ± 101 |
| 3.5 | | 186.1 | 0.01861 | 20.43 | 8694 ± 93 |
| 4 | | 147.7 | 0.01477 | 16.22 | 6901 ± 83 |
| 4.5 | | 107.9 | 0.01079 | 11.85 | 5040 ± 71 |
| 5 | | 81.6 | 0.00816 | 8.96 | 3811 ± 62 |
| 5.5 | | 72.4 | 0.00724 | 7.96 | 3385 ± 58 |
| 6 | | 67.1 | 0.00671 | 7.37 | 3137 ± 56 |
| 6.5 | | 63.0 | 0.00630 | 6.92 | 2944 ± 54 |
| 7 | | 66.3 | 0.00663 | 7.28 | 3096 ± 56 |
| 7.5 | | 68.6 | 0.00686 | 7.53 | 3205 ± 57 |
| 8 | | 73.1 | 0.00731 | 8.03 | 3416 ± 58 |
| 8.5 | | 76.9 | 0.00769 | 8.44 | 3592 ± 60 |
| 9 | | 91.3 | 0.00913 | 10.03 | 4268 ± 65 |
| 9.5 | | 77.0 | 0.00770 | 8.46 | 3598 ± 60 |
| 10 | 10' 6" | 57.2 | 0.00572 | 6.28 | 2671 ± 52 |
| 10.5 | ← | 39.7 | 0.00397 | 4.36 | 1857 ± 43 |
| 11 | | 32.7 | 0.00327 | 3.59 | 1526 ± 39 |
| 11.5 | | 33.1 | 0.00331 | 3.64 | 1547 ± 39 |
| 12 | | 31.7 | 0.00317 | 3.48 | 1482 ± 38 |
| 12.5 | | 31.1 | 0.00311 | 3.41 | 1451 ± 38 |
| 13 | | 31.8 | 0.00318 | 3.49 | 1485 ± 39 |
| 13.5 | | 32.1 | 0.00321 | 3.52 | 1499 ± 39 |
| 14 | | 36.0 | 0.00360 | 3.95 | 1680 ± 41 |
| 14.5 | | 37.7 | 0.00377 | 4.14 | 1760 ± 42 |
| 15 | | 37.7 | 0.00377 | 4.14 | 1763 ± 42 |
| 15.5 | | 36.8 | 0.00368 | 4.04 | 1720 ± 41 |
| 16 | | 34.2 | 0.00342 | 3.75 | 1597 ± 40 |
| 16.5 | | 33.6 | 0.00336 | 3.69 | 1569 ± 40 |
| 17 | | 27.7 | 0.00277 | 3.05 | 1296 ± 36 |
| 17.5 | | 24.7 | 0.00247 | 2.71 | 1152 ± 34 |
| 18 | | 25.6 | 0.00256 | 2.81 | 1195 ± 35 |
| 18.5 | | 25.6 | 0.00256 | 2.82 | 1198 ± 35 |
| 19 | | 26.3 | 0.00263 | 2.89 | 1229 ± 35 |

*The top 1 foot of the bore hole does not represent a true 4π geometery, so a valid calibration factor is not available.

## BH#

| Depth (feet) | Level of water table | µg/g | % by mass | pCi/g | raw data (cpm) |
|---|---|---|---|---|---|
| 0 | | not calibrated* | not calibrated* | not calibrated* | 3964 ± 63 |
| 0.5 | | not calibrated* | not calibrated* | not calibrated* | 5678 ± 75 |
| 1 | | not calibrated* | not calibrated* | not calibrated* | 5809 ± 76 |
| 1.5 | | 161.2 | 0.01612 | 17.70 | 7531 ± 87 |
| 2 | | 272.4 | 0.02724 | 29.92 | 12728 ± 113 |
| 2.5 | | 496.9 | 0.04969 | 54.57 | 23218 ± 152 |
| 3 | | 884.5 | 0.08845 | 97.14 | 41328 ± 203 |
| 3.5 | | 1178.0 | 0.11780 | 129.37 | 55039 ± 235 |
| 4 | 4' 6" | 1362.7 | 0.13627 | 149.65 | 63669 ± 252 |
| 4.5 | ← | 1492.2 | 0.14922 | 163.88 | 69723 ± 264 |
| 5 | | 826.9 | 0.08269 | 90.81 | 38635 ± 197 |
| 5.5 | | 387.3 | 0.03873 | 42.53 | 18096 ± 135 |
| 6 | | 265.6 | 0.02656 | 29.17 | 12412 ± 111 |
| 6.5 | | 190.3 | 0.01903 | 20.90 | 8892 ± 94 |
| 7 | | 155.6 | 0.01556 | 17.08 | 7268 ± 85 |
| 7.5 | | 147.2 | 0.01472 | 16.16 | 6877 ± 83 |
| 8 | | 173.8 | 0.01738 | 19.09 | 8120 ± 90 |
| 8.5 | | 222.0 | 0.02220 | 24.38 | 10372 ± 102 |
| 9 | | 232.3 | 0.02323 | 25.51 | 10854 ± 104 |
| 9.5 | | 173.7 | 0.01737 | 19.08 | 8118 ± 90 |
| 10 | | 133.7 | 0.01337 | 14.68 | 6246 ± 79 |
| 10.5 | | 123.9 | 0.01239 | 13.60 | 5788 ± 76 |
| 11 | | 118.5 | 0.01185 | 13.01 | 5537 ± 74 |
| 11.5 | | 152.6 | 0.01526 | 16.76 | 7130 ± 84 |
| 12 | | 155.8 | 0.01558 | 17.11 | 7280 ± 85 |
| 12.5 | | 97.7 | 0.00977 | 10.73 | 4563 ± 68 |
| 13 | | 70.9 | 0.00709 | 7.79 | 3314 ± 58 |
| 13.5 | | 57.5 | 0.00575 | 6.31 | 2685 ± 52 |
| 14 | | 49.4 | 0.00494 | 5.42 | 2307 ± 48 |
| 14.5 | | 41.0 | 0.00410 | 4.50 | 1915 ± 44 |
| 15 | | 45.7 | 0.00457 | 5.02 | 2137 ± 46 |
| 15.5 | | 51.3 | 0.00513 | 5.64 | 2398 ± 49 |
| 16 | | 45.4 | 0.00454 | 4.99 | 2121 ± 46 |
| 16.5 | | 41.0 | 0.00410 | 4.50 | 1914 ± 44 |
| 17 | | 42.3 | 0.00423 | 4.65 | 1977 ± 44 |
| 17.5 | | 37.5 | 0.00375 | 4.11 | 1750 ± 42 |
| 18 | | 37.9 | 0.00379 | 4.17 | 1773 ± 42 |
| 18.5 | | 38.5 | 0.00385 | 4.22 | 1797 ± 42 |
| 19 | | 28.2 | 0.00282 | 3.09 | 1316 ± 36 |

*The top 1 foot of the bore hole does not represent a true 4π geometery, so a valid calibration factor is not available.

BH#2?

| Depth (feet) | Level of water table | µg/g | % by n. | pCi/g | raw data (cpm) |
|---|---|---|---|---|---|
| 0 | | not calibrated* | not calibrated* | not calibrated* | 11525 ± 107 |
| 0.5 | | not calibrated* | not calibrated* | not calibrated* | 6860 ± 83 |
| 1 | | not calibrated* | not calibrated* | not calibrated* | 4197 ± 65 |
| 1.5 | | 75.5 | 0.00755 | 8.29 | 3528 ± 59 |
| 2 | | 68.4 | 0.00684 | 7.51 | 3197 ± 57 |
| 2.5 | | 70.9 | 0.00709 | 7.79 | 3314 ± 58 |
| 3 | | 79.3 | 0.00793 | 8.71 | 3705 ± 61 |
| 3.5 | | 88.3 | 0.00883 | 9.70 | 4126 ± 64 |
| 4 | | 72.6 | 0.00726 | 7.97 | 3391 ± 58 |
| 4.5 | | 100.5 | 0.01005 | 11.04 | 4695 ± 69 |
| 5 | | 141.6 | 0.01416 | 15.56 | 6618 ± 81 |
| 5.5 | | 157.7 | 0.01577 | 17.32 | 7370 ± 86 |
| 6 | | 160.8 | 0.01608 | 17.66 | 7513 ± 87 |
| 6.5 | | 117.9 | 0.01179 | 12.95 | 5509 ± 74 |
| 7 | | 93.6 | 0.00936 | 10.28 | 4373 ± 66 |
| 7.5 | | 75.9 | 0.00759 | 8.33 | 3544 ± 60 |
| 8 | | 49.8 | 0.00498 | 5.46 | 2325 ± 48 |
| 8.5 | 9' 0" | 41.5 | 0.00415 | 4.56 | 1938 ± 44 |
| 9 | ← | 38.7 | 0.00387 | 4.24 | 1806 ± 42 |
| 9.5 | | 43.4 | 0.00434 | 4.77 | 2028 ± 45 |
| 10 | | 57.1 | 0.00571 | 6.27 | 2666 ± 52 |
| 10.5 | | 102.3 | 0.01023 | 11.23 | 4778 ± 69 |
| 11 | | 168.8 | 0.01688 | 18.54 | 7889 ± 89 |
| 11.5 | | 228.4 | 0.02284 | 25.08 | 10671 ± 103 |
| 12 | | 163.9 | 0.01639 | 18.00 | 7658 ± 88 |
| 12.5 | | 78.6 | 0.00786 | 8.63 | 3673 ± 61 |
| 13 | | 50.2 | 0.00502 | 5.51 | 2344 ± 48 |
| 13.5 | | 45.0 | 0.00450 | 4.94 | 2103 ± 46 |
| 14 | | 44.4 | 0.00444 | 4.88 | 2075 ± 46 |
| 14.5 | | 42.6 | 0.00426 | 4.68 | 1989 ± 45 |
| 15 | | 41.8 | 0.00418 | 4.59 | 1953 ± 44 |
| 15.5 | | 42.4 | 0.00424 | 4.65 | 1980 ± 44 |
| 16 | | 47.8 | 0.00478 | 5.25 | 2235 ± 47 |
| 16.5 | | 44.1 | 0.00441 | 4.84 | 2060 ± 45 |
| 17 | | 40.2 | 0.00402 | 4.41 | 1877 ± 43 |
| 17.5 | | 38.1 | 0.00381 | 4.19 | 1782 ± 42 |
| 18 | | 33.2 | 0.00332 | 3.65 | 1551 ± 39 |

*The top 1 foot of the bore hole does not represent a true 4π geometery, so a valid calibration factor is not available.

BH#2?

| Depth (feet) | Level of water table | µg/g | % by ma | pCi/g | raw data (cpm) |
|---|---|---|---|---|---|
| 0 | | not calibrated* | not calibrated* | not calibrated* | 1194 ± 35 |
| 0.5 | | not calibrated* | not calibrated* | not calibrated* | 1382 ± 37 |
| 1 | | not calibrated* | not calibrated* | not calibrated* | 1656 ± 41 |
| 1.5 | | 45.1 | 0.00451 | 4.95 | 2107 ± 46 |
| 2 | | 61.7 | 0.00617 | 6.78 | 2883 ± 54 |
| 2.5 | | 111.8 | 0.01118 | 12.28 | 5226 ± 72 |
| 3 | | 154.2 | 0.01542 | 16.93 | 7205 ± 85 |
| 3.5 | 4' 0" | 111.0 | 0.01110 | 12.19 | 5186 ± 72 |
| 4 | ← | 96.2 | 0.00962 | 10.57 | 4495 ± 67 |
| 4.5 | | 103.1 | 0.01031 | 11.33 | 4819 ± 69 |
| 5 | | 111.6 | 0.01116 | 12.26 | 5214 ± 72 |
| 5.5 | | 109.1 | 0.01091 | 11.98 | 5099 ± 71 |
| 6 | | 107.5 | 0.01075 | 11.81 | 5025 ± 71 |
| 6.5 | | 98.0 | 0.00980 | 10.76 | 4578 ± 68 |
| 7 | | 83.4 | 0.00834 | 9.15 | 3895 ± 62 |
| 7.5 | | 62.6 | 0.00626 | 6.87 | 2924 ± 54 |
| 8 | | 42.8 | 0.00428 | 4.71 | 2002 ± 45 |
| 8.5 | | 35.5 | 0.00355 | 3.89 | 1657 ± 41 |
| 9 | | 33.6 | 0.00336 | 3.69 | 1569 ± 40 |
| 9.5 | | 34.7 | 0.00347 | 3.81 | 1622 ± 40 |
| 10 | | 34.7 | 0.00347 | 3.81 | 1623 ± 40 |
| 10.5 | | 35.4 | 0.00354 | 3.88 | 1652 ± 41 |
| 11 | | 33.9 | 0.00339 | 3.72 | 1584 ± 40 |
| 11.5 | | 33.3 | 0.00333 | 3.66 | 1556 ± 39 |
| 12 | | 32.0 | 0.00320 | 3.52 | 1496 ± 39 |
| 12.5 | | 32.6 | 0.00326 | 3.58 | 1522 ± 39 |
| 13 | | 32.3 | 0.00323 | 3.55 | 1510 ± 39 |
| 13.5 | | 30.2 | 0.00302 | 3.31 | 1409 ± 38 |
| 14 | | 28.2 | 0.00282 | 3.10 | 1319 ± 36 |
| 14.5 | | 27.5 | 0.00275 | 3.02 | 1283 ± 36 |
| 15 | | 23.5 | 0.00235 | 2.58 | 1096 ± 33 |
| 15.5 | | 23.1 | 0.00231 | 2.54 | 1079 ± 33 |
| 16 | | 24.0 | 0.00240 | 2.63 | 1121 ± 33 |
| 16.5 | | 24.6 | 0.00246 | 2.70 | 1149 ± 34 |
| 17 | | 25.9 | 0.00259 | 2.84 | 1208 ± 35 |
| 17.5 | | 0.0 | 0.00000 | 0.00 | ± 0 |

*The top 1 foot of the bore hole does not represent a true 4π geometery, so a valid calibration factor is not available.

BH#

| Depth (feet) | Level of water table | µg/g | % by mass | pCi/g | raw data (cpm) |
|---|---|---|---|---|---|
| 0 | | not calibrated* | not calibrated* | not calibrated* | 5276 ± 73 |
| 0.5 | | not calibrated* | not calibrated* | not calibrated* | 15062 ± 123 |
| 1 | | not calibrated* | not calibrated* | not calibrated* | 22229 ± 149 |
| 1.5 | | 279.1 | 0.02791 | 30.65 | 13042 ± 114 |
| 2 | | 103.8 | 0.01038 | 11.40 | 4851 ± 70 |
| 2.5 | | 55.7 | 0.00557 | 6.12 | 2602 ± 51 |
| 3 | | 41.5 | 0.00415 | 4.56 | 1938 ± 44 |
| 3.5 | | 34.3 | 0.00343 | 3.77 | 1604 ± 40 |
| 4 | | 33.0 | 0.00330 | 3.62 | 1541 ± 39 |
| 4.5 | | 32.0 | 0.00320 | 3.52 | 1496 ± 39 |
| 5 | | 27.9 | 0.00279 | 3.06 | 1302 ± 36 |
| 5.5 | | 24.4 | 0.00244 | 2.68 | 1142 ± 34 |
| 6 | | 24.2 | 0.00242 | 2.66 | 1130 ± 34 |
| 6.5 | 7' 1" | 25.4 | 0.00254 | 2.79 | 1187 ± 34 |
| 7 | ← | 25.8 | 0.00258 | 2.83 | 1204 ± 35 |
| 7.5 | | 25.9 | 0.00259 | 2.85 | 1212 ± 35 |
| 8 | | 28.7 | 0.00287 | 3.15 | 1340 ± 37 |
| 8.5 | | 28.5 | 0.00285 | 3.13 | 1331 ± 36 |
| 9 | | 25.2 | 0.00252 | 2.77 | 1177 ± 34 |
| 9.5 | | 27.7 | 0.00277 | 3.04 | 1292 ± 36 |
| 10 | | 27.1 | 0.00271 | 2.97 | 1265 ± 36 |
| 10.5 | | 27.3 | 0.00273 | 3.00 | 1276 ± 36 |
| 11 | | 22.8 | 0.00228 | 2.50 | 1064 ± 33 |
| 11.5 | | 21.8 | 0.00218 | 2.40 | 1019 ± 32 |
| 12 | | 21.2 | 0.00212 | 2.32 | 989 ± 31 |
| 12.5 | | 24.0 | 0.00240 | 2.63 | 1120 ± 33 |
| 13 | | 24.3 | 0.00243 | 2.67 | 1137 ± 34 |
| 13.5 | | 26.5 | 0.00265 | 2.91 | 1239 ± 35 |
| 14 | | 34.3 | 0.00343 | 3.77 | 1602 ± 40 |
| 14.5 | | 38.1 | 0.00381 | 4.19 | 1781 ± 42 |
| 15 | | 29.0 | 0.00290 | 3.18 | 1354 ± 37 |
| 15.5 | | 24.4 | 0.00244 | 2.68 | 1140 ± 34 |
| 16 | | 24.3 | 0.00243 | 2.67 | 1135 ± 34 |
| 16.5 | | 23.2 | 0.00232 | 2.55 | 1083 ± 33 |
| 17 | | 23.8 | 0.00238 | 2.62 | 1113 ± 33 |
| 17.5 | | 23.3 | 0.00233 | 2.56 | 1090 ± 33 |
| 18 | | 23.4 | 0.00234 | 2.57 | 1092 ± 33 |
| 18.5 | | 23.4 | 0.00234 | 2.57 | 1093 ± 33 |
| 19 | | 24.4 | 0.00244 | 2.68 | 1140 ± 34 |

*The top 1 foot of the bore hole does not represent a true 4π geometery, so a valid calibration factor is not available.

BH#

| Depth (feet) | Level of water table | µg/g | % by mass | pCi/g | raw data (cpm) |
|---|---|---|---|---|---|
| 0 | | not calibrated* | not calibrated* | not calibrated* | 2158 ± 46 |
| 0.5 | | not calibrated* | not calibrated* | not calibrated* | 3658 ± 60 |
| 1 | | not calibrated* | not calibrated* | not calibrated* | 5269 ± 73 |
| 1.5 | | 146.7 | 0.01467 | 16.11 | 6856 ± 83 |
| 2 | | 233.9 | 0.02339 | 25.69 | 10929 ± 105 |
| 2.5 | | 269.2 | 0.02692 | 29.57 | 12580 ± 112 |
| 3 | | 192.5 | 0.01925 | 21.14 | 8995 ± 95 |
| 3.5 | | 131.1 | 0.01311 | 14.40 | 6125 ± 78 |
| 4 | | 112.7 | 0.01127 | 12.38 | 5266 ± 73 |
| 4.5 | | 105.0 | 0.01050 | 11.53 | 4905 ± 70 |
| 5 | | 102.4 | 0.01024 | 11.24 | 4783 ± 69 |
| 5.5 | | 83.1 | 0.00831 | 9.12 | 3882 ± 62 |
| 6 | | 62.8 | 0.00628 | 6.89 | 2932 ± 54 |
| 6.5 | 6' 9" | 43.6 | 0.00436 | 4.79 | 2036 ± 45 |
| 7 | ← | 32.0 | 0.00320 | 3.51 | 1494 ± 39 |
| 7.5 | | 26.7 | 0.00267 | 2.93 | 1247 ± 35 |
| 8 | | 25.3 | 0.00253 | 2.78 | 1184 ± 34 |
| 8.5 | | 24.2 | 0.00242 | 2.66 | 1133 ± 34 |
| 9 | | 23.6 | 0.00236 | 2.59 | 1102 ± 33 |
| 9.5 | | 24.0 | 0.00240 | 2.64 | 1122 ± 33 |
| 10 | | 25.5 | 0.00255 | 2.80 | 1193 ± 35 |
| 10.5 | | 25.1 | 0.00251 | 2.75 | 1171 ± 34 |
| 11 | | 23.4 | 0.00234 | 2.57 | 1094 ± 33 |
| 11.5 | | 27.2 | 0.00272 | 2.99 | 1273 ± 36 |
| 12 | | 26.1 | 0.00261 | 2.87 | 1219 ± 35 |
| 12.5 | | 23.3 | 0.00233 | 2.56 | 1088 ± 33 |
| 13 | | 27.7 | 0.00277 | 3.04 | 1293 ± 36 |
| 13.5 | | 33.8 | 0.00338 | 3.71 | 1580 ± 40 |
| 14 | | 37.6 | 0.00376 | 4.13 | 1755 ± 42 |
| 14.5 | | 27.5 | 0.00275 | 3.03 | 1287 ± 36 |
| 15 | | 24.5 | 0.00245 | 2.70 | 1147 ± 34 |
| 15.5 | | 25.2 | 0.00252 | 2.76 | 1176 ± 34 |
| 16 | | 25.4 | 0.00254 | 2.79 | 1189 ± 34 |
| 16.5 | | 25.2 | 0.00252 | 2.77 | 1179 ± 34 |
| 17 | | 23.9 | 0.00239 | 2.62 | 1115 ± 33 |
| 17.5 | | 25.1 | 0.00251 | 2.76 | 1174 ± 34 |
| 18 | | 29.3 | 0.00293 | 3.21 | 1367 ± 37 |

*The top 1 foot of the bore hole does not represent a true 4π geometery, so a valid calibration factor is not available.

BH#[illegible]

| Depth (feet) | Level of water table | µg/g | % by n[illegible] | pCi/g | raw data (cpm) |
|---|---|---|---|---|---|
| 0 | | not calibrated* | not calibrated* | not calibrated* | 1958 ± 44 |
| 0.5 | | not calibrated* | not calibrated* | not calibrated* | 2247 ± 47 |
| 1 | | not calibrated* | not calibrated* | not calibrated* | 2810 ± 53 |
| 1.5 | | 69.5 | 0.00695 | 7.63 | 3246 ± 57 |
| 2 | | 92.8 | 0.00928 | 10.19 | 4337 ± 66 |
| 2.5 | | 180.7 | 0.01807 | 19.84 | 8441 ± 92 |
| 3 | | 423.2 | 0.04232 | 46.48 | 19773 ± 141 |
| 3.5 | | 530.3 | 0.05303 | 58.23 | 24776 ± 157 |
| 4 | | 555.7 | 0.05557 | 61.03 | 25966 ± 161 |
| 4.5 | | 625.4 | 0.06254 | 68.68 | 29221 ± 171 |
| 5 | | 625.0 | 0.06250 | 68.63 | 29200 ± 171 |
| 5.5 | 5' 11" | 404.8 | 0.04048 | 44.46 | 18914 ± 138 |
| 6 | ← | 196.3 | 0.01963 | 21.55 | 9170 ± 96 |
| 6.5 | | 112.8 | 0.01128 | 12.39 | 5271 ± 73 |
| 7 | | 64.9 | 0.00649 | 7.13 | 3033 ± 55 |
| 7.5 | | 43.7 | 0.00437 | 4.80 | 2043 ± 45 |
| 8 | | 33.6 | 0.00336 | 3.69 | 1568 ± 40 |
| 8.5 | | 34.3 | 0.00343 | 3.77 | 1602 ± 40 |
| 9 | | 31.3 | 0.00313 | 3.44 | 1462 ± 38 |
| 9.5 | | 32.6 | 0.00326 | 3.58 | 1524 ± 39 |
| 10 | | 32.6 | 0.00326 | 3.58 | 1521 ± 39 |
| 10.5 | | 31.8 | 0.00318 | 3.49 | 1484 ± 39 |
| 11 | | 33.2 | 0.00332 | 3.65 | 1553 ± 39 |
| 11.5 | | 33.3 | 0.00333 | 3.65 | 1555 ± 39 |
| 12 | | 37.5 | 0.00375 | 4.11 | 1750 ± 42 |
| 12.5 | | 53.1 | 0.00531 | 5.83 | 2479 ± 50 |
| 13 | | 51.5 | 0.00515 | 5.66 | 2407 ± 49 |
| 13.5 | | 52.5 | 0.00525 | 5.77 | 2455 ± 50 |
| 14 | | 40.5 | 0.00405 | 4.45 | 1893 ± 44 |
| 14.5 | | 32.8 | 0.00328 | 3.61 | 1534 ± 39 |
| 15 | | 29.2 | 0.00292 | 3.21 | 1365 ± 37 |
| 15.5 | | 32.5 | 0.00325 | 3.57 | 1518 ± 39 |
| 16 | | 34.3 | 0.00343 | 3.76 | 1601 ± 40 |
| 16.5 | | 33.7 | 0.00337 | 3.70 | 1574 ± 40 |
| 17 | | 31.3 | 0.00313 | 3.44 | 1462 ± 38 |
| 17.5 | | 36.3 | 0.00363 | 3.99 | 1697 ± 41 |
| 18 | | 36.8 | 0.00368 | 4.04 | 1718 ± 41 |
| 18.5 | | 35.4 | 0.00354 | 3.89 | 1656 ± 41 |
| 19 | | 36.6 | 0.00366 | 4.02 | 1710 ± 41 |

*The top 1 foot of the bore hole does not represent a true $4\pi$ geometery, so a valid calibration factor is not available.

BH# [illegible]

| Depth (feet) | Level of water table | µg/g | % by mass | pCi/g | raw data (cpm) |
|---|---|---|---|---|---|
| 0 | | not calibrated* | not calibrated* | not calibrated* | 1095 ± 33 |
| 0.5 | | not calibrated* | not calibrated* | not calibrated* | 1281 ± 36 |
| 1 | | not calibrated* | not calibrated* | not calibrated* | 1427 ± 38 |
| 1.5 | | 33.6 | 0.00336 | 3.69 | 1570 ± 40 |
| 2 | | 35.2 | 0.00352 | 3.86 | 1643 ± 41 |
| 2.5 | | 39.0 | 0.00390 | 4.28 | 1822 ± 43 |
| 3 | | 41.6 | 0.00416 | 4.57 | 1943 ± 44 |
| 3.5 | | 40.9 | 0.00409 | 4.49 | 1911 ± 44 |
| 4 | | 40.8 | 0.00408 | 4.48 | 1904 ± 44 |
| 4.5 | | 37.9 | 0.00379 | 4.16 | 1769 ± 42 |
| 5 | | 37.2 | 0.00372 | 4.09 | 1740 ± 42 |
| 5.5 | | 37.1 | 0.00371 | 4.08 | 1735 ± 42 |
| 6 | 6' 6" | 34.3 | 0.00343 | 3.77 | 1602 ± 40 |
| 6.5 | ← | 31.9 | 0.00319 | 3.51 | 1492 ± 39 |
| 7 | | 33.9 | 0.00339 | 3.72 | 1583 ± 40 |
| 7.5 | | 37.0 | 0.00370 | 4.06 | 1729 ± 42 |

*The top 1 foot of the bore hole does not represent a true 4π geometery, so a valid calibration factor is not available.

BH#

| Depth (feet) | Level of water table | µg/g | % by mass | pCi/g | raw data (cpm) |
|---|---|---|---|---|---|
| 0 | | not calibrated* | not calibrated* | not calibrated* | 1289 ± 36 |
| 0.5 | | not calibrated* | not calibrated* | not calibrated* | 1866 ± 43 |
| 1 | | not calibrated* | not calibrated* | not calibrated* | 2100 ± 46 |
| 1.5 | | 45.1 | 0.00451 | 4.95 | 2106 ± 46 |
| 2 | | 43.8 | 0.00438 | 4.81 | 2045 ± 45 |
| 2.5 | | 45.3 | 0.00453 | 4.98 | 2117 ± 46 |
| 3 | | 46.6 | 0.00466 | 5.12 | 2179 ± 47 |
| 3.5 | | 46.1 | 0.00461 | 5.07 | 2156 ± 46 |
| 4 | | 44.6 | 0.00446 | 4.90 | 2084 ± 46 |
| 4.5 | | 50.8 | 0.00508 | 5.58 | 2375 ± 49 |
| 5 | | 53.6 | 0.00536 | 5.89 | 2506 ± 50 |
| 5.5 | | 48.9 | 0.00489 | 5.37 | 2286 ± 48 |
| 6 | | 38.3 | 0.00383 | 4.21 | 1790 ± 42 |
| 6.5 | | 36.8 | 0.00368 | 4.04 | 1719 ± 41 |
| 7 | | 34.0 | 0.00340 | 3.73 | 1589 ± 40 |
| 7.5 | | 38.5 | 0.00385 | 4.23 | 1800 ± 42 |
| 8 | 8' 7" | 40.1 | 0.00401 | 4.40 | 1874 ± 43 |
| 8.5 | | 38.1 | 0.00381 | 4.18 | 1778 ± 42 |
| 9 | | 39.7 | 0.00397 | 4.36 | 1856 ± 43 |
| 9.5 | | 37.3 | 0.00373 | 4.10 | 1743 ± 42 |
| 10 | | 39.2 | 0.00392 | 4.31 | 1833 ± 43 |
| 10.5 | | 41.7 | 0.00417 | 4.58 | 1947 ± 44 |
| 11 | | 40.5 | 0.00405 | 4.44 | 1890 ± 43 |
| 11.5 | | 40.6 | 0.00406 | 4.46 | 1896 ± 44 |
| 12 | | 39.1 | 0.00391 | 4.29 | 1826 ± 43 |
| 12.5 | | 39.6 | 0.00396 | 4.35 | 1850 ± 43 |
| 13 | | 43.1 | 0.00431 | 4.73 | 2014 ± 45 |
| 13.5 | | 46.0 | 0.00460 | 5.05 | 2148 ± 46 |
| 14 | | 42.8 | 0.00428 | 4.70 | 1999 ± 45 |
| 14.5 | | 41.7 | 0.00417 | 4.58 | 1950 ± 44 |
| 15 | | 42.4 | 0.00424 | 4.65 | 1980 ± 44 |
| 15.5 | | 42.2 | 0.00422 | 4.63 | 1971 ± 44 |
| 16 | | 41.8 | 0.00418 | 4.60 | 1955 ± 44 |
| 16.5 | | 45.1 | 0.00451 | 4.95 | 2107 ± 46 |
| 17 | | 44.7 | 0.00447 | 4.91 | 2088 ± 46 |
| 17.5 | | 43.4 | 0.00434 | 4.77 | 2029 ± 45 |
| 18 | | 45.4 | 0.00454 | 4.99 | 2121 ± 46 |

*The top 1 foot of the bore hole does not represent a true 4π geometery, so a valid calibration factor is not available.

BH#

| Depth (feet) | Level of water table | µg/g | % by m | pCi/g | raw data (cpm) |
|---|---|---|---|---|---|
| 0 | | not calibrated* | not calibrated* | not calibrated* | 3491 ± 59 |
| 0.5 | | not calibrated* | not calibrated* | not calibrated* | 6119 ± 78 |
| 1 | 1' 7" | not calibrated* | not calibrated* | not calibrated* | 7931 ± 89 |
| 1.5 | | 182.9 | 0.01829 | 20.08 | 8544 ± 92 |
| 2 | | 179.2 | 0.01792 | 19.68 | 8373 ± 92 |
| 2.5 | | 183.0 | 0.01830 | 20.10 | 8550 ± 92 |
| 3 | | 162.7 | 0.01627 | 17.86 | 7600 ± 87 |
| 3.5 | | 157.1 | 0.01571 | 17.25 | 7340 ± 86 |
| 4 | | 157.9 | 0.01579 | 17.34 | 7377 ± 86 |
| 4.5 | | 154.1 | 0.01541 | 16.93 | 7202 ± 85 |
| 5 | | 247.7 | 0.02477 | 27.20 | 11573 ± 108 |
| 5.5 | | 478.5 | 0.04785 | 52.55 | 22356 ± 150 |
| 6 | | 1300.2 | 0.13002 | 142.79 | 60751 ± 246 |
| 6.5 | | 2259.3 | 0.22593 | 248.12 | 105565 ± 325 |
| 7 | | 1549.1 | 0.15491 | 170.13 | 72380 ± 269 |
| 7.5 | | 415.5 | 0.04155 | 45.63 | 19414 ± 139 |
| 8 | | 102.3 | 0.01023 | 11.23 | 4779 ± 69 |
| 8.5 | | 45.3 | 0.00453 | 4.98 | 2118 ± 46 |
| 9 | | 36.5 | 0.00365 | 4.01 | 1707 ± 41 |
| 9.5 | | 32.0 | 0.00320 | 3.51 | 1495 ± 39 |
| 10 | | 32.1 | 0.00321 | 3.52 | 1499 ± 39 |
| 10.5 | | 32.2 | 0.00322 | 3.54 | 1505 ± 39 |
| 11 | | 31.3 | 0.00313 | 3.44 | 1464 ± 38 |
| 11.5 | | 31.5 | 0.00315 | 3.46 | 1472 ± 38 |
| 12 | | 32.1 | 0.00321 | 3.53 | 1501 ± 39 |
| 12.5 | | 35.6 | 0.00356 | 3.91 | 1664 ± 41 |
| 13 | | 35.0 | 0.00350 | 3.84 | 1634 ± 40 |
| 13.5 | | 33.4 | 0.00334 | 3.67 | 1562 ± 40 |
| 14 | | 37.0 | 0.00370 | 4.07 | 1730 ± 42 |
| 14.5 | | 37.7 | 0.00377 | 4.14 | 1763 ± 42 |
| 15 | | 34.6 | 0.00346 | 3.80 | 1617 ± 40 |
| 15.5 | | 37.8 | 0.00378 | 4.15 | 1764 ± 42 |
| 16 | | 29.9 | 0.00299 | 3.28 | 1397 ± 37 |
| 16.5 | | 27.7 | 0.00277 | 3.04 | 1293 ± 36 |
| 17 | | 28.2 | 0.00282 | 3.10 | 1319 ± 36 |

*The top 1 foot of the bore hole does not represent a true 4π geometery, so a valid calibration factor is not available.

# BH#3[illegible]

| Depth (feet) | Level of water table | µg/g | % by [illegible] | pCi/g | raw data (cpm) |
|---|---|---|---|---|---|
| 0 | | not calibrated* | not calibrated* | not calibrated* | 1436 ± 38 |
| 0.5 | | not calibrated* | not calibrated* | not calibrated* | 1411 ± 38 |
| 1 | | not calibrated* | not calibrated* | not calibrated* | 2097 ± 46 |
| 1.5 | | 75.6 | 0.00756 | 8.30 | 3530 ± 59 |
| 2 | | 174.9 | 0.01749 | 19.21 | 8173 ± 90 |
| 2.5 | | 295.5 | 0.02955 | 32.45 | 13807 ± 118 |
| 3 | | 351.0 | 0.03510 | 38.54 | 16398 ± 128 |
| 3.5 | 4' 2" | 476.9 | 0.04769 | 52.37 | 22283 ± 149 |
| 4 | ← | 659.9 | 0.06599 | 72.47 | 30834 ± 176 |
| 4.5 | | 886.6 | 0.08866 | 97.36 | 41424 ± 204 |
| 5 | | 654.9 | 0.06549 | 71.93 | 30601 ± 175 |
| 5.5 | | 317.2 | 0.03172 | 34.83 | 14820 ± 122 |
| 6 | | 147.8 | 0.01478 | 16.23 | 6906 ± 83 |
| 6.5 | | 67.7 | 0.00677 | 7.44 | 3164 ± 56 |
| 7 | | 41.3 | 0.00413 | 4.53 | 1928 ± 44 |
| 7.5 | | 31.6 | 0.00316 | 3.47 | 1478 ± 38 |
| 8 | | 31.3 | 0.00313 | 3.44 | 1463 ± 38 |
| 8.5 | | 27.5 | 0.00275 | 3.02 | 1284 ± 36 |
| 9 | | 27.7 | 0.00277 | 3.04 | 1292 ± 36 |
| 9.5 | | 27.8 | 0.00278 | 3.05 | 1298 ± 36 |
| 10 | | 28.2 | 0.00282 | 3.10 | 1319 ± 36 |
| 10.5 | | 27.9 | 0.00279 | 3.06 | 1303 ± 36 |
| 11 | | 27.5 | 0.00275 | 3.02 | 1285 ± 36 |
| 11.5 | | 25.3 | 0.00253 | 2.78 | 1183 ± 34 |
| 12 | | 24.2 | 0.00242 | 2.66 | 1131 ± 34 |
| 12.5 | | 25.8 | 0.00258 | 2.84 | 1207 ± 35 |
| 13 | | 26.2 | 0.00262 | 2.88 | 1225 ± 35 |
| 13.5 | | 25.5 | 0.00255 | 2.80 | 1193 ± 35 |
| 14 | | 26.8 | 0.00268 | 2.95 | 1254 ± 35 |
| 14.5 | | 28.3 | 0.00283 | 3.10 | 1321 ± 36 |
| 15 | | 29.6 | 0.00296 | 3.25 | 1383 ± 37 |
| 15.5 | | 30.4 | 0.00304 | 3.34 | 1419 ± 38 |
| 16 | | 34.4 | 0.00344 | 3.78 | 1607 ± 40 |
| 16.5 | | 29.1 | 0.00291 | 3.19 | 1359 ± 37 |

*The top 1 foot of the bore hole does not represent a true 4π geometery, so a valid calibration factor is not available.

BH#[illegible]

| Depth (feet) | Level of water table | µg/g | % by mass | pCi/g | raw data (cpm) |
|---|---|---|---|---|---|
| 0 | | not calibrated* | not calibrated* | not calibrated* | 5145 ± 72 |
| 0.5 | | not calibrated* | not calibrated* | not calibrated* | 15031 ± 123 |
| 1 | | not calibrated* | not calibrated* | not calibrated* | 20924 ± 145 |
| 1.5 | | 272.6 | 0.02726 | 29.94 | 12738 ± 113 |
| 2 | | 98.7 | 0.00987 | 10.84 | 4611 ± 68 |
| 2.5 | | 55.8 | 0.00558 | 6.12 | 2605 ± 51 |
| 3 | | 42.0 | 0.00420 | 4.61 | 1963 ± 44 |
| 3.5 | | 35.3 | 0.00353 | 3.88 | 1651 ± 41 |
| 4 | 4' 6" | 30.7 | 0.00307 | 3.37 | 1433 ± 38 |
| 4.5 | ← | 33.1 | 0.00331 | 3.64 | 1547 ± 39 |
| 5 | | 26.6 | 0.00266 | 2.92 | 1243 ± 35 |
| 5.5 | | 20.0 | 0.00200 | 2.19 | 933 ± 31 |
| 6 | | 20.2 | 0.00202 | 2.22 | 945 ± 31 |
| 6.5 | | 22.2 | 0.00222 | 2.44 | 1037 ± 32 |
| 7 | | 24.7 | 0.00247 | 2.71 | 1155 ± 34 |
| 7.5 | | 26.5 | 0.00265 | 2.91 | 1239 ± 35 |
| 8 | | 27.1 | 0.00271 | 2.98 | 1267 ± 36 |
| 8.5 | | 27.4 | 0.00274 | 3.01 | 1280 ± 36 |
| 9 | | 28.3 | 0.00283 | 3.11 | 1324 ± 36 |
| 9.5 | | 27.4 | 0.00274 | 3.00 | 1278 ± 36 |
| 10 | | 28.0 | 0.00280 | 3.08 | 1310 ± 36 |
| 10.5 | | 26.9 | 0.00269 | 2.95 | 1256 ± 35 |
| 11 | | 22.9 | 0.00229 | 2.52 | 1072 ± 33 |
| 11.5 | | 22.3 | 0.00223 | 2.45 | 1044 ± 32 |
| 12 | | 23.9 | 0.00239 | 2.63 | 1118 ± 33 |
| 12.5 | | 24.5 | 0.00245 | 2.70 | 1147 ± 34 |
| 13 | | 24.7 | 0.00247 | 2.72 | 1156 ± 34 |
| 13.5 | | 27.8 | 0.00278 | 3.05 | 1298 ± 36 |
| 14 | | 34.3 | 0.00343 | 3.77 | 1604 ± 40 |
| 14.5 | | 37.0 | 0.00370 | 4.07 | 1731 ± 42 |
| 15 | | 29.3 | 0.00293 | 3.22 | 1371 ± 37 |
| 15.5 | | 24.1 | 0.00241 | 2.64 | 1125 ± 34 |
| 16 | | 25.1 | 0.00251 | 2.75 | 1172 ± 34 |
| 16.5 | | 22.7 | 0.00227 | 2.49 | 1060 ± 33 |
| 17 | | 21.4 | 0.00214 | 2.35 | 1000 ± 32 |
| 17.5 | | 24.5 | 0.00245 | 2.70 | 1147 ± 34 |
| 18 | | 22.4 | 0.00224 | 2.46 | 1047 ± 32 |
| 18.5 | | 22.6 | 0.00226 | 2.48 | 1056 ± 32 |
| 19 | | 22.9 | 0.00229 | 2.51 | 1068 ± 33 |

*The top 1 foot of the bore hole does not represent a true 4π geometery, so a valid calibration factor is not available.

**BH# [illegible]**

| Depth (feet) | Level of water table | µg/g | % by n[illegible] | pCi/g | raw data (cpm) |
|---|---|---|---|---|---|
| 0 | | not calibrated* | not calibrated* | not calibrated* | 15022 ± 123 |
| 0.5 | | not calibrated* | not calibrated* | not calibrated* | 20073 ± 142 |
| 1 | | not calibrated* | not calibrated* | not calibrated* | 23361 ± 153 |
| 1.5 | | 615.5 | 0.06155 | 67.59 | 28757 ± 170 |
| 2 | 2' 6" | 548.8 | 0.05488 | 60.27 | 25643 ± 160 |
| 2.5 | ← | 388.4 | 0.03884 | 42.65 | 18146 ± 135 |
| 3 | | 240.4 | 0.02404 | 26.40 | 11233 ± 106 |
| 3.5 | | 206.4 | 0.02064 | 22.67 | 9646 ± 98 |
| 4 | | 215.0 | 0.02150 | 23.61 | 10045 ± 100 |
| 4.5 | | 241.2 | 0.02412 | 26.48 | 11268 ± 106 |
| 5 | | 259.2 | 0.02592 | 28.47 | 12111 ± 110 |
| 5.5 | | 240.3 | 0.02403 | 26.39 | 11228 ± 106 |
| 6 | | 245.2 | 0.02452 | 26.93 | 11458 ± 107 |
| 6.5 | | 165.0 | 0.01650 | 18.12 | 7708 ± 88 |
| 7 | | 103.8 | 0.01038 | 11.39 | 4848 ± 70 |
| 7.5 | | 64.2 | 0.00642 | 7.05 | 2998 ± 55 |
| 8 | | 59.9 | 0.00599 | 6.58 | 2799 ± 53 |
| 8.5 | | 63.7 | 0.00637 | 6.99 | 2976 ± 55 |
| 9 | | 76.3 | 0.00763 | 8.38 | 3567 ± 60 |
| 9.5 | | 68.0 | 0.00680 | 7.47 | 3179 ± 56 |
| 10 | | 51.8 | 0.00518 | 5.69 | 2419 ± 49 |
| 10.5 | | 43.8 | 0.00438 | 4.81 | 2047 ± 45 |
| 11 | | 38.4 | 0.00384 | 4.21 | 1792 ± 42 |
| 11.5 | | 34.6 | 0.00346 | 3.80 | 1616 ± 40 |
| 12 | | 33.7 | 0.00337 | 3.70 | 1574 ± 40 |
| 12.5 | | 32.9 | 0.00329 | 3.61 | 1538 ± 39 |
| 13 | | 33.8 | 0.00338 | 3.71 | 1577 ± 40 |
| 13.5 | | 34.9 | 0.00349 | 3.83 | 1631 ± 40 |
| 14 | | 35.1 | 0.00351 | 3.85 | 1638 ± 40 |
| 14.5 | | 37.7 | 0.00377 | 4.14 | 1763 ± 42 |
| 15 | | 37.9 | 0.00379 | 4.17 | 1773 ± 42 |
| 15.5 | | 39.3 | 0.00393 | 4.31 | 1834 ± 43 |
| 16 | | 47.4 | 0.00474 | 5.20 | 2214 ± 47 |
| 16.5 | | 35.3 | 0.00353 | 3.87 | 1648 ± 41 |
| 17 | | 31.7 | 0.00317 | 3.48 | 1482 ± 38 |

*The top 1 foot of the bore hole does not represent a true 4π geometery, so a valid calibration factor is not available.

## MW #1

| Depth (feet) | Level of water table | raw data (cpm) |
|---|---|---|
| 0 | | 2980 ± 55 |
| 0.5 | | 4468 ± 67 |
| 1 | | 6653 ± 82 |
| 1.5 | | 14162 ± 119 |
| 2 | | 23493 ± 153 |
| 2.5 | | 21271 ± 146 |
| 3 | | 11278 ± 106 |
| 3.5 | | 8457 ± 92 |
| 4 | | 7327 ± 86 |
| 4.5 | | 6395 ± 80 |
| 5 | | 6540 ± 81 |
| 5.5 | | 6203 ± 79 |
| 6 | | 6988 ± 84 |
| 6.5 | | 7487 ± 87 |
| 7 | 7' 5" | 7258 ± 85 |
| 7.5 | ← | 7331 ± 86 |
| 8 | | 7713 ± 88 |
| 8.5 | | 7664 ± 88 |
| 9 | | 8122 ± 90 |
| 9.5 | | 7483 ± 87 |
| 10 | | 7839 ± 89 |
| 10.5 | | 8047 ± 90 |
| 11 | | 8553 ± 92 |
| 11.5 | | 12015 ± 110 |
| 12 | | 8670 ± 93 |
| 12.5 | | 9162 ± 96 |
| 13 | | 10225 ± 101 |
| 13.5 | | 7513 ± 87 |
| 14 | | 5827 ± 76 |
| 14.5 | | 5757 ± 76 |
| 15 | | 7029 ± 84 |
| 15.5 | | 6665 ± 82 |
| 16 | | 7346 ± 86 |
| 16.5 | | 6448 ± 80 |
| 17 | | 6267 ± 79 |

W W # 2

| Depth (feet) | Level of water table | raw data (cpm) |
|---|---|---|
| 0 | | 805 ± 28 |
| 0.5 | | 1181 ± 34 |
| 1 | | 2775 ± 53 |
| 1.5 | | 4999 ± 71 |
| 2 | | 6883 ± 83 |
| 2.5 | | 7553 ± 87 |
| 3 | | 8474 ± 92 |
| 3.5 | | 9855 ± 99 |
| 4 | | 7059 ± 84 |
| 4.5 | | 4654 ± 68 |
| 5 | | 2982 ± 55 |
| 5.5 | | 2044 ± 45 |
| 6 | | 1540 ± 39 |
| 6.5 | | 1239 ± 35 |
| 7 | 7' 7" | 1212 ± 35 |
| 7.5 | ← | 1166 ± 34 |
| 8 | | 1125 ± 34 |
| 8.5 | | 1118 ± 33 |
| 9 | | 1153 ± 34 |
| 9.5 | | 1131 ± 34 |
| 10 | | 1162 ± 34 |
| 10.5 | | 1108 ± 33 |
| 11 | | 1082 ± 33 |
| 11.5 | | 949 ± 31 |
| 12 | | 858 ± 29 |
| 12.5 | | 780 ± 28 |
| 13 | | 733 ± 27 |

WW#3

| Depth (feet) | Level of water table | raw data (cpm) |
|---|---|---|
| 0 | | 907 ± 30 |
| 0.5 | | 1227 ± 35 |
| 1 | | 2215 ± 47 |
| 1.5 | | 3253 ± 57 |
| 2 | | 3543 ± 60 |
| 2.5 | | 2736 ± 52 |
| 3 | | 1860 ± 43 |
| 3.5 | | 1483 ± 39 |
| 4 | | 1427 ± 38 |
| 4.5 | | 1625 ± 40 |
| 5 | | 2897 ± 54 |
| 5.5 | | 4995 ± 71 |
| 6 | 6' 6" | 4868 ± 70 |
| 6.5 | ← | 3328 ± 58 |
| 7 | | 1993 ± 45 |
| 7.5 | | 1748 ± 42 |
| 8 | | 1386 ± 37 |
| 8.5 | | 1312 ± 36 |
| 9 | | 1375 ± 37 |
| 9.5 | | 1479 ± 38 |
| 10 | | 1470 ± 38 |
| 10.5 | | 1404 ± 37 |
| 11 | | 1440 ± 38 |
| 11.5 | | 1604 ± 40 |
| 12 | | 1592 ± 40 |
| 12.5 | | 1593 ± 40 |
| 13 | | 1672 ± 41 |
| 13.5 | | 1591 ± 40 |
| 14 | | 1516 ± 39 |
| 14.5 | | 1344 ± 37 |
| 15 | | 1388 ± 37 |
| 15.5 | | 1415 ± 38 |
| 16 | | 1387 ± 37 |
| 16.5 | | 1417 ± 38 |
| 17 | | 1308 ± 36 |
| 17.5 | | 1393 ± 37 |

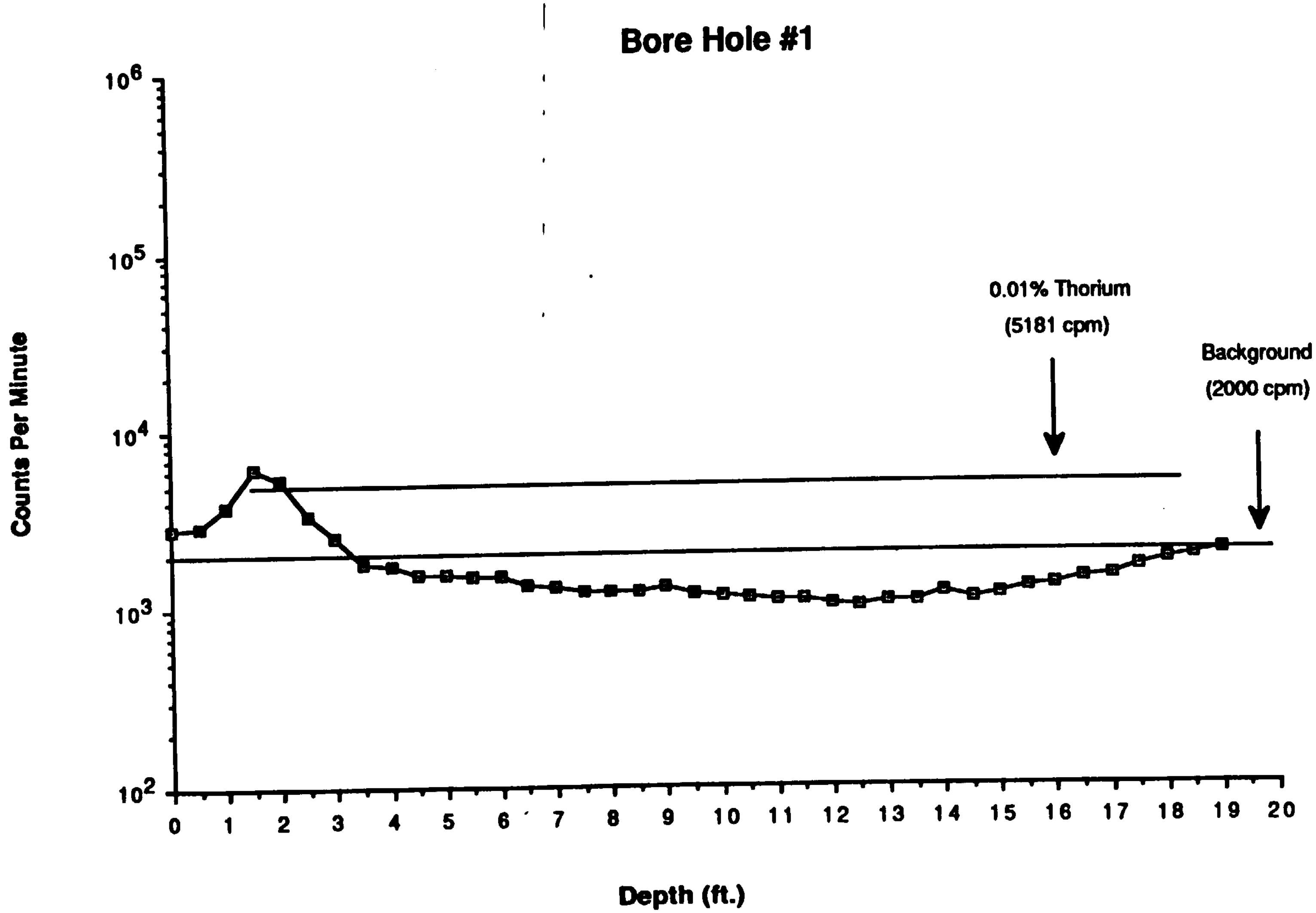
WW#4

| Depth (feet) | Level of water table | raw data (cpm) |
| --- | --- | --- |
| 0 | | 2687 ± 52 |
| 0.5 | | 8173 ± 90 |
| 1 | | 8906 ± 94 |
| 1.5 | | 5357 ± 73 |
| 2 | | 5284 ± 73 |
| 2.5 | | 6464 ± 80 |
| 3 | | 6874 ± 83 |
| 3.5 | | 8360 ± 91 |
| 4 | | 8070 ± 90 |
| 4.5 | | 6883 ± 83 |
| 5 | | 4518 ± 67 |
| 5.5 | | 3207 ± 57 |
| 6 | | 2449 ± 49 |
| 6.5 | 6' 11" | 2139 ± 46 |
| 7 | ← | 2082 ± 46 |
| 7.5 | | 2037 ± 45 |
| 8 | | 1855 ± 43 |
| 8.5 | | 1818 ± 43 |
| 9 | | 1824 ± 43 |
| 9.5 | | 1875 ± 43 |
| 10 | | 1805 ± 42 |
| 10.5 | | 1552 ± 39 |
| 11 | | 1351 ± 37 |
| 11.5 | | 1240 ± 35 |
| 12 | | 1149 ± 34 |
| 12.5 | | 998 ± 32 |
| 13 | | 961 ± 31 |
| 13.5 | | 954 ± 31 |
| 14 | | 992 ± 31 |
| 14.5 | | 1101 ± 33 |
| 15 | | 1105 ± 33 |
| 15.5 | | 1167 ± 34 |
| 16 | | 1130 ± 34 |

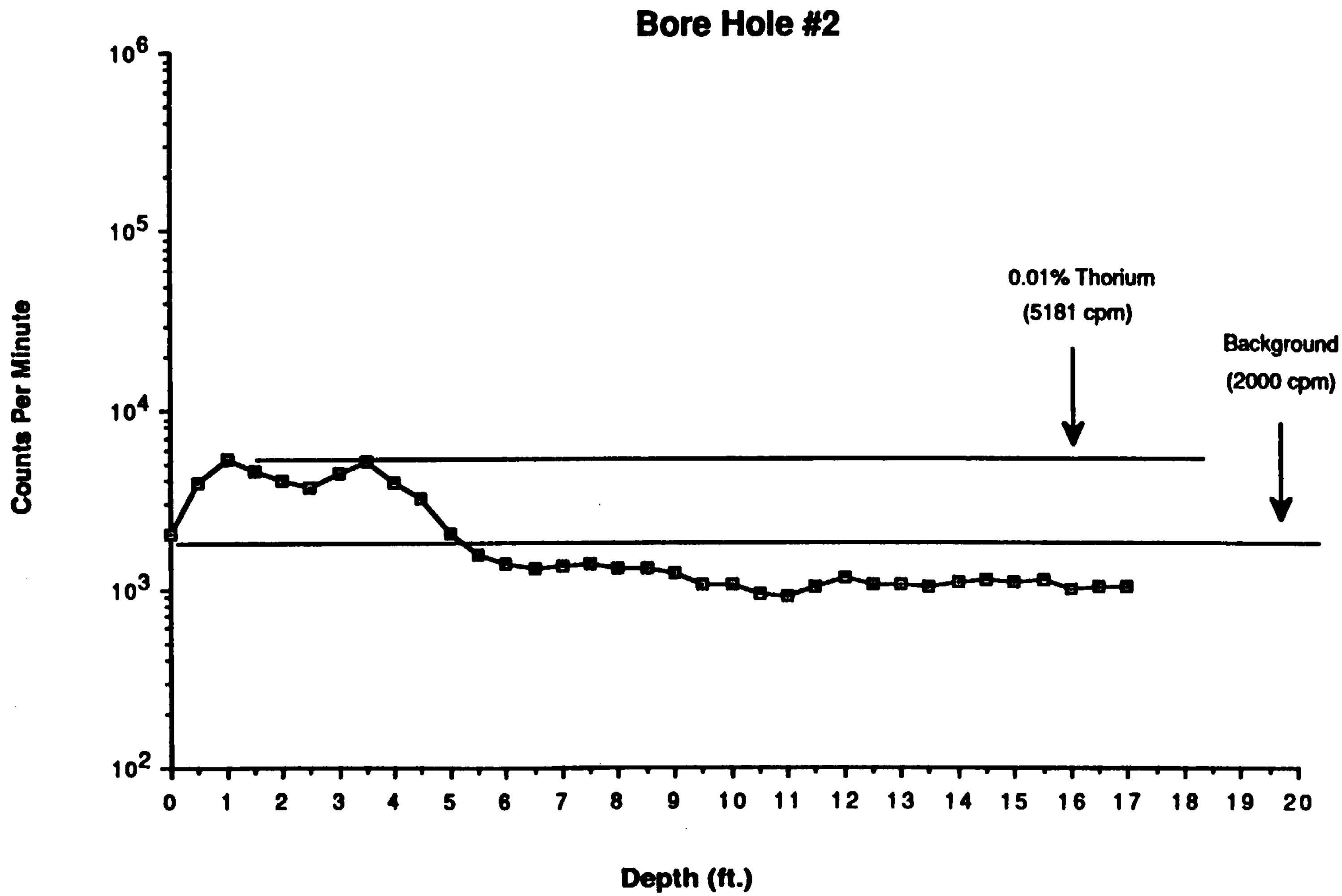
WW#5

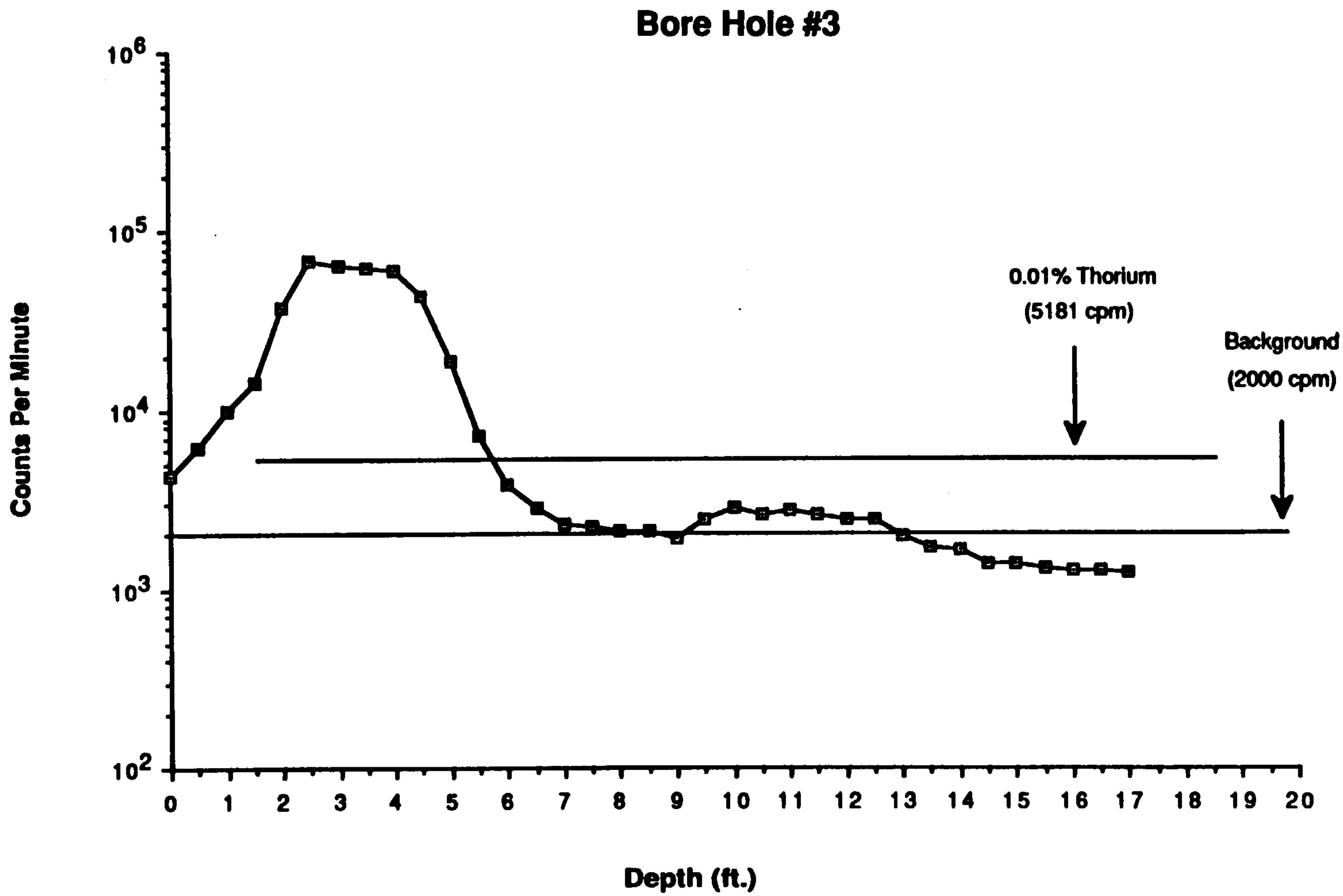
| Depth (feet) | Level of water table | raw data (cpm) |
|---|---|---|
| 0 | | 416 ± 20 |
| 0.5 | | 583 ± 24 |
| 1 | | 724 ± 27 |
| 1.5 | | 732 ± 27 |
| 2 | | 758 ± 28 |
| 2.5 | | 1020 ± 32 |
| 3 | | 1084 ± 33 |
| 3.5 | 4' 0" | 1116 ± 33 |
| 4 | ← | 1108 ± 33 |
| 4.5 | | 1133 ± 34 |
| 5 | | 1123 ± 34 |
| 5.5 | | 1146 ± 34 |
| 6 | | 1102 ± 33 |
| 6.5 | | 1436 ± 38 |
| 7 | | 1520 ± 39 |
| 7.5 | | 1602 ± 40 |
| 8 | | 1262 ± 36 |
| 8.5 | | 950 ± 31 |
| 9 | | 813 ± 29 |
| 9.5 | | 737 ± 27 |
| 10 | | 750 ± 27 |
| 10.5 | | 816 ± 29 |
| 11 | | 923 ± 30 |
| 11.5 | | 917 ± 30 |
| 12 | | 985 ± 31 |
| 12.5 | | 1066 ± 33 |
| 13 | | 1259 ± 35 |

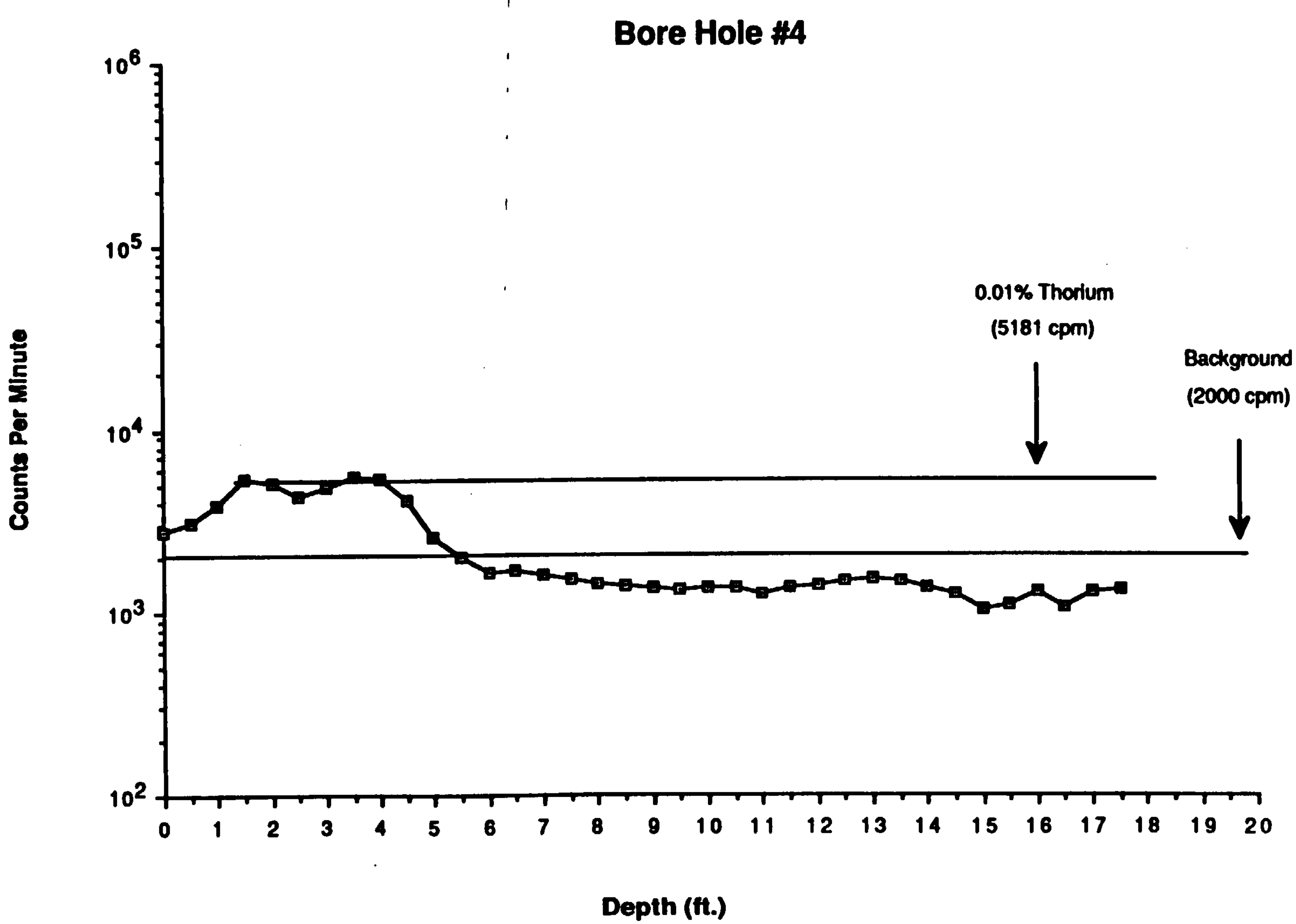
# Appendix C: Graphs of Bore Hole Logging Data.



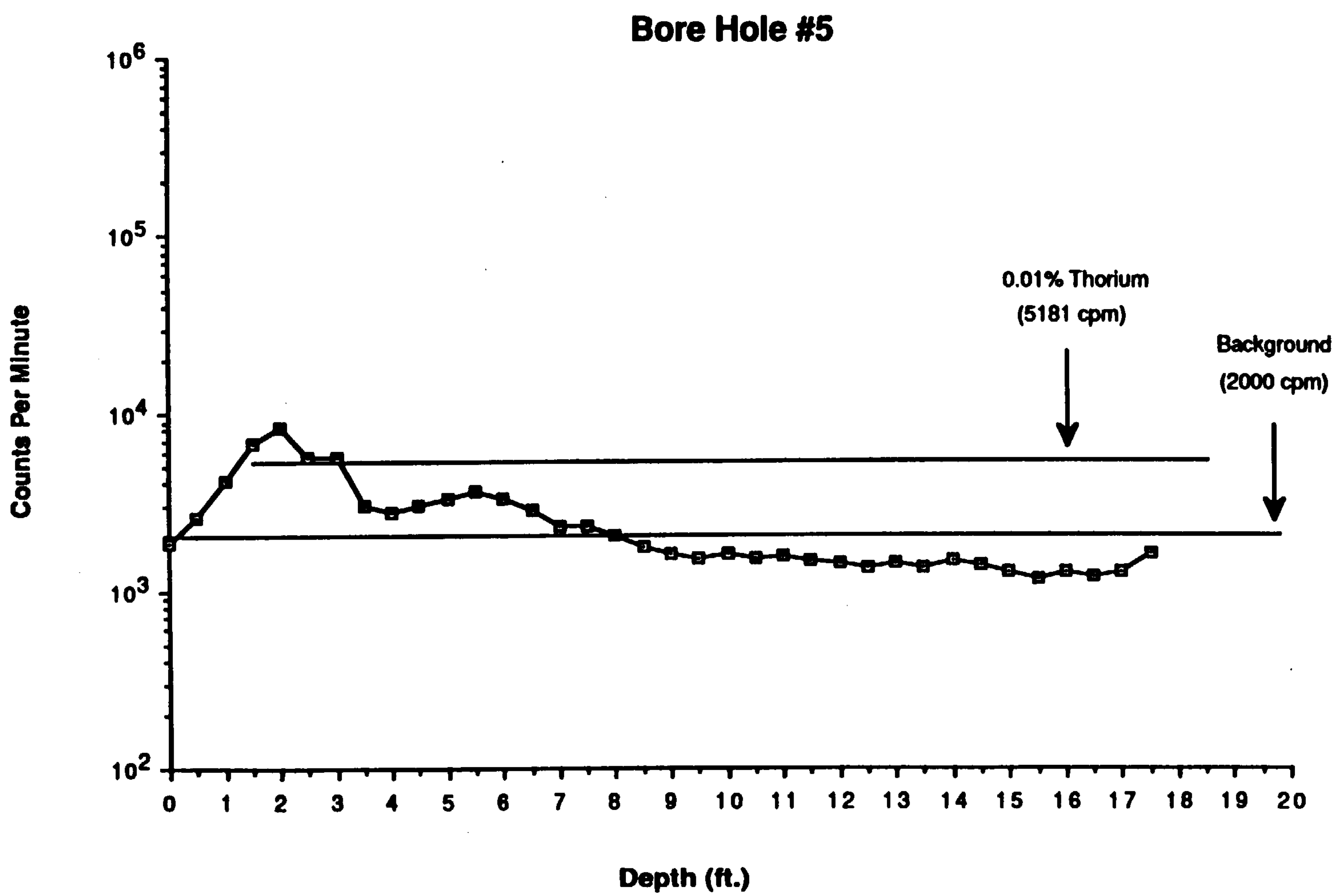
Bore Hole #1
Counts Per Minute
10^6
10^5
10^4
10^3
10^2
0.01% Thorium
(5181 cpm)
Background
(2000 cpm)
0 1 2 3 4 5 6 7 8 9 10 11 12 13 14 15 16 17 18 19 20
Depth (ft.)

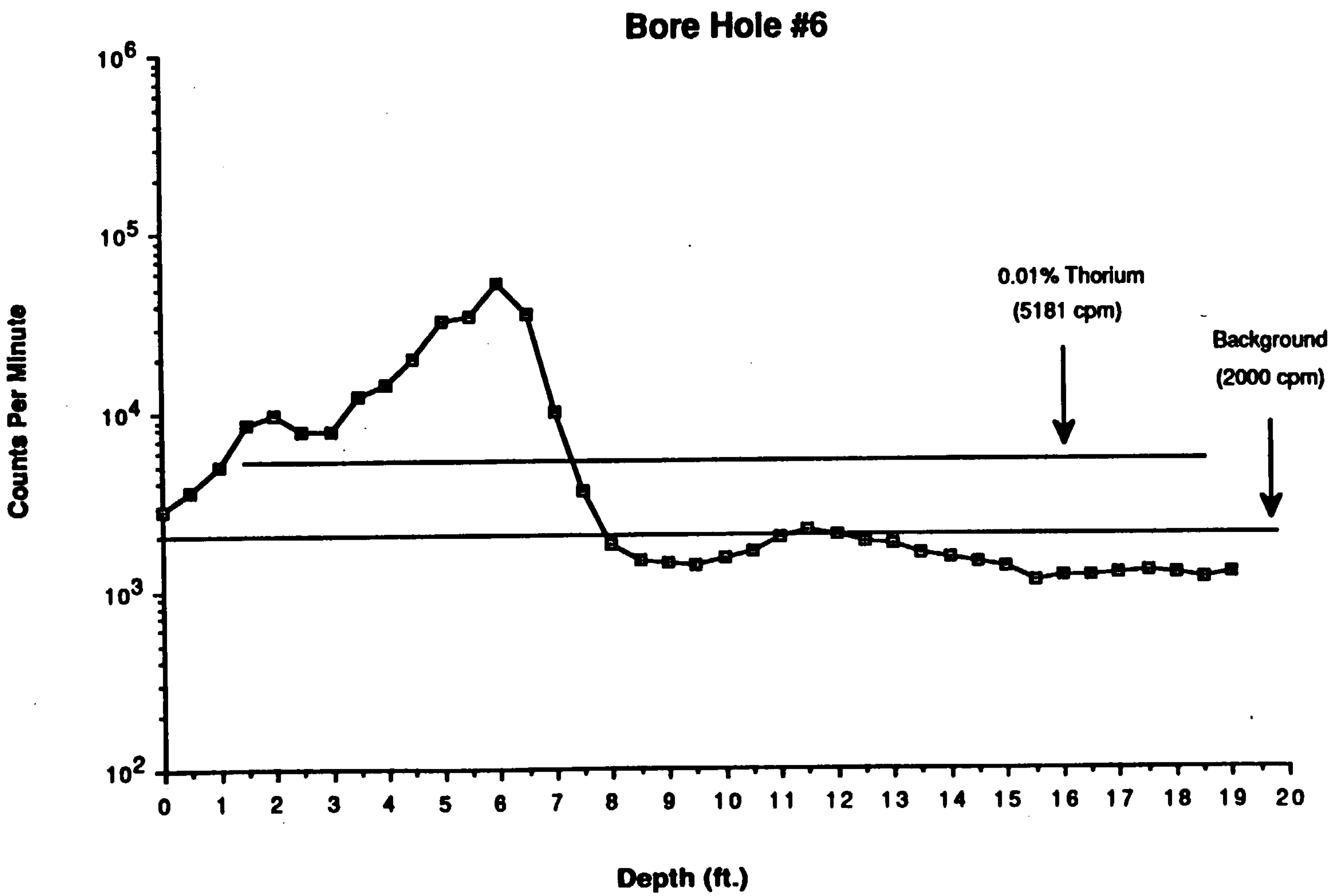

Bore Hole #2
Counts Per Minute
10^6
10^5
10^4
10^3
10^2
0.01% Thorium
(5181 cpm)
Background
(2000 cpm)
0 1 2 3 4 5 6 7 8 9 10 11 12 13 14 15 16 17 18 19 20
Depth (ft.)


Bore Hole #3
Counts Per Minute
$10^6$
$10^5$
$10^4$
$10^3$
$10^2$
0.01% Thorium
(5181 cpm)
Background
(2000 cpm)
0 1 2 3 4 5 6 7 8 9 10 11 12 13 14 15 16 17 18 19 20
Depth (ft.)

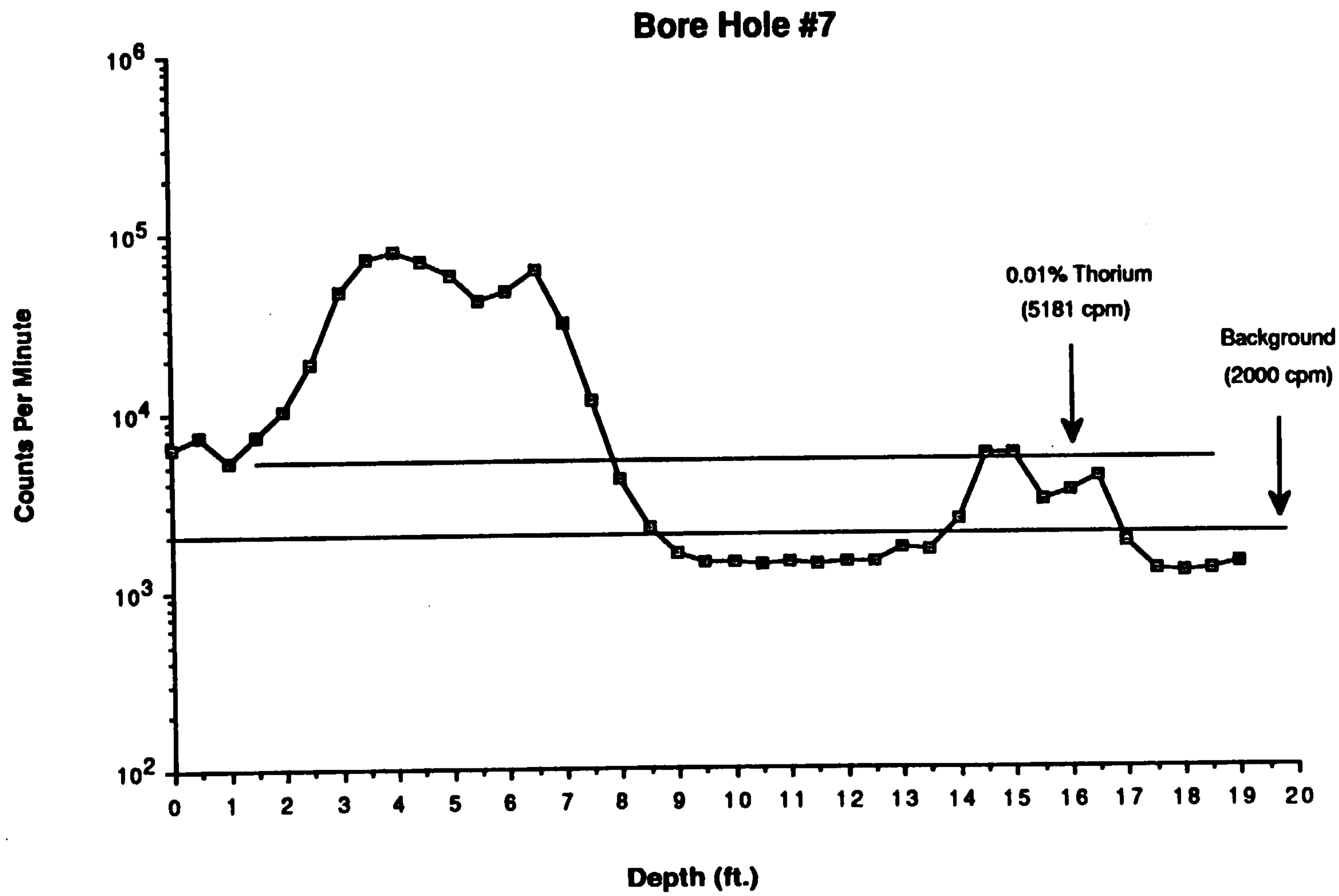


Bore Hole #4
Counts Per Minute
10^6
10^5
10^4
10^3
10^2
0.01% Thorium
(5181 cpm)
Background
(2000 cpm)
0 1 2 3 4 5 6 7 8 9 10 11 12 13 14 15 16 17 18 19 20
Depth (ft.)

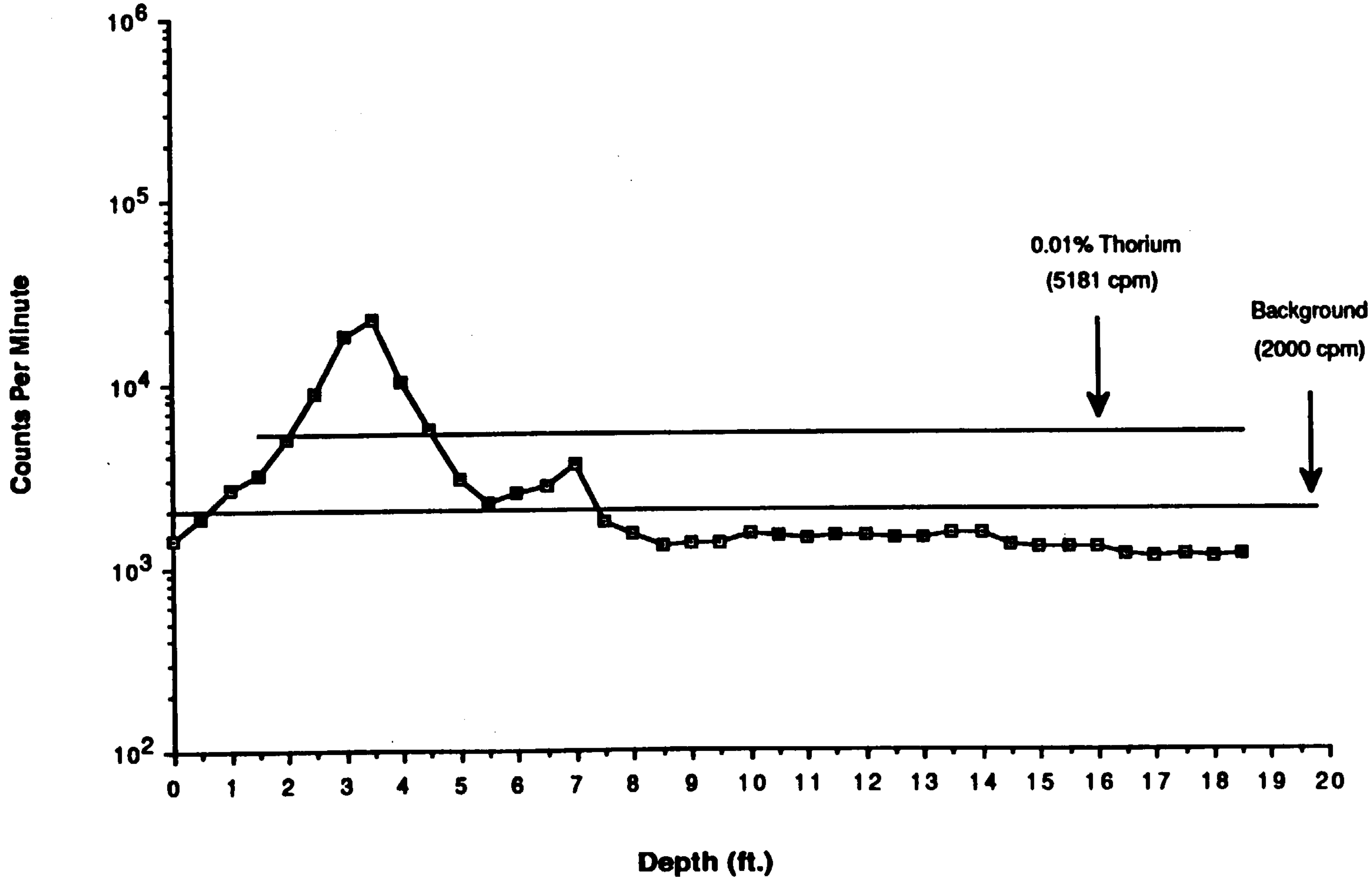

Bore Hole #5
$10^6$
$10^5$
$10^4$
$10^3$
$10^2$
Counts Per Minute
0.01% Thorium
(5181 cpm)
Background
(2000 cpm)
0 1 2 3 4 5 6 7 8 9 10 11 12 13 14 15 16 17 18 19 20
Depth (ft.)



Bore Hole #6
Counts Per Minute
10^6
10^5
10^4
10^3
10^2
0 1 2 3 4 5 6 7 8 9 10 11 12 13 14 15 16 17 18 19 20
Depth (ft.)
0.01% Thorium
(5181 cpm)
Background
(2000 cpm)

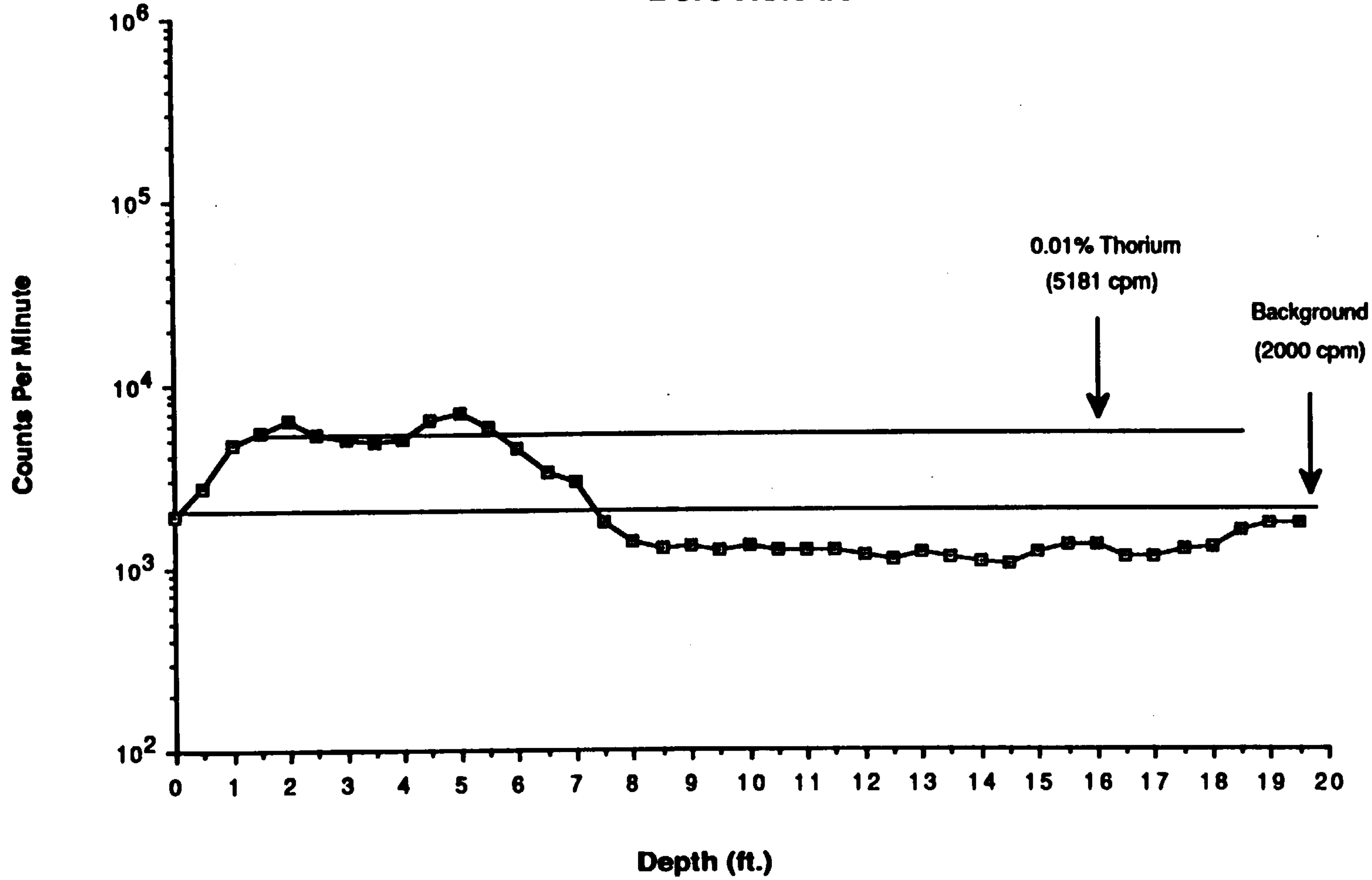

Bore Hole #7
Counts Per Minute
$10^6$
$10^5$
$10^4$
$10^3$
$10^2$
0.01% Thorium
(5181 cpm)
Background
(2000 cpm)
0 1 2 3 4 5 6 7 8 9 10 11 12 13 14 15 16 17 18 19 20
Depth (ft.)

## Bore Hole #8

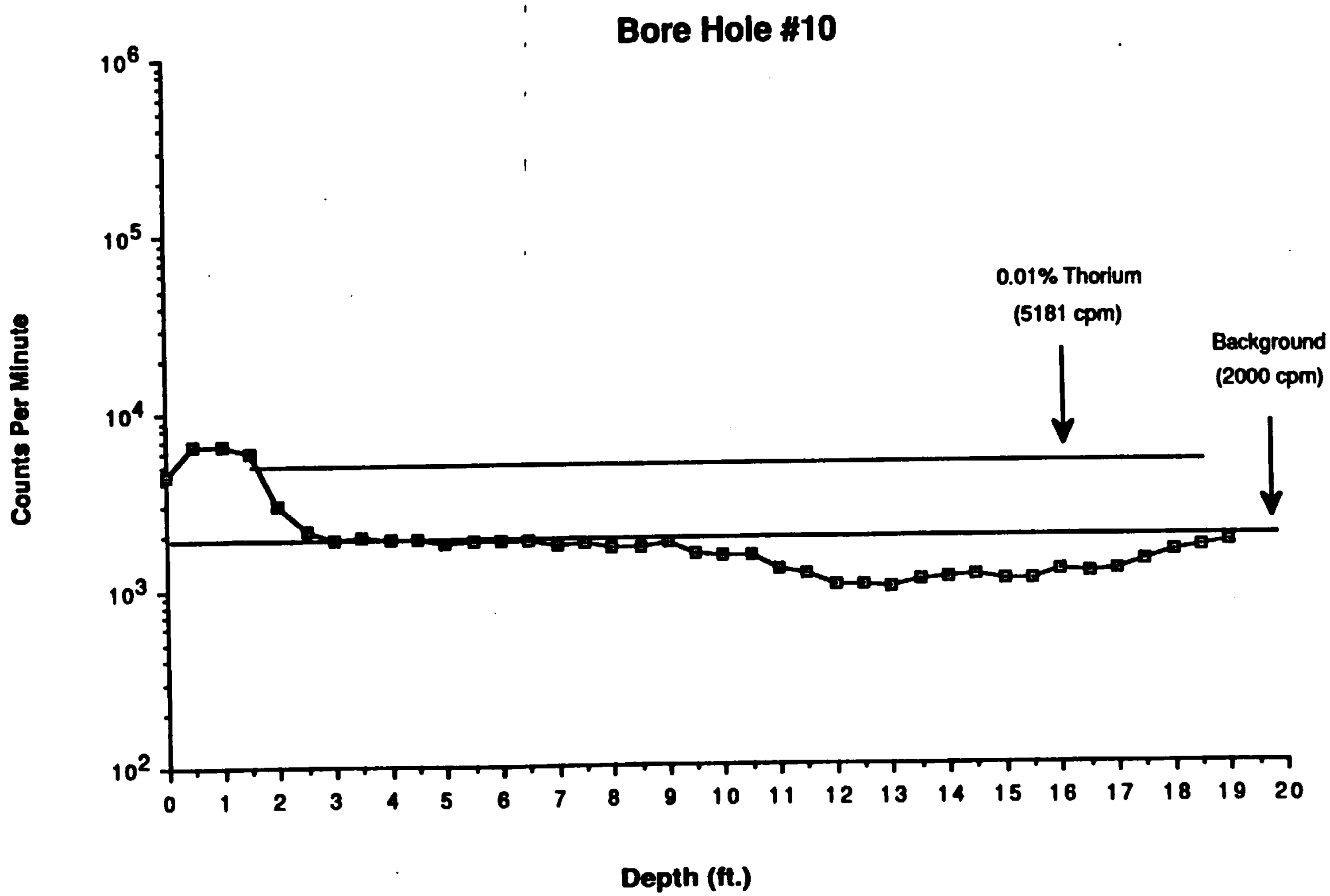


Counts Per Minute
$10^6$
$10^5$
$10^4$
$10^3$
$10^2$
0 1 2 3 4 5 6 7 8 9 10 11 12 13 14 15 16 17 18 19 20
Depth (ft.)
0.01% Thorium
(5181 cpm)
Background
(2000 cpm)

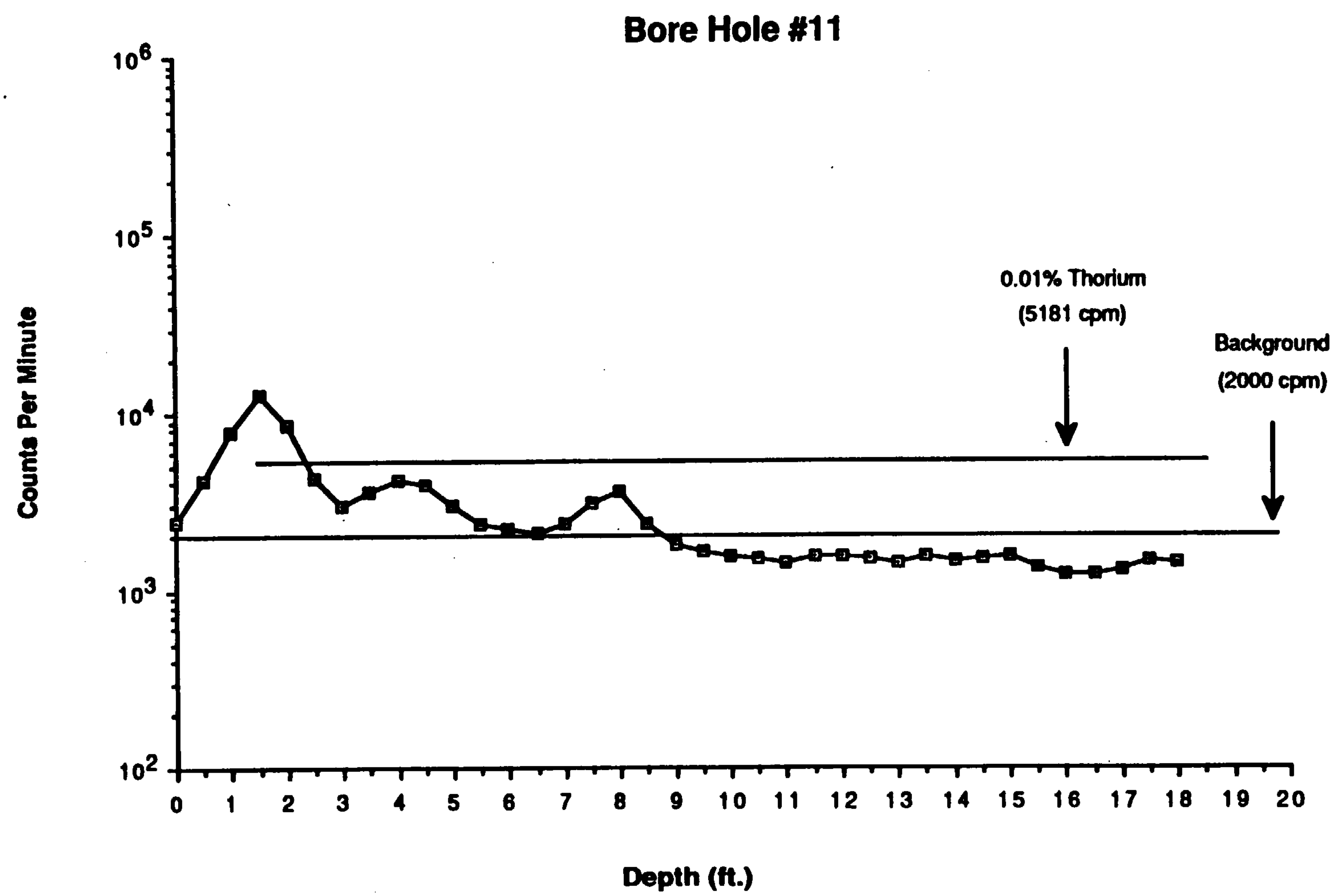
# Bore Hole #9



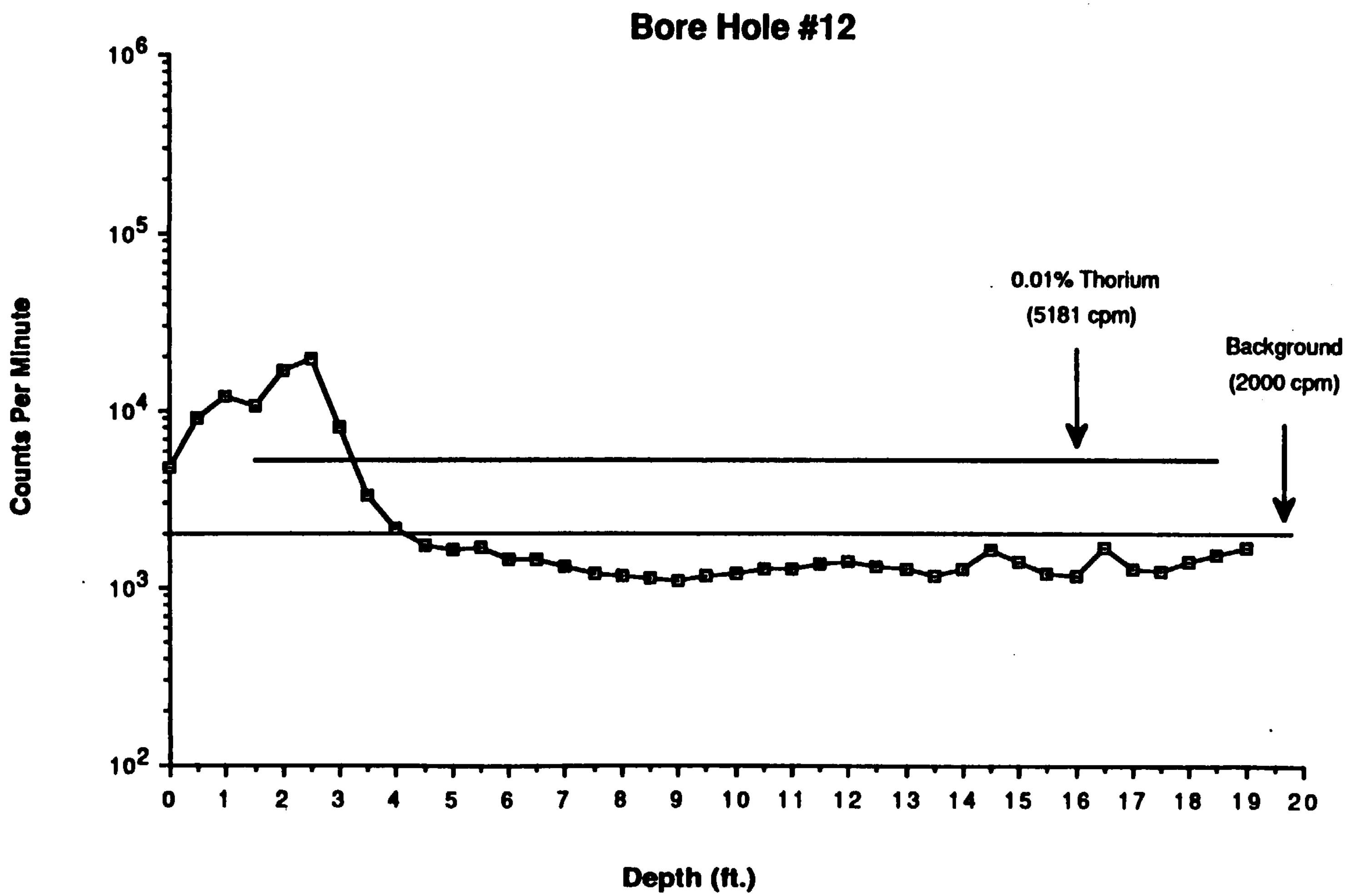
Counts Per Minute
$10^6$
$10^5$
$10^4$
$10^3$
$10^2$
0.01% Thorium
(5181 cpm)
Background
(2000 cpm)
0 1 2 3 4 5 6 7 8 9 10 11 12 13 14 15 16 17 18 19 20
Depth (ft.)



Bore Hole #10
0.01% Thorium
(5181 cpm)
Background
(2000 cpm)
Counts Per Minute
10^6
10^5
10^4
10^3
10^2
0 1 2 3 4 5 6 7 8 9 10 11 12 13 14 15 16 17 18 19 20
Depth (ft.)

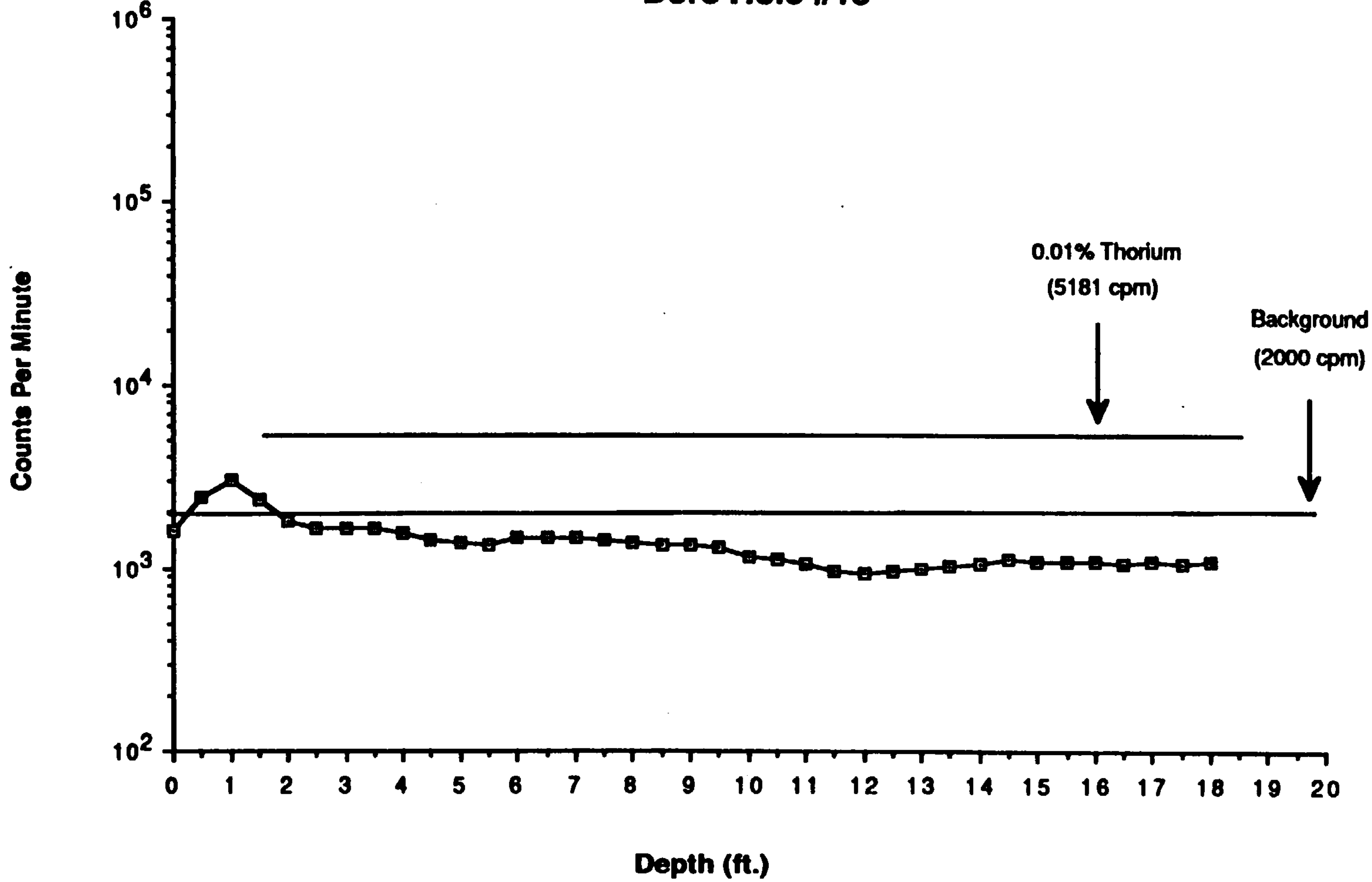


Bore Hole #11
Counts Per Minute
$10^6$
$10^5$
$10^4$
$10^3$
$10^2$
0 1 2 3 4 5 6 7 8 9 10 11 12 13 14 15 16 17 18 19 20
Depth (ft.)
0.01% Thorium
(5181 cpm)
Background
(2000 cpm)

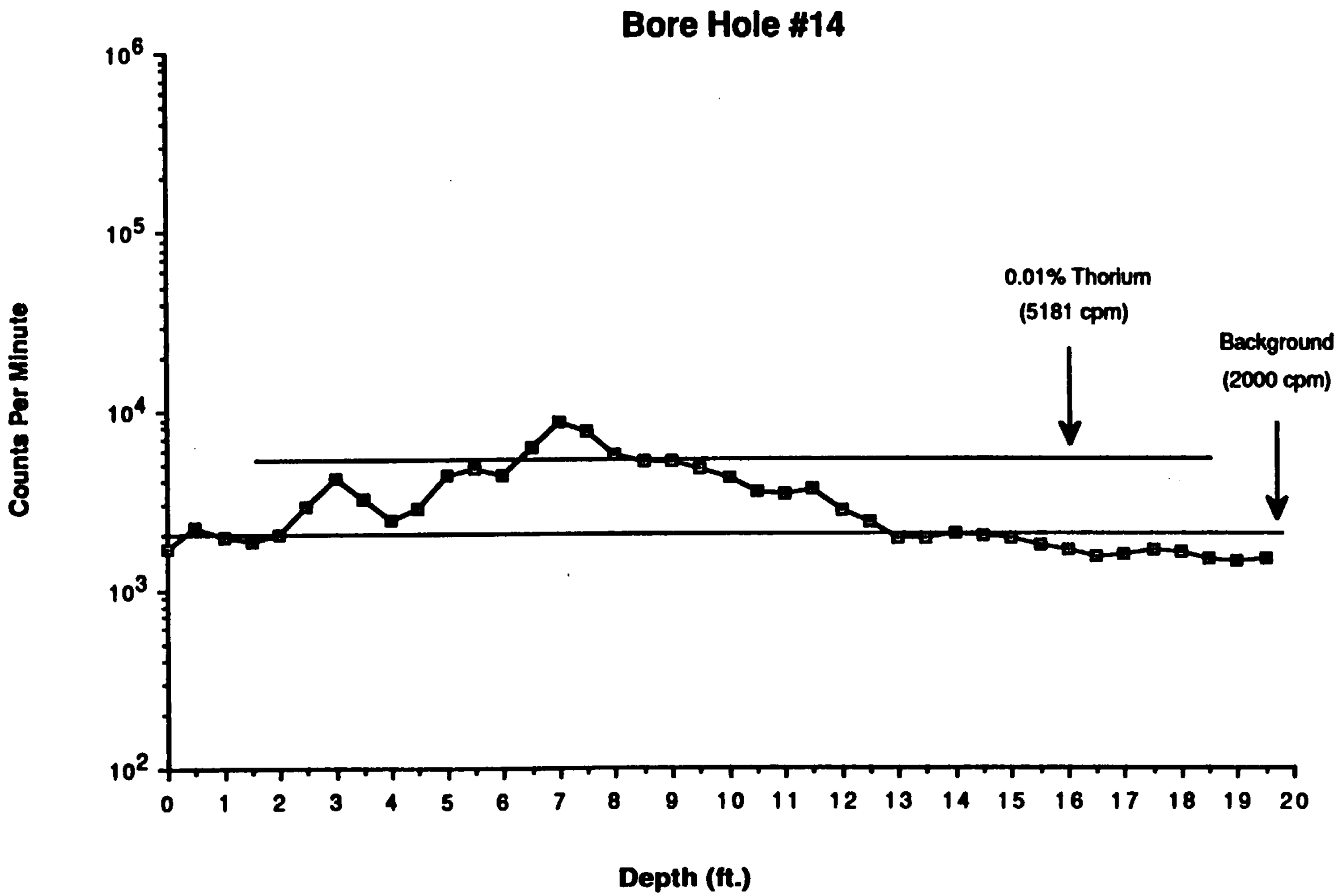


Bore Hole #12
Counts Per Minute
10^6
10^5
10^4
10^3
10^2
0.01% Thorium
(5181 cpm)
Background
(2000 cpm)
0 1 2 3 4 5 6 7 8 9 10 11 12 13 14 15 16 17 18 19 20
Depth (ft.)

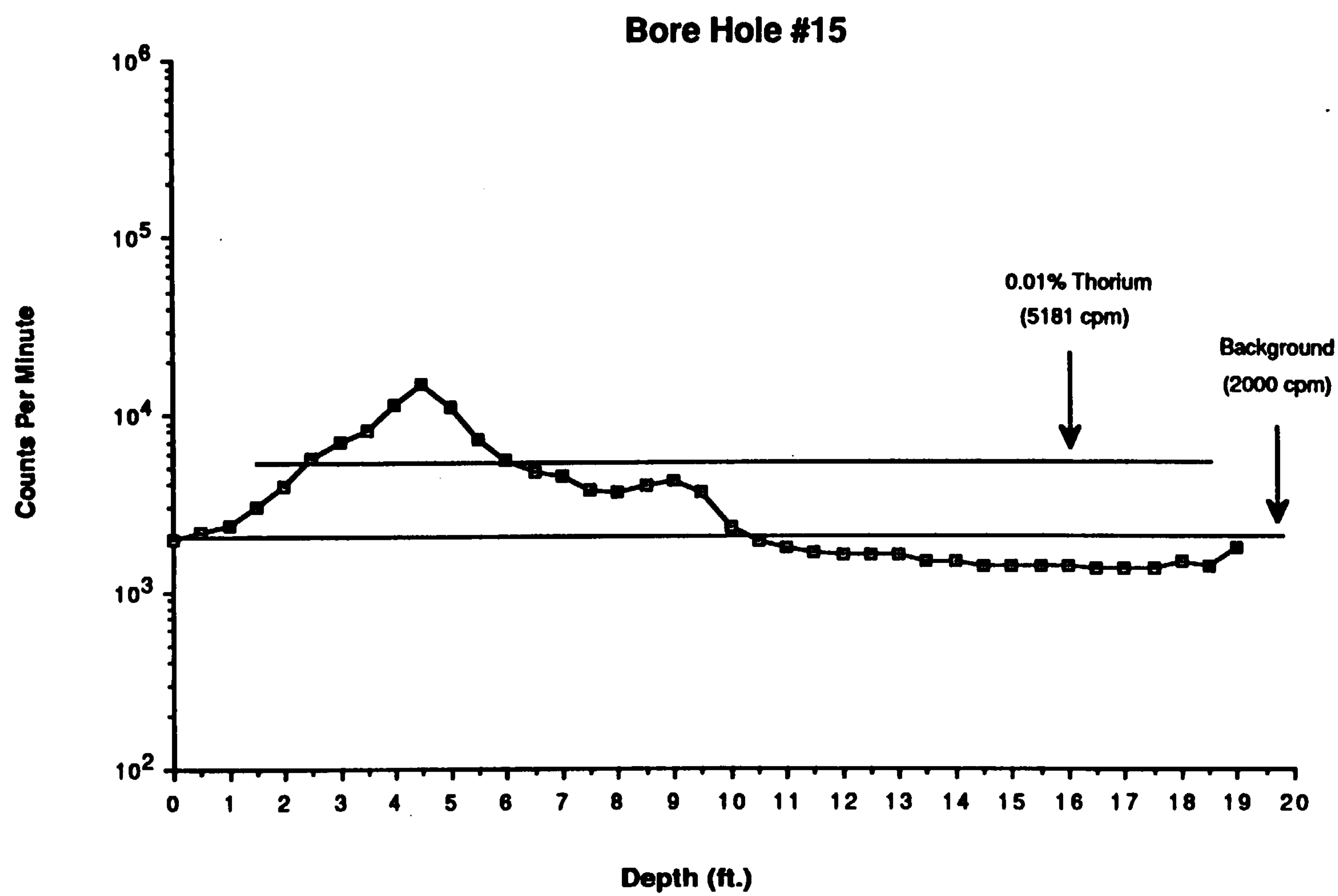
# Bore Hole #13



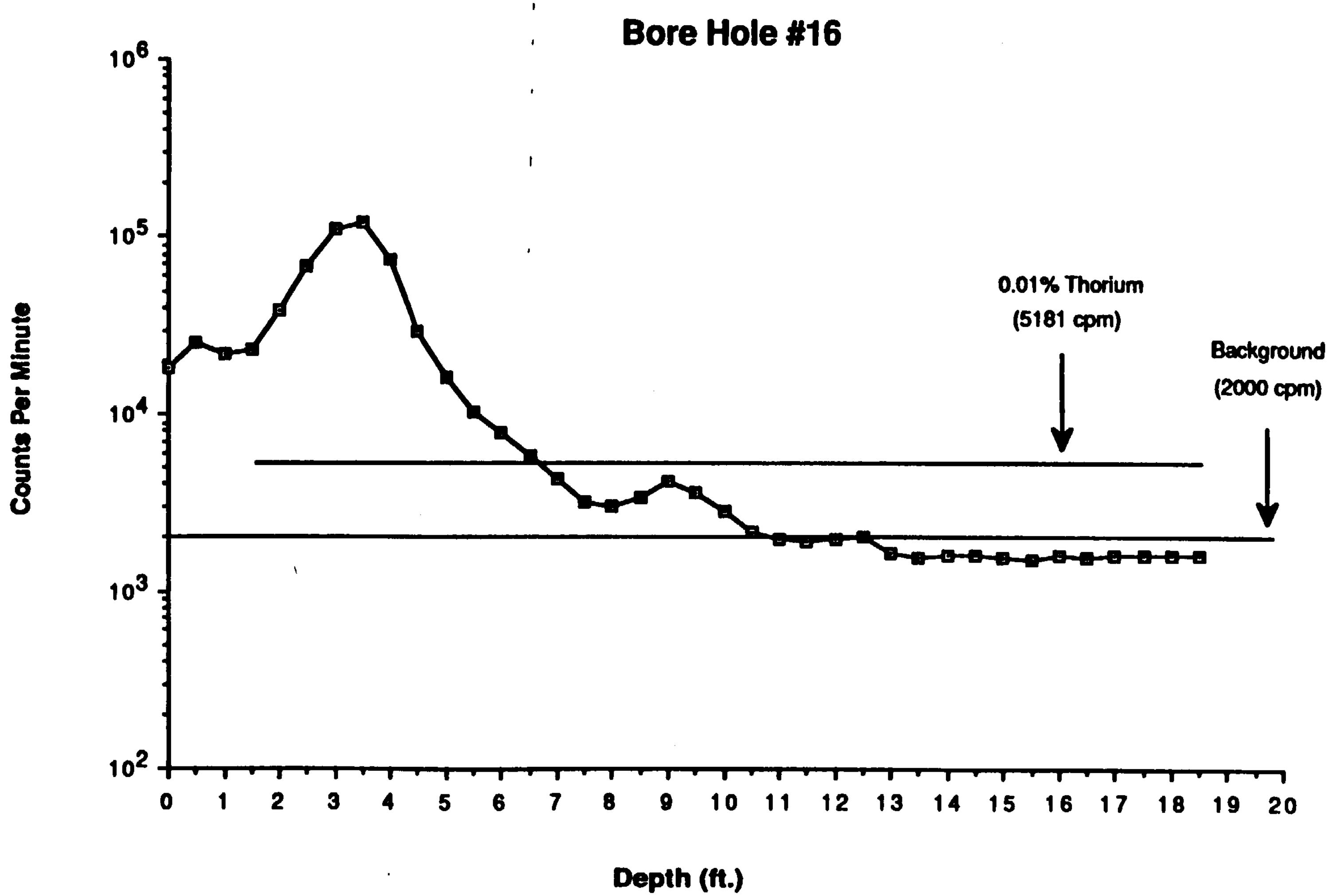
$10^6$
$10^5$
$10^4$
$10^3$
$10^2$
Counts Per Minute
0.01% Thorium
(5181 cpm)
Background
(2000 cpm)
0 1 2 3 4 5 6 7 8 9 10 11 12 13 14 15 16 17 18 19 20
Depth (ft.)

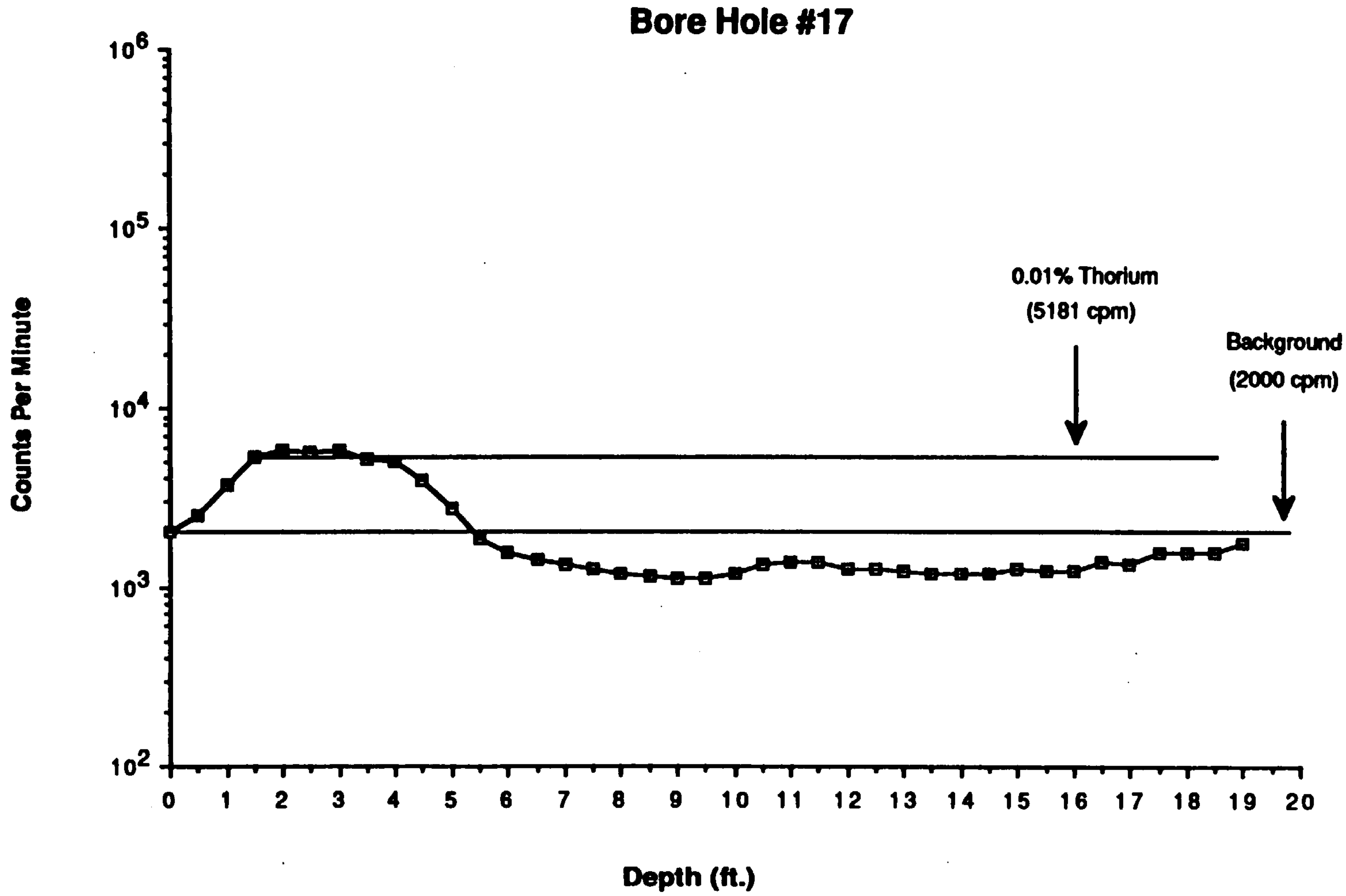


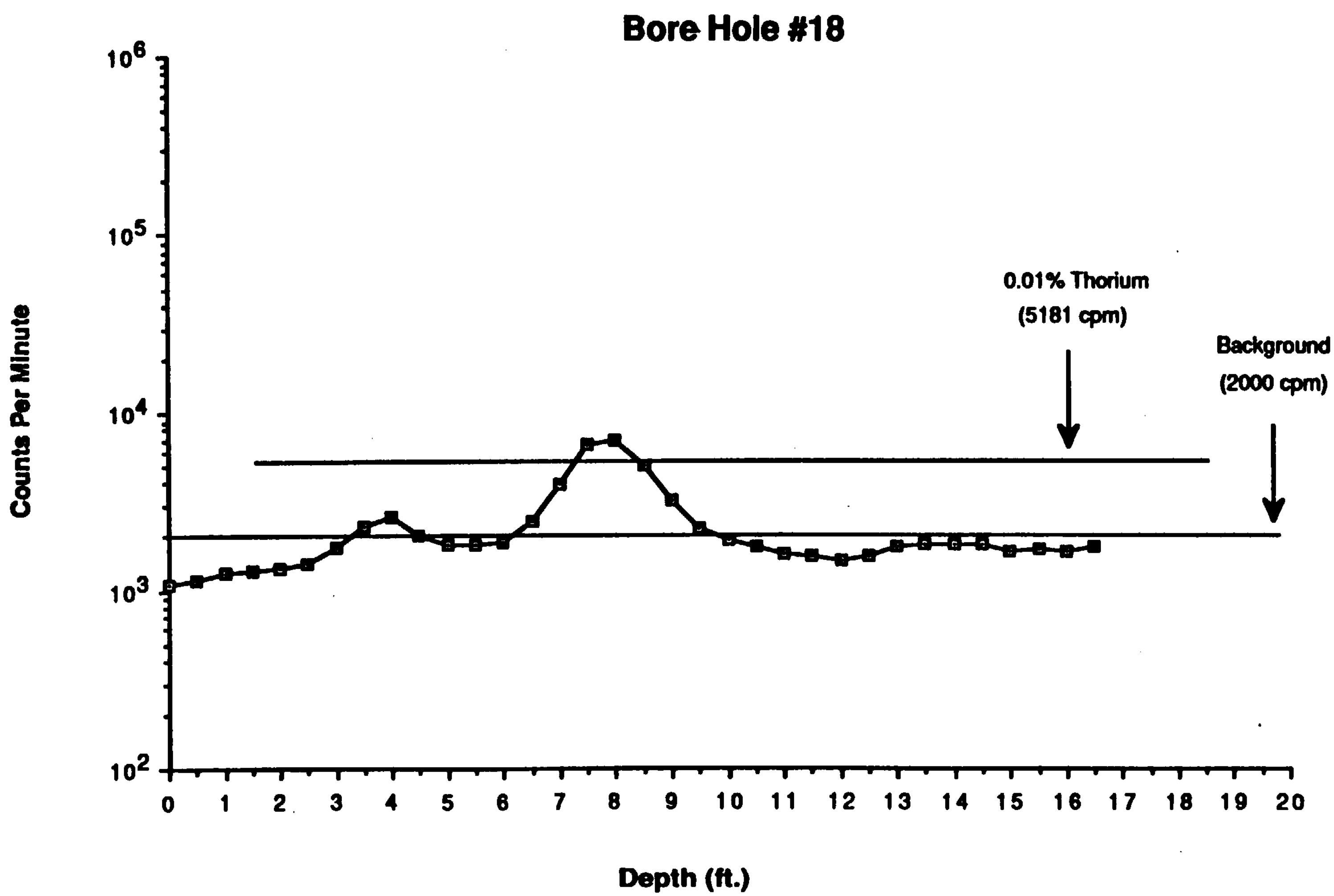
Bore Hole #14
$10^6$
$10^5$
$10^4$
$10^3$
$10^2$
Counts Per Minute
0.01% Thorium
(5181 cpm)
Background
(2000 cpm)
0 1 2 3 4 5 6 7 8 9 10 11 12 13 14 15 16 17 18 19 20
Depth (ft.)



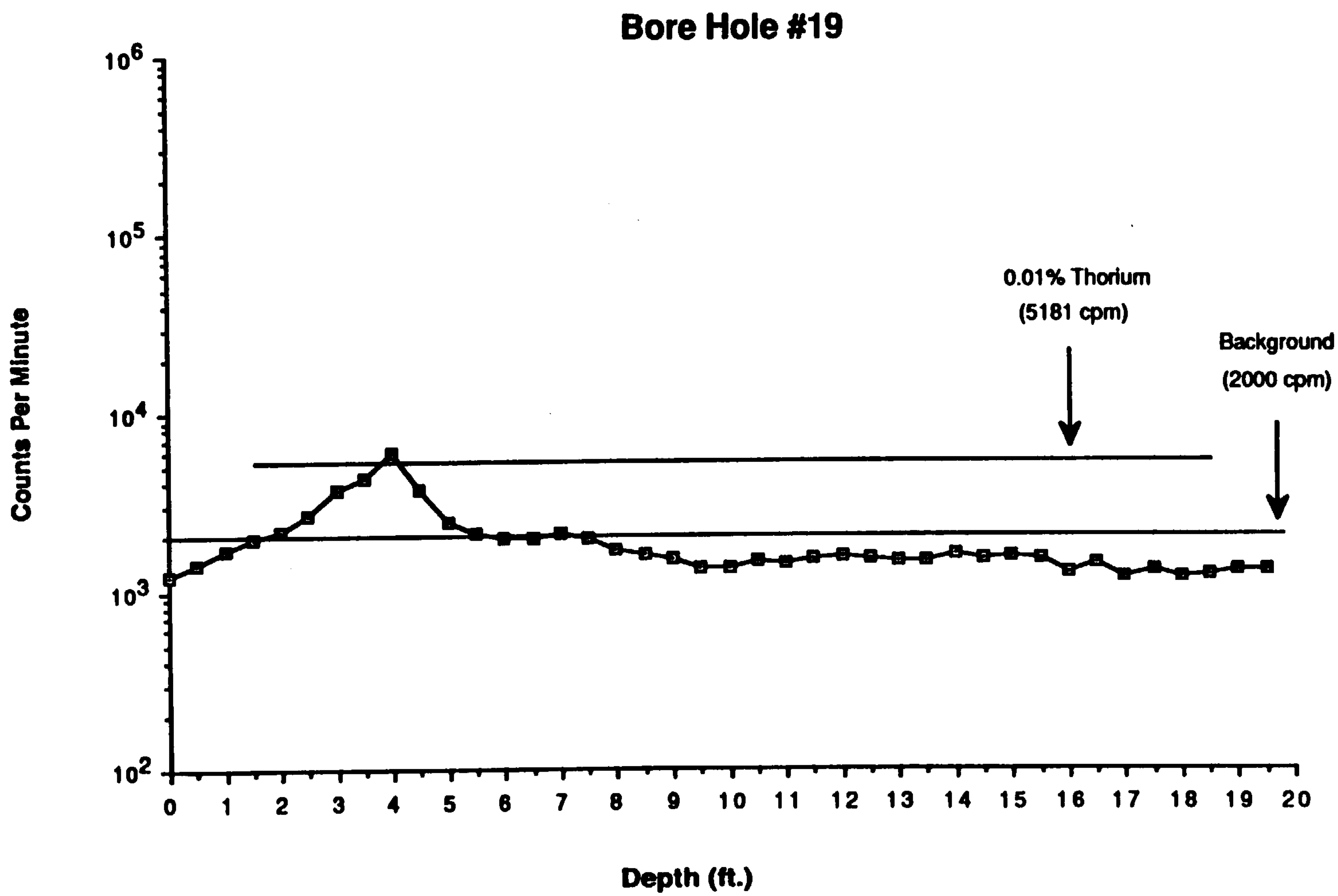
Bore Hole #15
$10^6$
$10^5$
$10^4$
$10^3$
$10^2$
Counts Per Minute
0.01% Thorium
(5181 cpm)
Background
(2000 cpm)
0 1 2 3 4 5 6 7 8 9 10 11 12 13 14 15 16 17 18 19 20
Depth (ft.)


Bore Hole #16
Counts Per Minute
$10^6$
$10^5$
$10^4$
$10^3$
$10^2$
0.01% Thorium
(5181 cpm)
Background
(2000 cpm)
0 1 2 3 4 5 6 7 8 9 10 11 12 13 14 15 16 17 18 19 20
Depth (ft.)

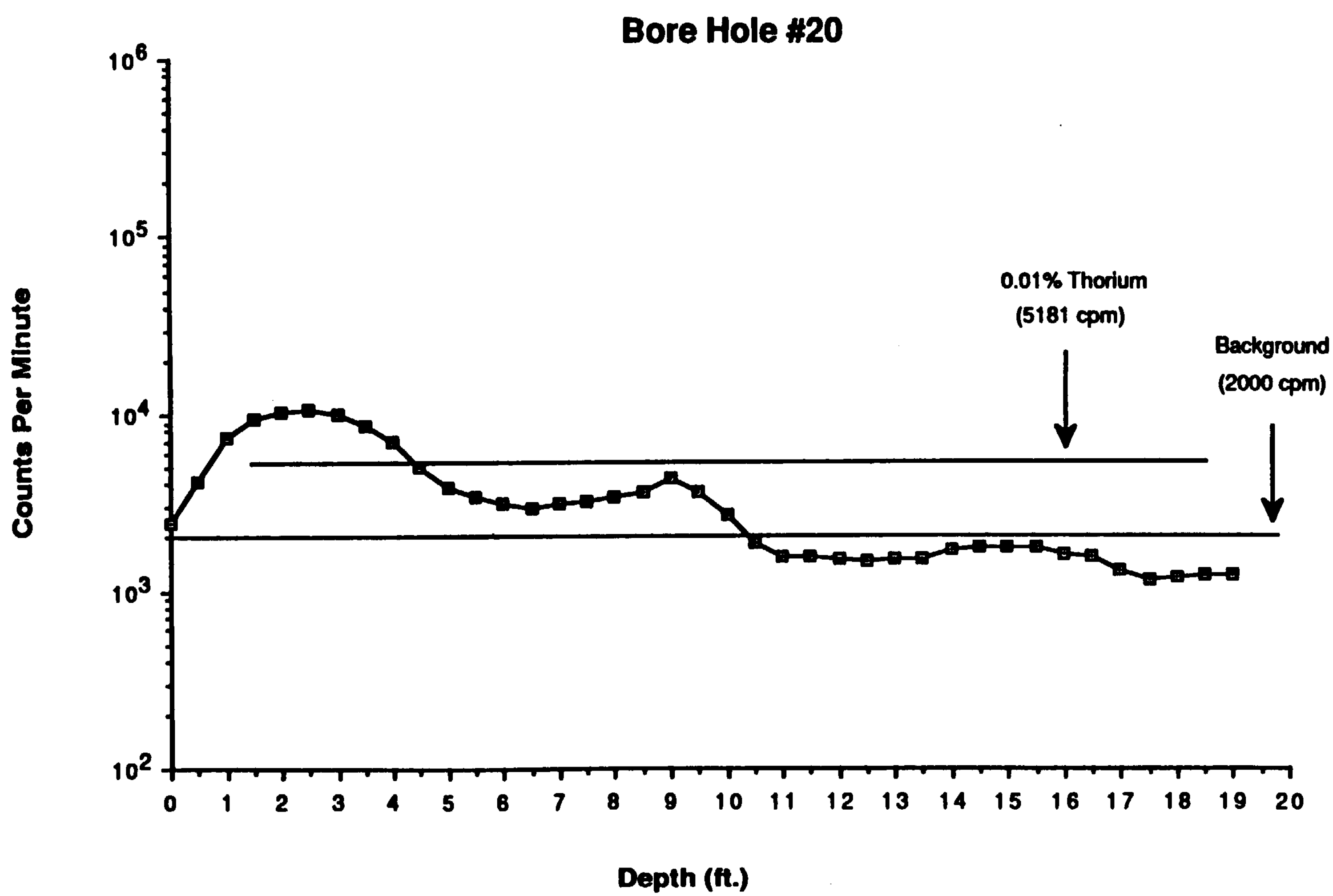

Bore Hole #17
Counts Per Minute
$10^6$
$10^5$
$10^4$
$10^3$
$10^2$
0.01% Thorium
(5181 cpm)
Background
(2000 cpm)
0 1 2 3 4 5 6 7 8 9 10 11 12 13 14 15 16 17 18 19 20
Depth (ft.)



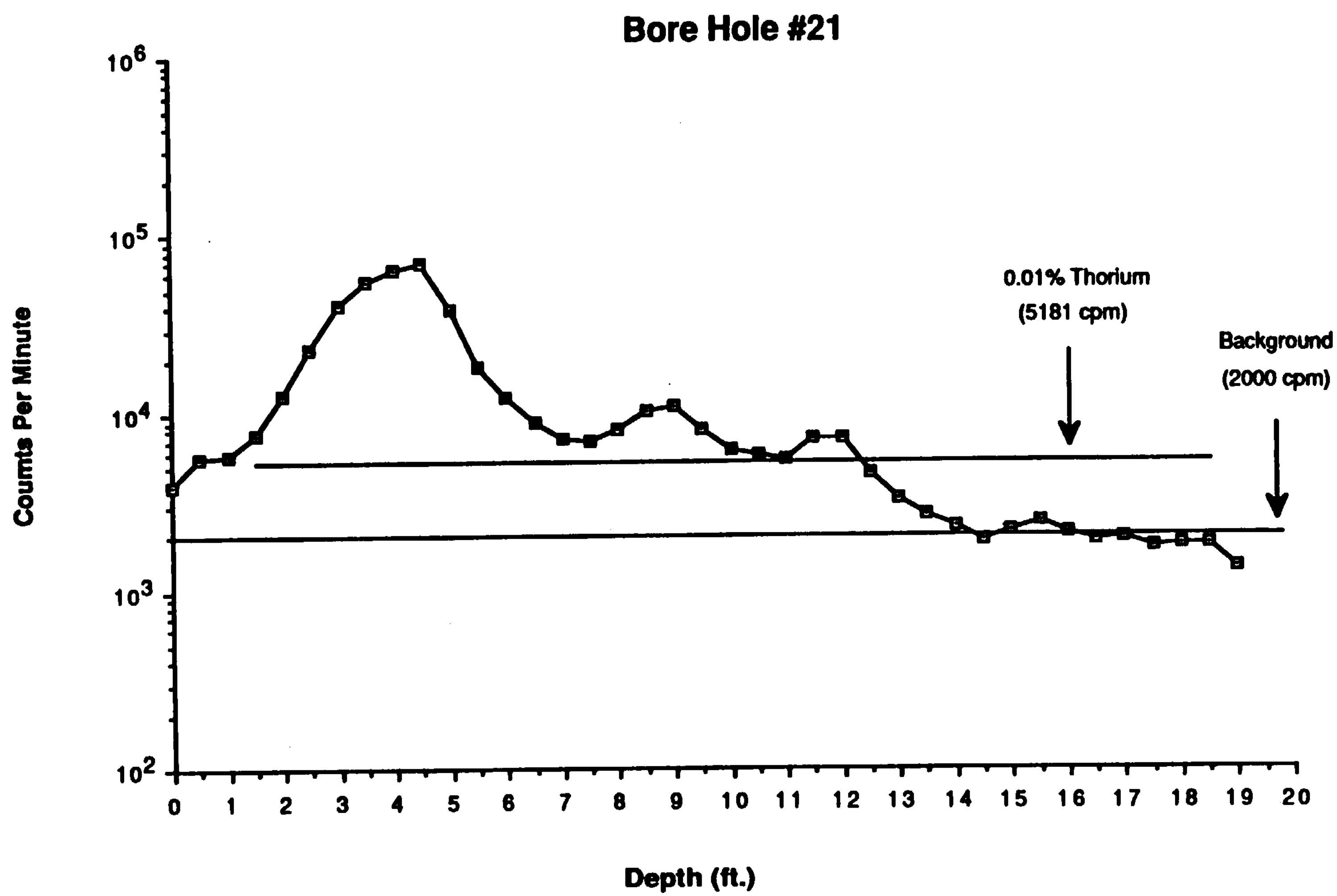
Bore Hole #18
Counts Per Minute
$10^6$
$10^5$
$10^4$
$10^3$
$10^2$
0.01% Thorium
(5181 cpm)
Background
(2000 cpm)
0 1 2 3 4 5 6 7 8 9 10 11 12 13 14 15 16 17 18 19 20
Depth (ft.)



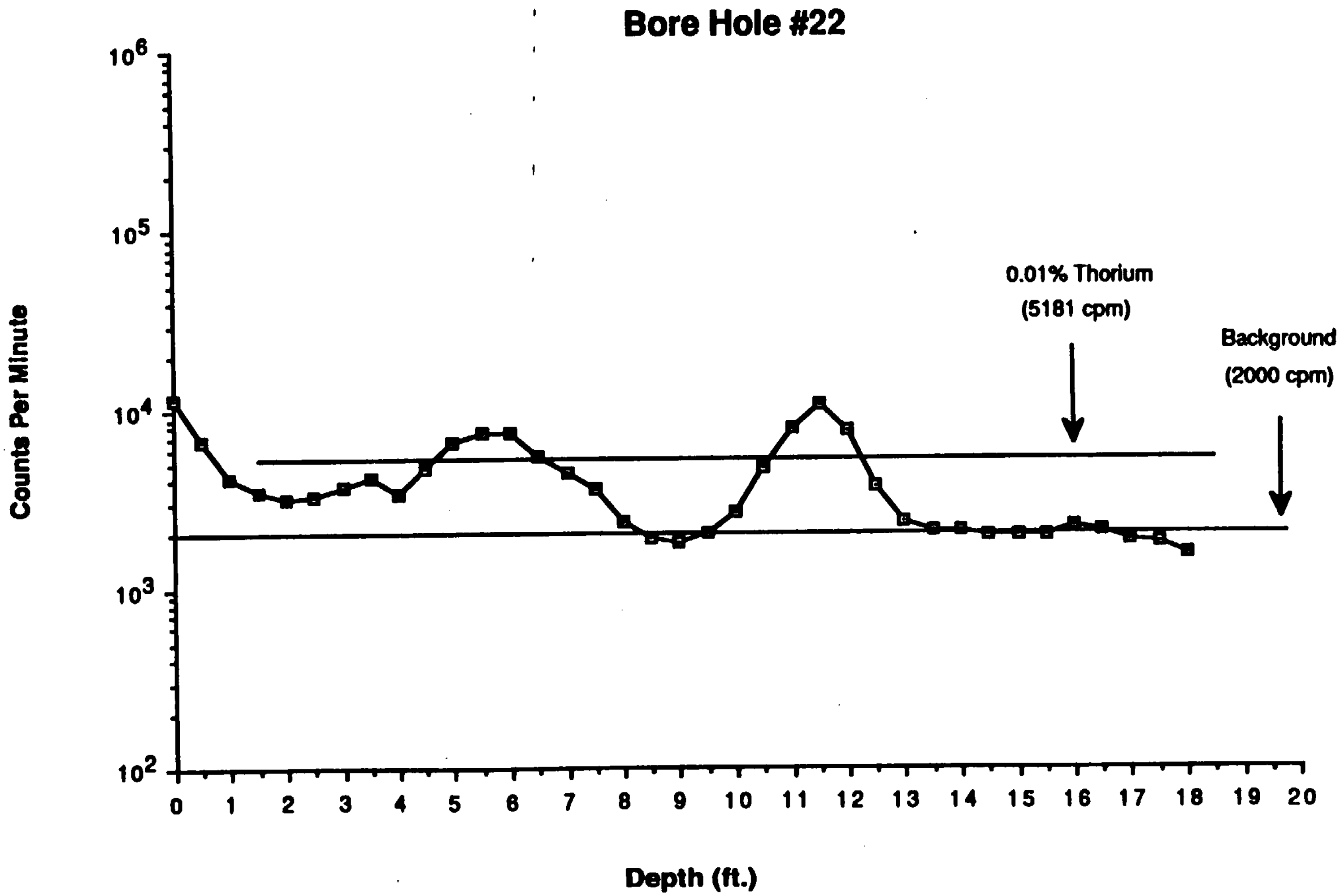
Bore Hole #19
Counts Per Minute
10^6
10^5
10^4
10^3
10^2
0.01% Thorium
(5181 cpm)
Background
(2000 cpm)
0 1 2 3 4 5 6 7 8 9 10 11 12 13 14 15 16 17 18 19 20
Depth (ft.)



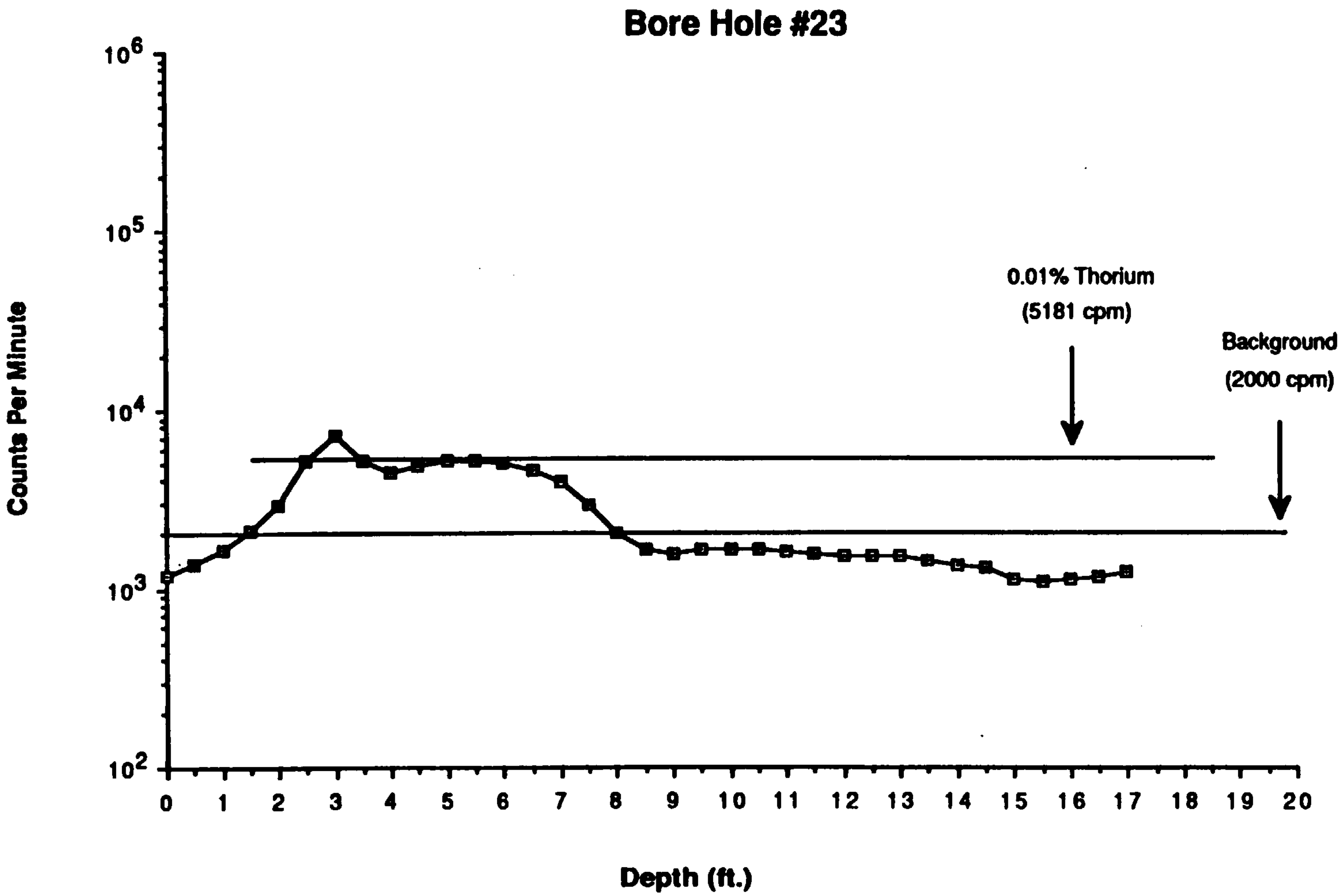
Bore Hole #20
Counts Per Minute
10^6
10^5
10^4
10^3
10^2
0.01% Thorium
(5181 cpm)
Background
(2000 cpm)
0 1 2 3 4 5 6 7 8 9 10 11 12 13 14 15 16 17 18 19 20
Depth (ft.)

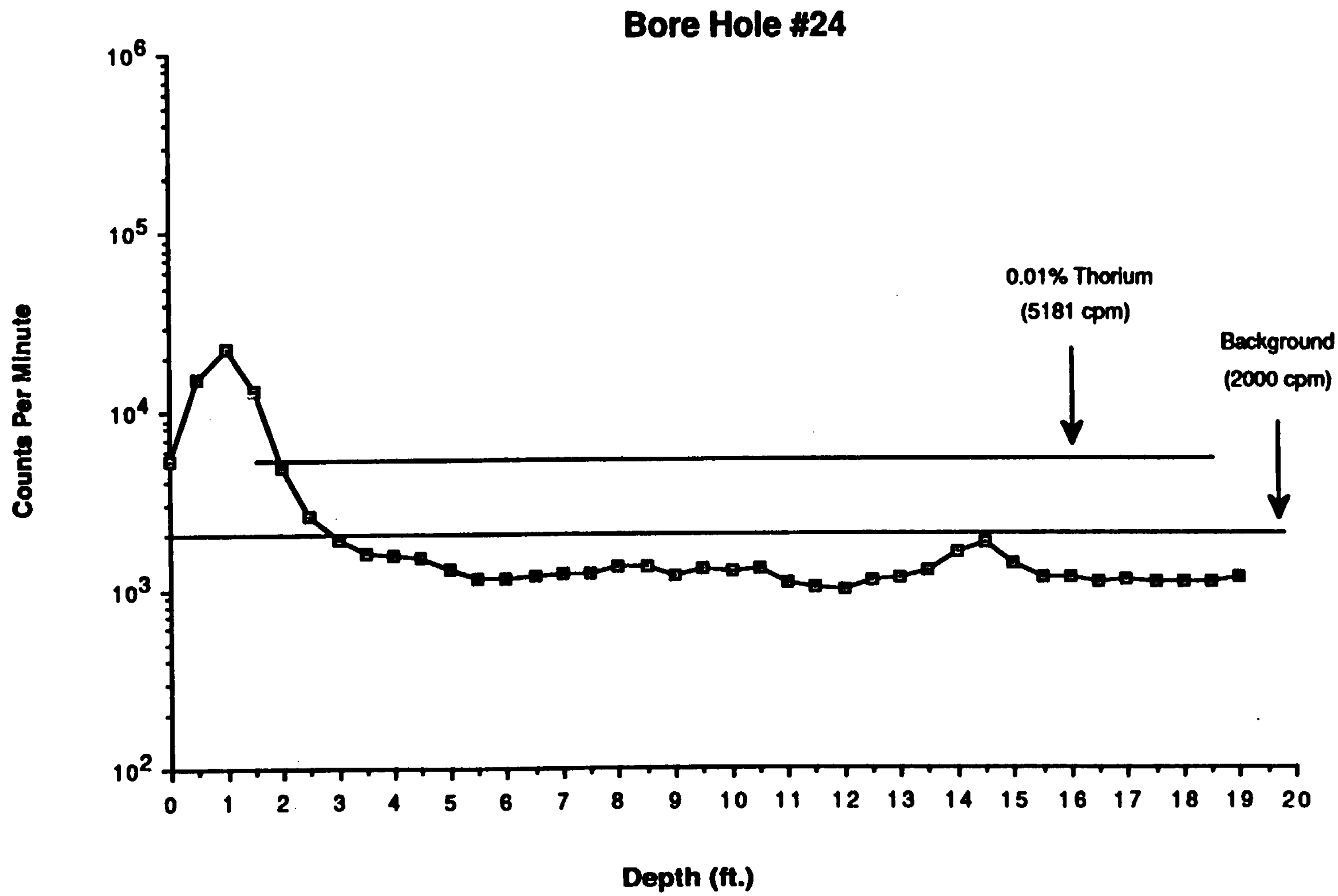


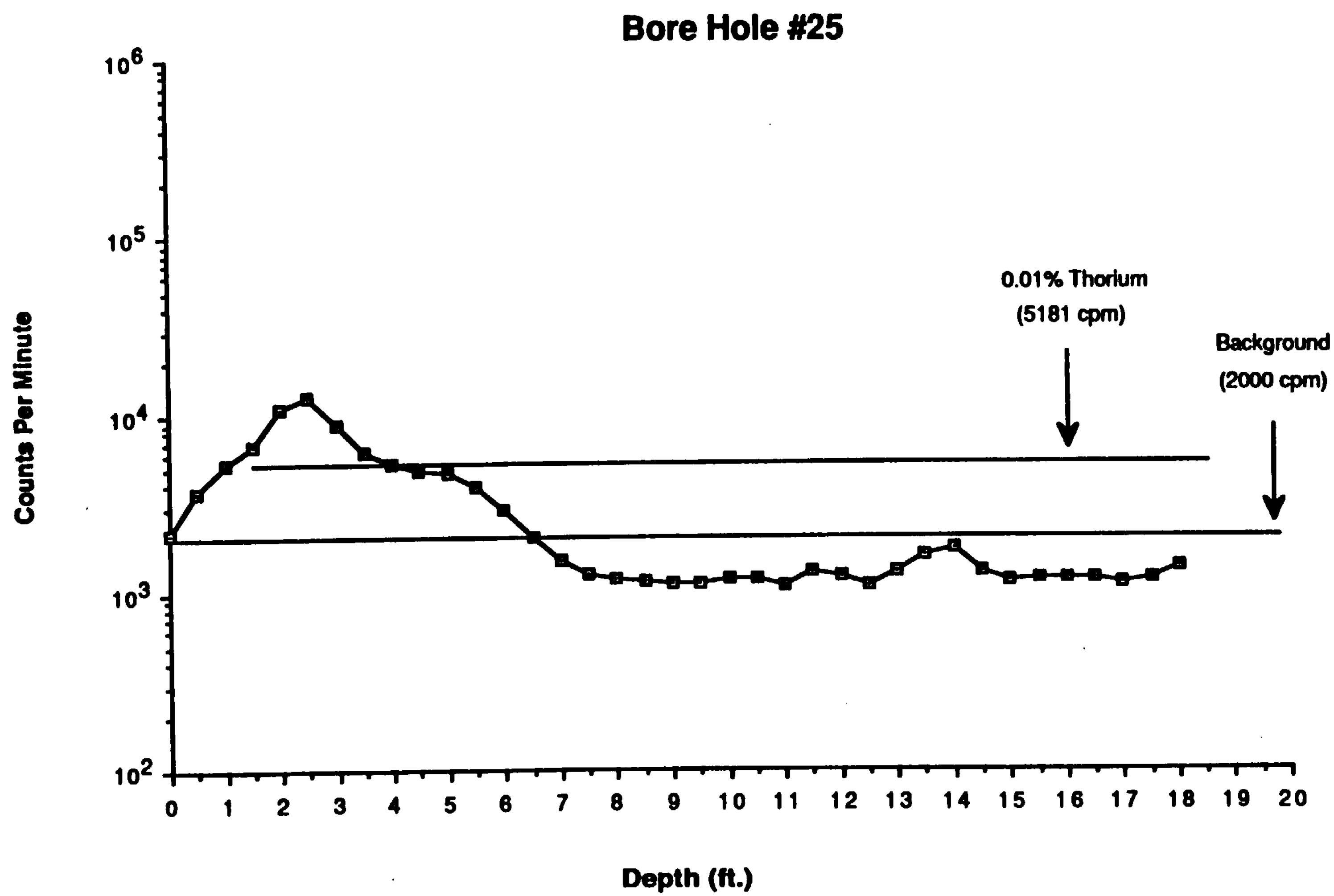
Bore Hole #21
Counts Per Minute
$10^6$
$10^5$
$10^4$
$10^3$
$10^2$
0.01% Thorium
(5181 cpm)
Background
(2000 cpm)
0 1 2 3 4 5 6 7 8 9 10 11 12 13 14 15 16 17 18 19 20
Depth (ft.)

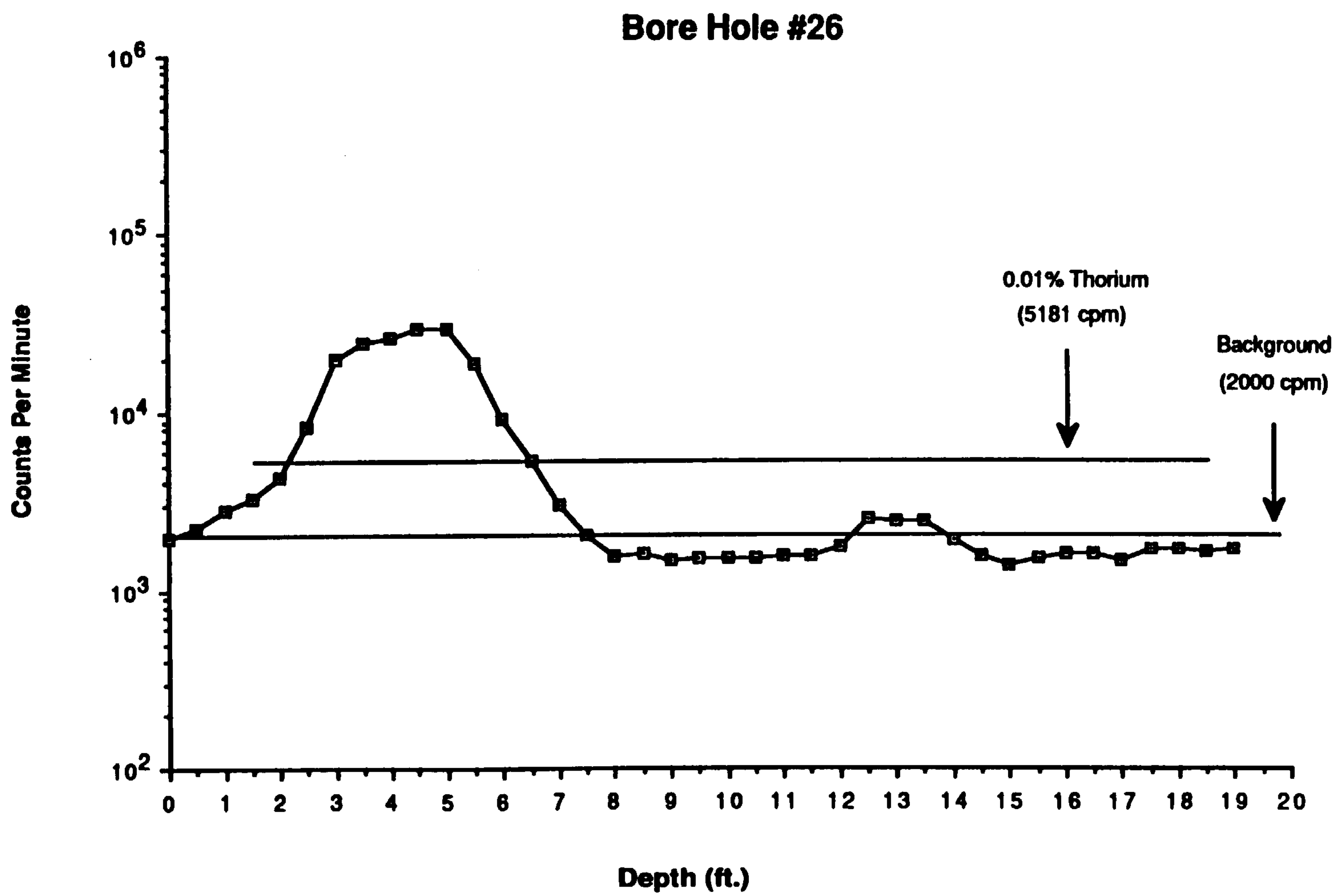


Bore Hole #22
Counts Per Minute
$10^6$
$10^5$
$10^4$
$10^3$
$10^2$
0.01% Thorium
(5181 cpm)
Background
(2000 cpm)
0 1 2 3 4 5 6 7 8 9 10 11 12 13 14 15 16 17 18 19 20
Depth (ft.)

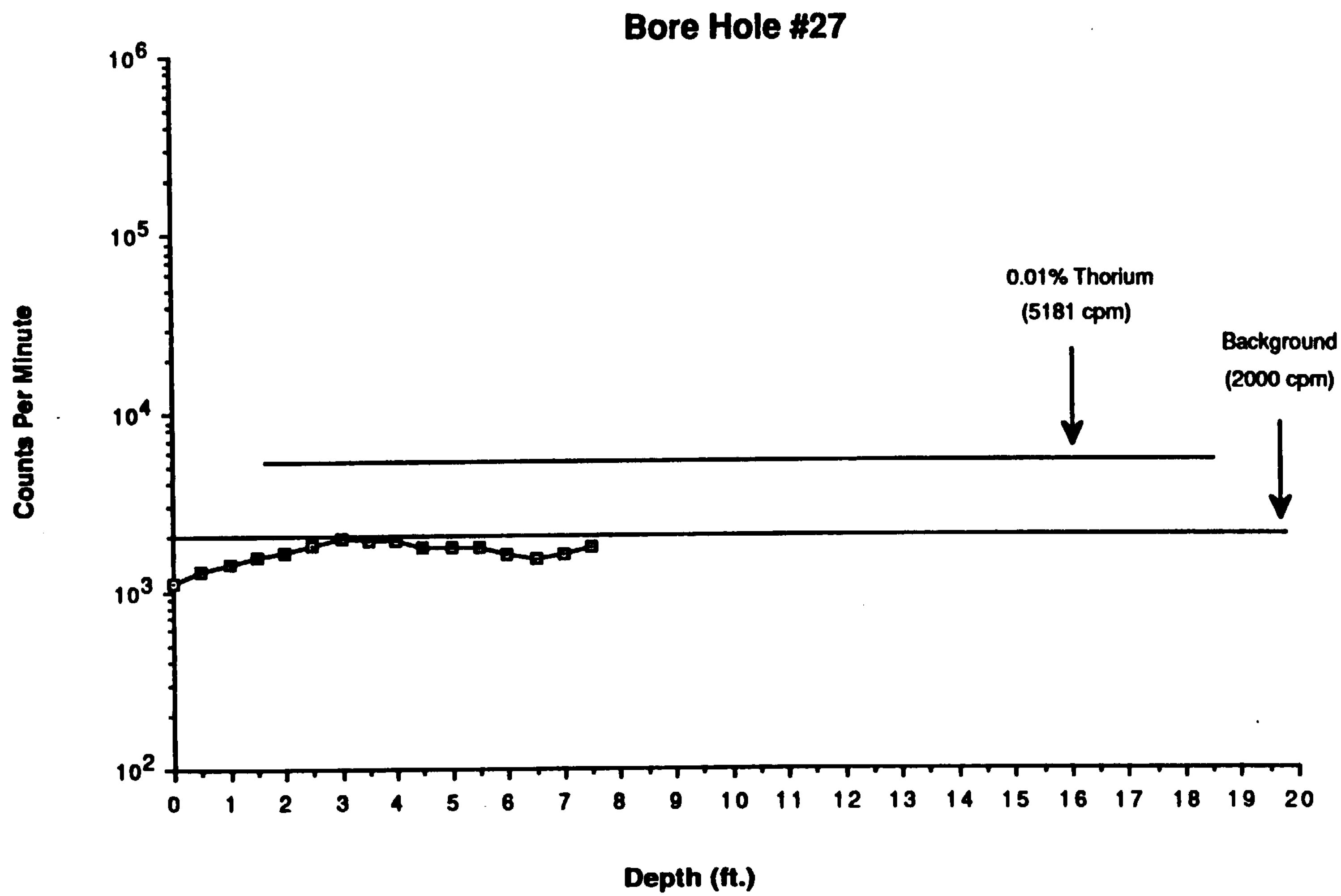

Bore Hole #23
Counts Per Minute
$10^6$
$10^5$
$10^4$
$10^3$
$10^2$
0.01% Thorium
(5181 cpm)
Background
(2000 cpm)
0 1 2 3 4 5 6 7 8 9 10 11 12 13 14 15 16 17 18 19 20
Depth (ft.)


Bore Hole #24
Counts Per Minute
$10^6$
$10^5$
$10^4$
$10^3$
$10^2$
0.01% Thorium
(5181 cpm)
Background
(2000 cpm)
0 1 2 3 4 5 6 7 8 9 10 11 12 13 14 15 16 17 18 19 20
Depth (ft.)

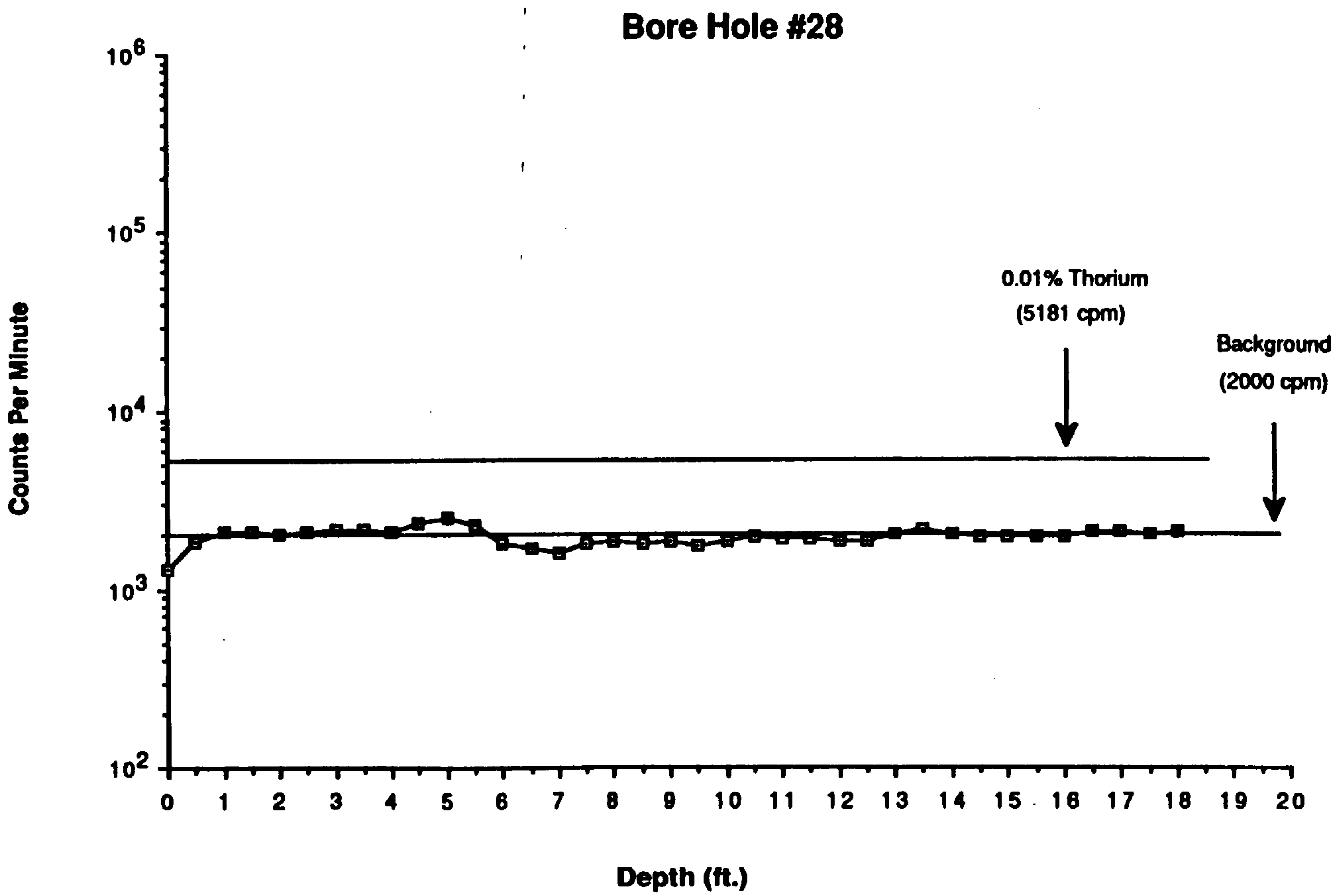

Bore Hole #25
Counts Per Minute
$10^6$
$10^5$
$10^4$
$10^3$
$10^2$
0.01% Thorium
(5181 cpm)
Background
(2000 cpm)
0 1 2 3 4 5 6 7 8 9 10 11 12 13 14 15 16 17 18 19 20
Depth (ft.)



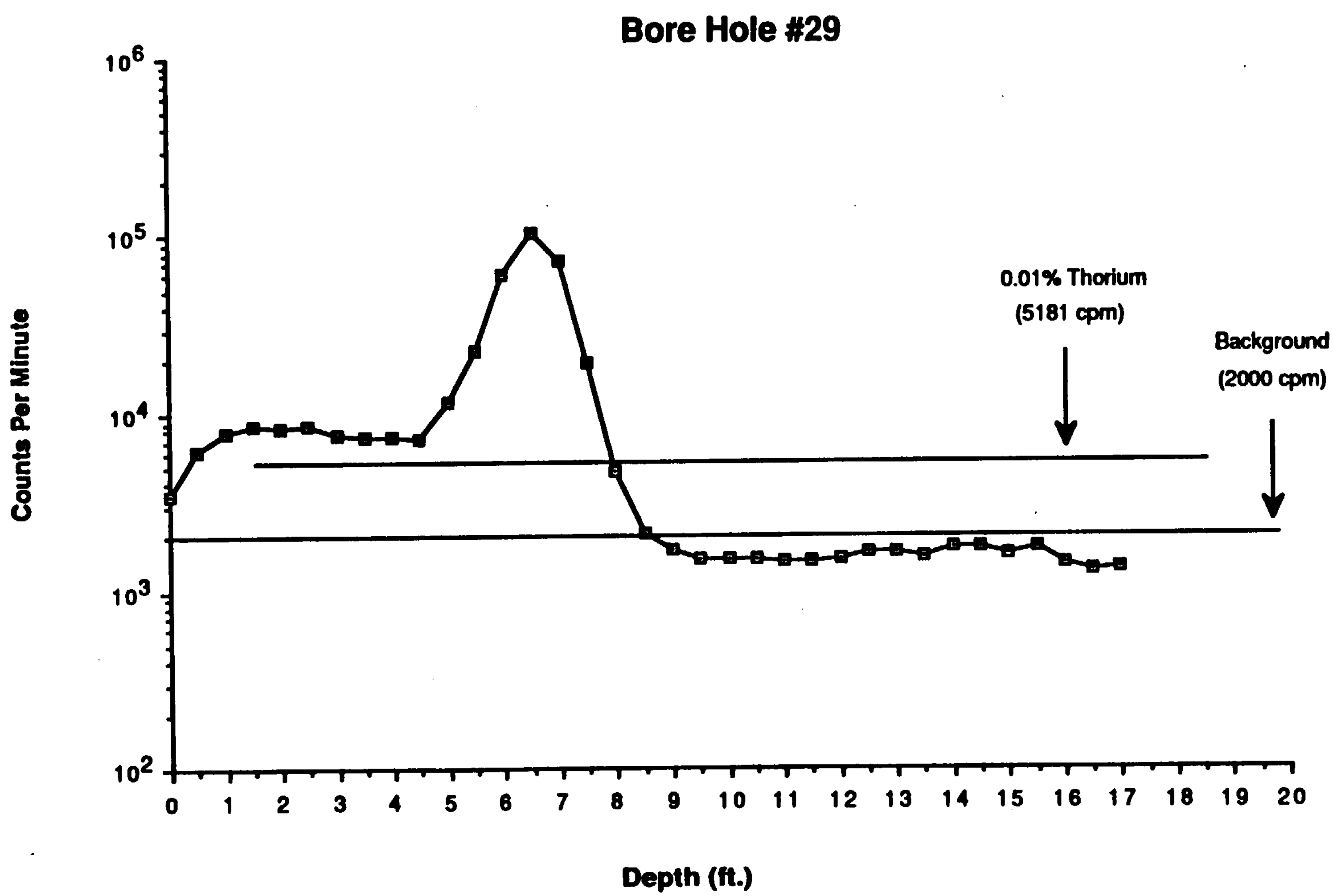
Bore Hole #26
Counts Per Minute
$10^6$
$10^5$
$10^4$
$10^3$
$10^2$
0.01% Thorium
(5181 cpm)
Background
(2000 cpm)
0 1 2 3 4 5 6 7 8 9 10 11 12 13 14 15 16 17 18 19 20
Depth (ft.)

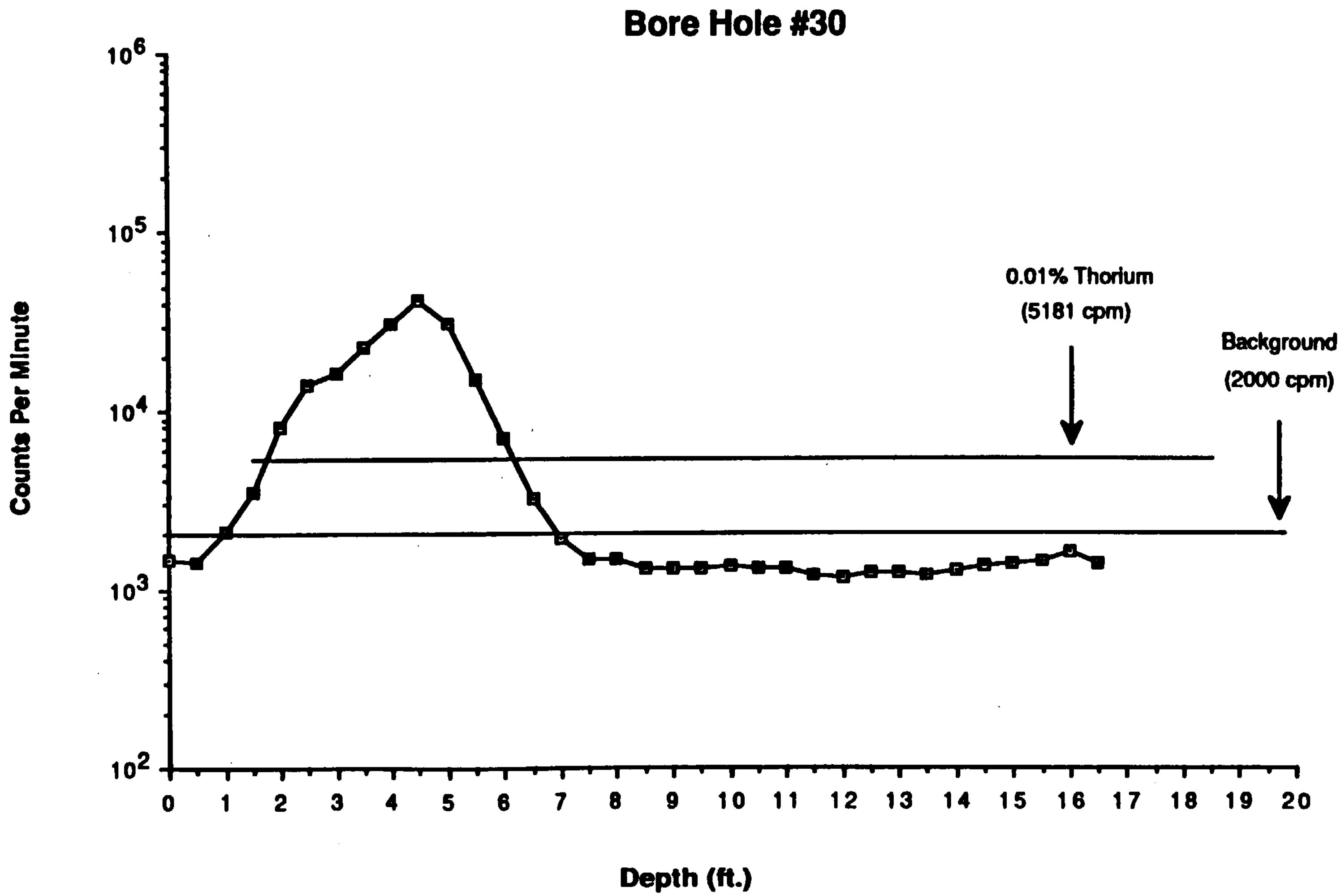


Bore Hole #27
Counts Per Minute
10^6
10^5
10^4
10^3
10^2
0.01% Thorium
(5181 cpm)
Background
(2000 cpm)
0 1 2 3 4 5 6 7 8 9 10 11 12 13 14 15 16 17 18 19 20
Depth (ft.)

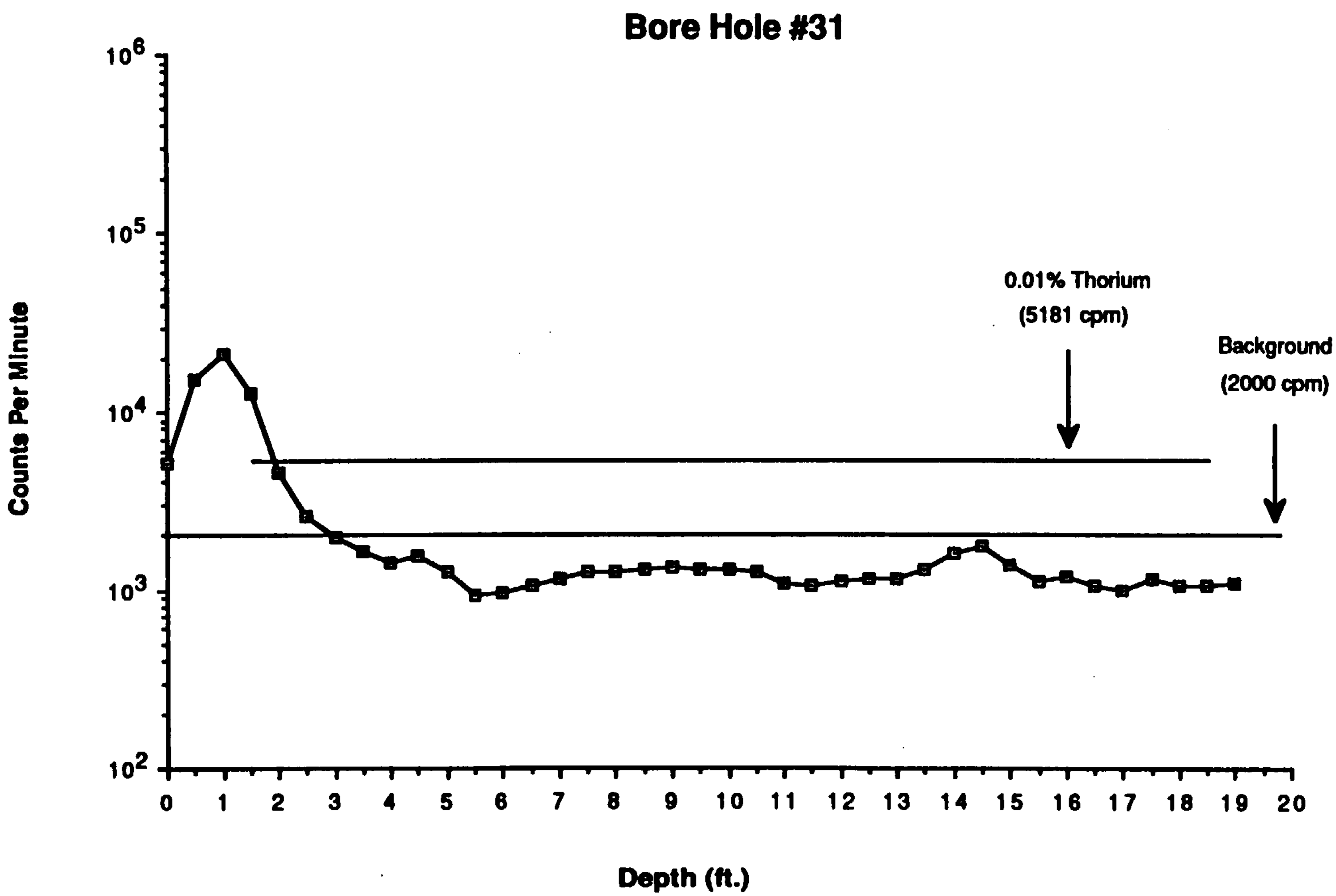


Bore Hole #28
Counts Per Minute
$10^6$
$10^5$
$10^4$
$10^3$
$10^2$
0.01% Thorium
(5181 cpm)
Background
(2000 cpm)
0 1 2 3 4 5 6 7 8 9 10 11 12 13 14 15 16 17 18 19 20
Depth (ft.)


Bore Hole #29
Counts Per Minute
$10^6$
$10^5$
$10^4$
$10^3$
$10^2$
0.01% Thorium
(5181 cpm)
Background
(2000 cpm)
0 1 2 3 4 5 6 7 8 9 10 11 12 13 14 15 16 17 18 19 20
Depth (ft.)

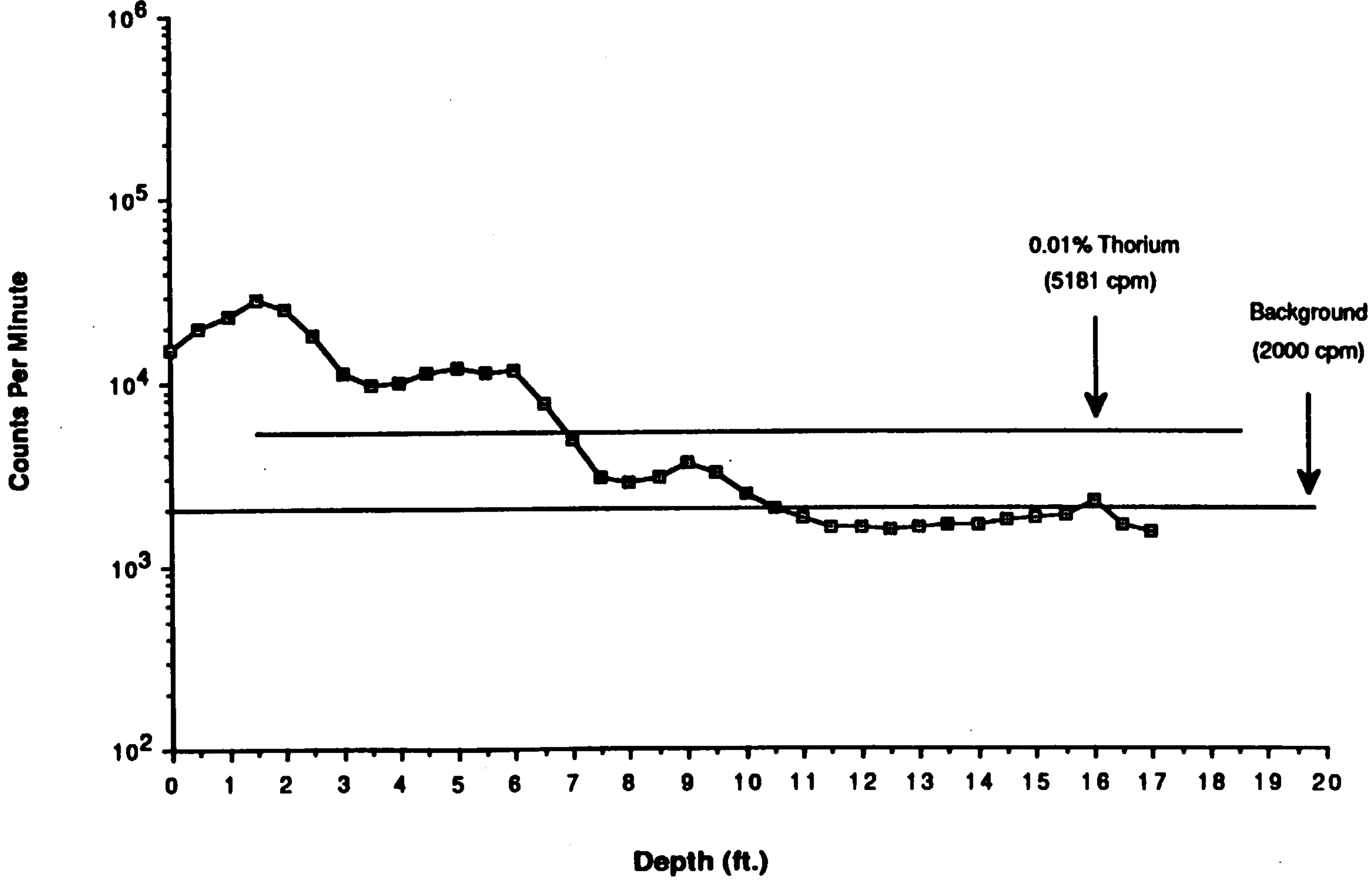


Bore Hole #30
Counts Per Minute
$10^6$
$10^5$
$10^4$
$10^3$
$10^2$
0.01% Thorium
(5181 cpm)
Background
(2000 cpm)
0 1 2 3 4 5 6 7 8 9 10 11 12 13 14 15 16 17 18 19 20
Depth (ft.)

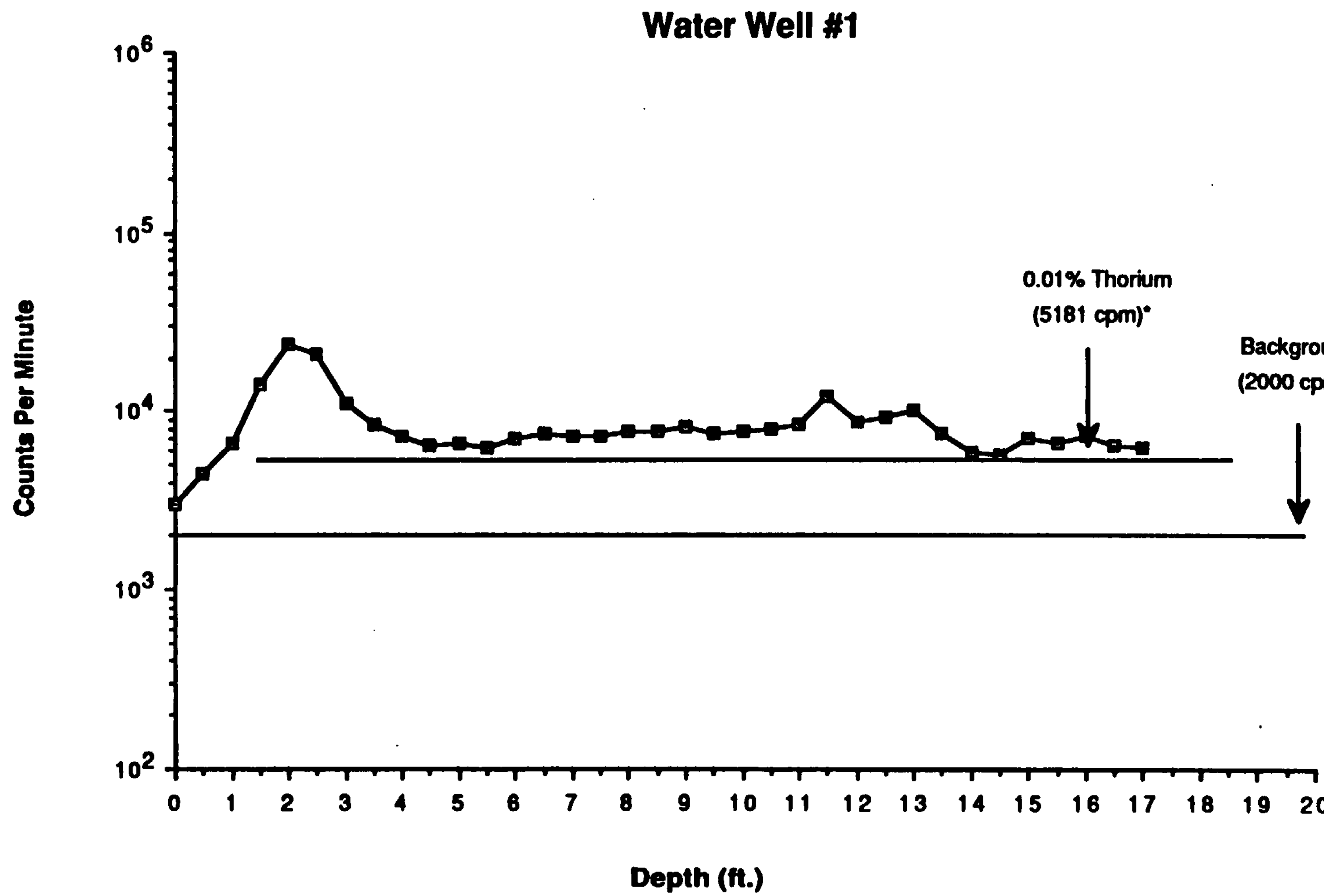


Bore Hole #31
Counts Per Minute
10^6
10^5
10^4
10^3
10^2
0.01% Thorium
(5181 cpm)
Background
(2000 cpm)
0 1 2 3 4 5 6 7 8 9 10 11 12 13 14 15 16 17 18 19 20
Depth (ft.)

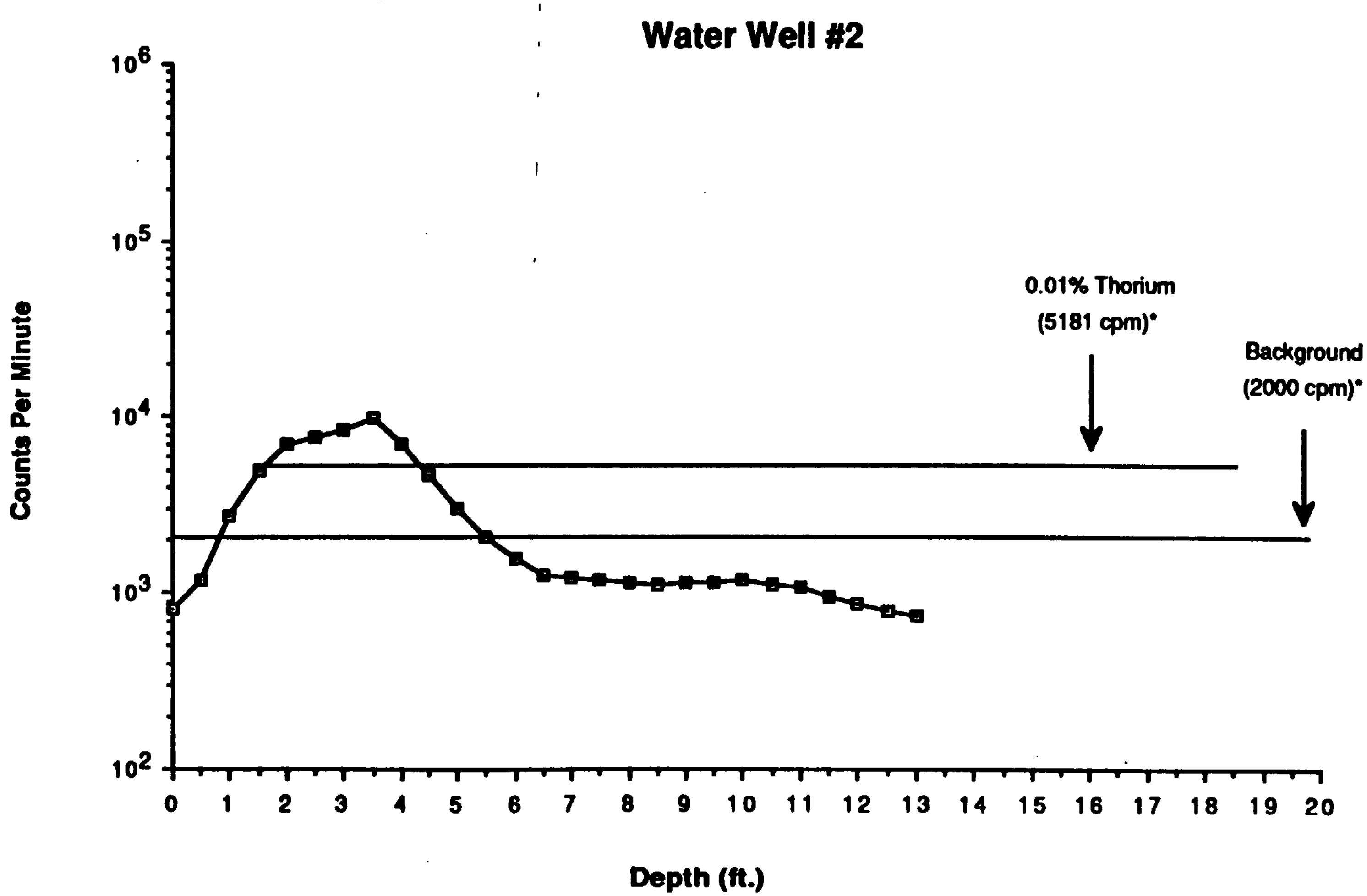
## Bore Hole #32



Bore Hole #32
Counts Per Minute
$10^6$
$10^5$
$10^4$
$10^3$
$10^2$
0.01% Thorium
(5181 cpm)
Background
(2000 cpm)
0 1 2 3 4 5 6 7 8 9 10 11 12 13 14 15 16 17 18 19 20
Depth (ft.)

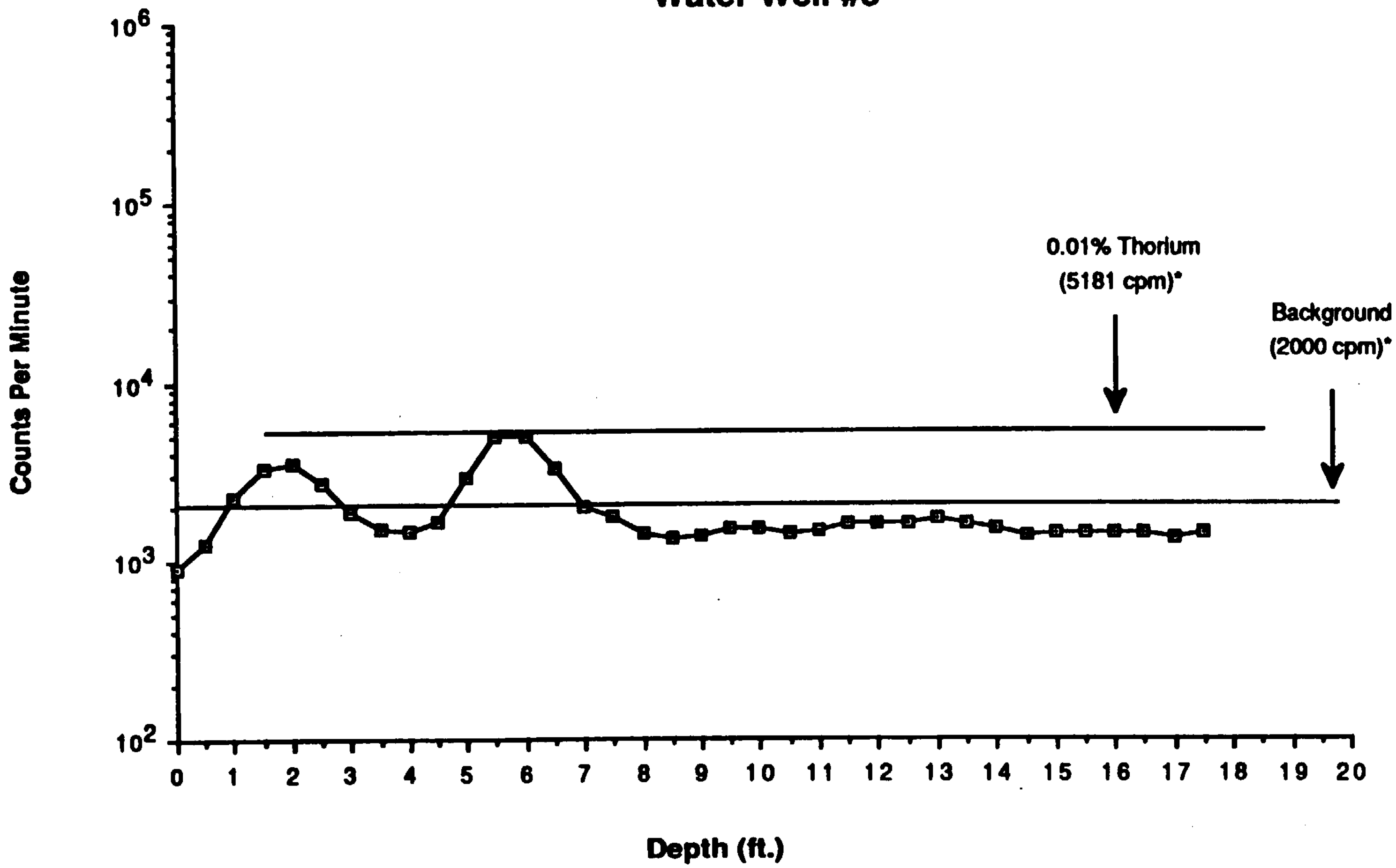



*based on calibration coefficient for boreholes

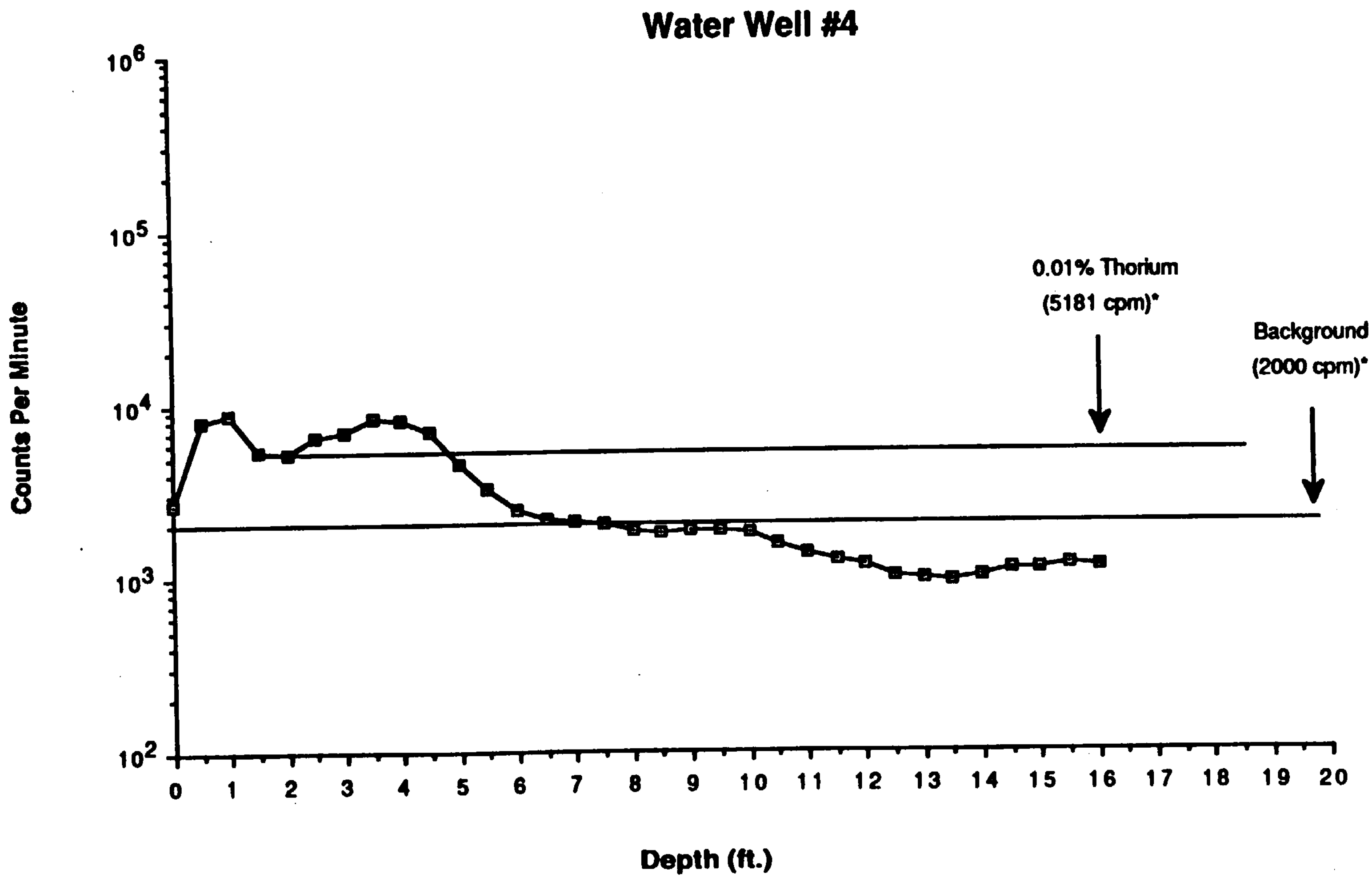



*based on calibration coefficient for boreholes

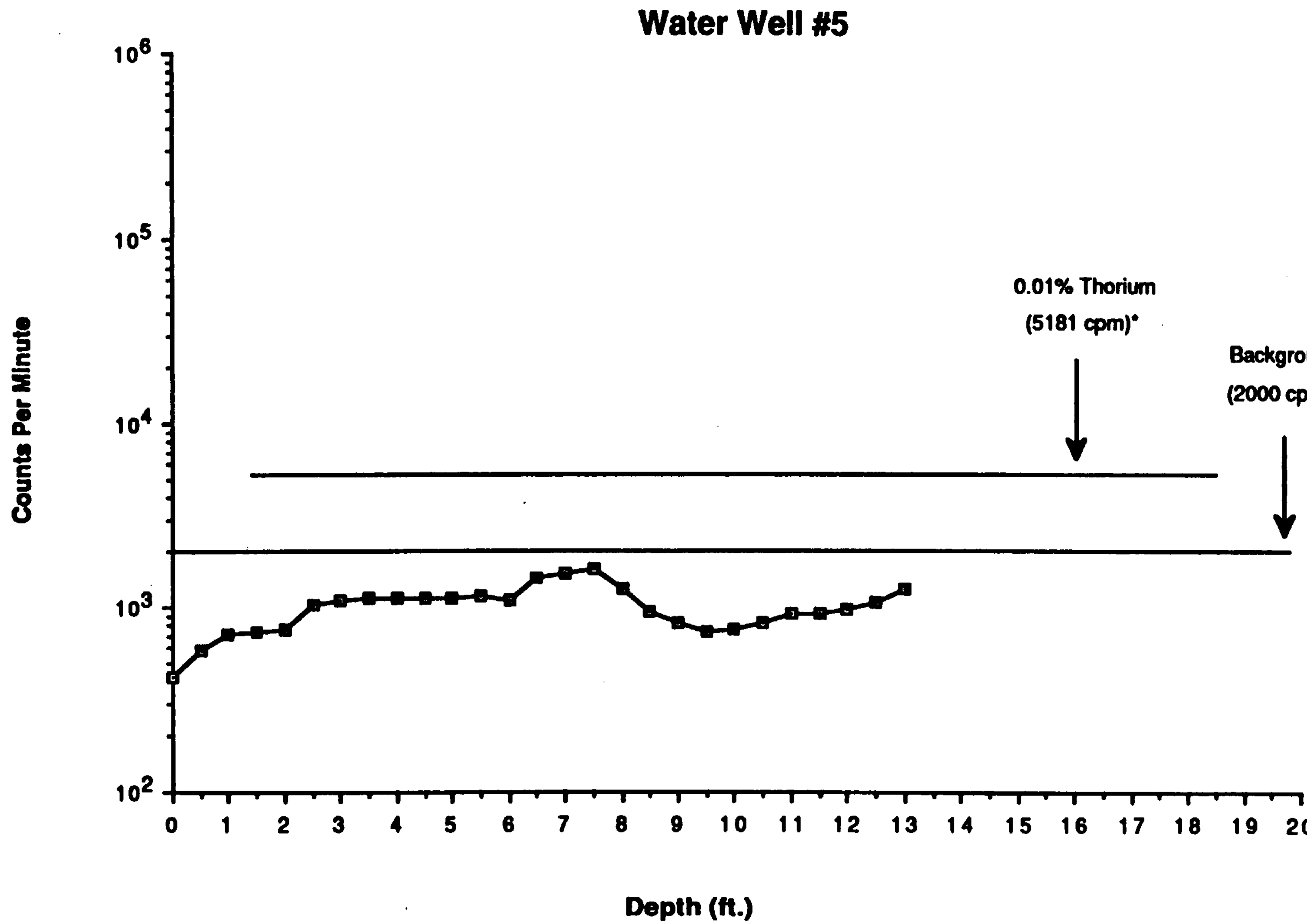
# Water Well #3




*based on calibration coefficient for boreholes




*based on calibration coefficient for boreholes




*based on calibration coefficient for boreholes

# Appendix D: Driller's Logs.

TERRA TESTING, INC.
WASHINGTON, PA. 15301

# TEST BORING RECORD

WATER LEVELS:
- BEFORE USING WATER ... -
- AT COMPLETION ... - ... 24 hrs ... n/a
- ENCOUNTERED ... 14.0'
- LOSS ... -
- OTHER ... -

CASING HAMMER WT. ... - lbs. DROP - in.
SAMPLER HAMMER WT. ... - lbs. DROP - in.
CASING SIZE ... - in. SPOON SIZE ... - in.
HOLLOW STEM AUGERS 3-1/4" I.D.
RIG USED ... CME 55
DRILLER ... W. Everett ... HELPER ... D. Novotny

PROJECT: Molycorp, Inc.
Washington, PA

CLIENT ... MOLYCORP, INC.
CLIENT PROJECT NO. ...
SURFACE ELEVATION ...
STARTED ... 8-1-90 ... COMPLETED ... 8-1-90
JOB NO. ... 90666
HOLE NO. ... 1 ... SHEET ... 1 ... OF ... 1

| DEPTH (feet) 0.0 | | SAMPLE NO. | HAMMER BLOWS ON SAMPLER/6" 1st | 2nd | 3rd | CASING BLOWS PER FT. | ELEV. (feet) | MATERIAL DEPTH (feet) 0.0 | DESCRIPTION |
|---|---|---|---|---|---|---|---|---|---|
| | AUGERED (0.0–20.0) | | | | | | | 2.0 | Brown silty clay with rock and slag fragments-humid. |
| | | | | | | | | 17.5 | Black and gray silty clay-moist to wet. |
| 20.0 | | | | | | | | 20.0 | Gray weathered claystone-dry. |
| | | | | | | | | | BOTTOM OF BORING @ 20.0' |
| | | | | | | | | | NOTE: INSTALLED 20' OF 2" Sch. 40 F.J. RISER. |

TERRA TESTING, INC.
WASHINGTON, PA. 15301

# TEST BORING RECORD

WATER LEVELS:
(B)EFORE USING WATER ... -
(C)OMPLETION ... 8.7' .. 24 hrs .... n/a
ENCOUNTERED ... 11.0'
LOSS ... -
OTHER ... -
CASING HAMMER WT. ... - lbs. DROP - in.
SAMPLER HAMMER WT. - lbs. DROP - in.
CASING SIZE ... - in. SPOON SIZE ... - in.
HOLLOW STEM AUGERS ... 3-1/4" I.D.
RIG USED ... CME 45-C
DRILLER W. Everett ... HELPER D. Novotny

PROJECT: Molycorp, Inc.
Washington, PA

CLIENT ... MOLYCORP, INC.
CLIENT PROJECT NO. ...
SURFACE ELEVATION ...
STARTED 8-30-90 ... COMPLETED 8-30-90
JOB NO. 90690
HOLE NO. 2 ... SHEET 1 ... OF 1

| (DEP)TH (fe)et | | SAMPLE NO. | HAMMER BLOWS ON SAMPLER/6" 1st | 2nd | 3rd | CASING BLOWS PER FT. | ELEV. (feet) | MATERIAL DEPTH (feet) 0.0 | DESCRIPTION | DEPTH DRILLED (feet) | CO(RE) RE(C.) |
|---|---|---|---|---|---|---|---|---|---|---|---|
| | AUG(ER) | | | | | | | | Slag and limestone boulders-moist. | | |
| | | | | | | | | 6.0 | | | |
| | | | | | | | | | Gray silty clay with rock fragments-wet. | | |
| .0 | | | | | | | | 19.0 | | | |
| | | | | | | | | | BOTTOM OF BORING @ 19.0' | | |
| | | | | | | | | | NOTE: INSTALLED 20' OF 2" SCH 40 F.J. PVC RISER. | | |

TERRA TESTING, INC.
WASHINGTON, PA. 15301

# TEST BORING RECORD

WATER LEVELS:
BEFORE USING WATER ... -
AT COMPLETION ... - ... 24 hrs ... n/a
ENCOUNTERED ... 14.0'
LOSS ... -
OTHER ... -
CASING HAMMER WT. ... - lbs. DROP - in.
SAMPLER HAMMER WT. ... - lbs. DROP - in.
CASING SIZE ... - in. SPOON SIZE ... - in.
HOLLOW STEM AUGERS ... 3-1/4" I.D.
RIG USED ... CME 55
DRILLER ... W. Everett ... HELPER ... D. Novotny

PROJECT: Molycorp, Inc.
Washington, PA

CLIENT: MOLYCORP, INC.
CLIENT PROJECT NO.
SURFACE ELEVATION
STARTED 8-1-90 COMPLETED 8-1-90
JOB NO. 90666
HOLE NO. 3 SHEET 1 OF 1

| | SAMPLE NO. | HAMMER BLOWS ON SAMPLER/6" 1st | 2nd | 3rd | CASING BLOWS PER FT. | ELEV. (feet) | MATERIAL DEPTH (feet) 0.0 | DESCRIPTION | DEPTH DRILLED (feet) | CORE REC'Y (feet) |
|---|---|---|---|---|---|---|---|---|---|---|
| AUGER | | | | | | | 2.0 | Gray silty clay with rock and slag fragments-humid. | | |
| | | | | | | | 5.0 | Gray silty clay-wet, soft. | | |
| | | | | | | | 12.0 | Brown silty clay with rock fragments-moist. | | |
| | | | | | | | 18.0 | Brown silty clay-wet, soft. | | |
| | | | | | | | 18.2 | Gray claystone-dry. | | |
| | | | | | | | | BOTTOM OF BORING @ 18.2' | | |
| | | | | | | | | NOTE: INSTALLED 20' of 2" Sch. 40 F.J. RISER. | | |

TERRA TESTING, INC.
WASHINGTON, PA. 15301

# TEST BORING RECORD

WATER LEVELS:
WHILE USING WATER -
AT COMPLETION - 24 hrs. n/a
ENCOUNTERED 12.0'
LOSS -
OTHER -
CASING HAMMER WT. - lbs. DROP - in.
SAMPLER HAMMER WT. - lbs. DROP - in.
CASING SIZE - in. SPOON SIZE - in.
HOLLOW STEM AUGERS 3-1/4" I.D.
RIG USED CME 55
DRILLER W. Everett HELPER D. Novotny

PROJECT: Molycorp, inc.
Washington, PA
CLIENT MOLYCORP, INC.
CLIENT PROJECT NO.
SURFACE ELEVATION
STARTED 8-1-90 COMPLETED 8-1-90
JOB NO. 90666
HOLE NO. 4 SHEET 1 OF 1

| DEPTH | | SAMPLE NO. | HAMMER BLOWS ON SAMPLER/6" 1st | 2nd | 3rd | CASING BLOWS PER FT. | ELEV. (feet) | MATERIAL DEPTH (feet) 0.0 | DESCRIPTION | DEPTH DRILLED (feet) | CORE REC. (feet) |
|---|---|---|---|---|---|---|---|---|---|---|---|
| | AUGERED | | | | | | | | Brown to gray sandy clay-moist. | | |
| | | | | | | | | 3.0 | | | |
| | | | | | | | | | Brown and gray silty clay-moist to wet. | | |
| | | | | | | | | 18.0 | | | |
| | | | | | | | | 18.3 | Gray claystone-dry. | | |
| | | | | | | | | | BOTTOM OF BORING @ 18.3' | | |
| | | | | | | | | | NOTE: INSTALLED 20' of 2" Sch. 40 F.J. RISER. | | |

TERRA TESTING, INC.
WASHINGTON, PA. 15301

# TEST BORING RECORD

WATER LEVELS:
B[illegible] USING WATER -
AT COMPLETION - 24 hrs n/a
ENCOUNTERED 8.0'
LOSS -
OTHER -
CASING HAMMER WT. - lbs. DROP - in.
SAMPLER HAMMER WT. - lbs. DROP - in.
CASING SIZE - in. SPOON SIZE - in.
HOLLOW STEM AUGERS 3-1/4" I.D.
RIG USED CME 55
DRILLER W. Everett HELPER D. Novotny

PROJECT: Molycorp, Inc
Washington, PA
CLIENT MOLYCORP, INC.
CLIENT PROJECT NO.
SURFACE ELEVATION
STARTED 8-1-90 COMPLETED 8-1-90
JOB NO. 90666
HOLE NO. 5 SHEET 1 OF 1

| | SAMPLE NO. | HAMMER BLOWS ON SAMPLER/6" 1st | 2nd | 3rd | CASING BLOWS PER FT. | ELEV. (feet) | MATERIAL DEPTH (feet) 0.0 | DESCRIPTION | DEPTH DRILLED (feet) | CORE REC'Y (feet) |
|---|---|---|---|---|---|---|---|---|---|---|
| AUGERED | | | | | | | | Brown to gray sandy clay-moist. | | |
| | | | | | | | 3.0 | Gray silty clay with rock fragments-wet. | | |
| | | | | | | | 18.0 | Gray claystone-dry. | | |
| | | | | | | | 18.3 | BOTTOM OF BORING @ 18.3' | | |
| | | | | | | | | NOTE: INSTALLED 20' OF 2" Sch. 40 F.J. RISER. | | |

TERRA TESTING, INC.
WASHINGTON, PA. 15301

# TEST BORING RECORD

WATER LEVELS:
BEFORE USING WATER -
AT COMPLETION - 24 hrs. n/a
ENCOUNTERED 10.0'
LOSS -
OTHER -
CASING HAMMER WT. - lbs. DROP - in.
SAMPLER HAMMER WT. - lbs. DROP - in.
CASING SIZE - in. SPOON SIZE - in.
HOLLOW STEM AUGERS 3-1/4" I.D.
RIG USED CME 55
DRILLER W. Everett HELPER D. Novotny

PROJECT: Molycorp, Inc.
Washington, PA

CLIENT MOLYCORP, INC.
CLIENT PROJECT NO.
SURFACE ELEVATION
STARTED 8-1-90 COMPLETED 8-1-90
JOB NO. 90666
HOLE NO. 6 SHEET 1 OF 1

| | SAMPLE NO. | HAMMER BLOWS ON SAMPLER/6" 1st | 2nd | 3rd | CASING BLOWS PER FT. | ELEV. (feet) | MATERIAL DEPTH (feet) 0.0 | DESCRIPTION | DEPTH DRILLED (feet) | CORE REC'Y (feet) |
|---|---|---|---|---|---|---|---|---|---|---|
| AUGERED | | | | | | | 2.0 | Gray slag and gravel-humid with some clay. | | |
| | | | | | | | 13.0 | Gray silty clay with rock fragments-humid to wet. | | |
| | | | | | | | 20.0 | Brown and gray silty clay-wet. | | |
| | | | | | | | | BOTTOM OF BORING @ 20.0' | | |
| | | | | | | | | NOTE: INSTALLED 20' OF 2" SCH. 40 F. J. RISER. | | |

TERRA TESTING, INC.
WASHINGTON, PA. 15301

# TEST BORING RECORD

WATER LEVELS:
- BEFORE USING WATER ..... -
- AT COMPLETION ..... - ..... 24 hrs ..... n/a
- ENCOUNTERED ..... 8.0'
- LOSS ..... -
- OTHER ..... -

CASING HAMMER WT. ..... - ..... lbs. DROP - ..... in.
SAMPLER HAMMER WT. ..... - ..... lbs. DROP - ..... in.
CASING SIZE ..... - in. SPOON SIZE ..... - ..... in.
HOLLOW STEM AUGERS ..... 3-1/4" ..... I.D.
RIG USED ..... CME 55
DRILLER ..... W. Everett ..... HELPER ..... D. Novotny

PROJECT: Molycorp, Inc.
Washington, PA

CLIENT ..... MOLYCORP, INC.
CLIENT PROJECT NO. .....
SURFACE ELEVATION .....
STARTED ..... 8-1-90 ..... COMPLETED ..... 8-1-90
JOB NO. ..... 90666
HOLE NO. ..... 7 ..... SHEET ..... 1 ..... OF ..... 1

| | SAMPLE NO. | HAMMER BLOWS ON SAMPLER/6" 1st | 2nd | 3rd | CASING BLOWS PER FT. | ELEV. (feet) | MATERIAL DEPTH (feet) 0.0 | DESCRIPTION | DEPTH DRILLED (feet) | CORE REC'Y (feet) |
|---|---|---|---|---|---|---|---|---|---|---|
| AUGERED | | | | | | | 2.0 | Gray slag and gravel with some clay-humid. | | |
| | | | | | | | 18.5 | Gray silty clay-moist to wet. | | |
| | | | | | | | 20.0 | Gray claystone-dry. | | |

BOTTOM OF BORING @ 20.0'

NOTE: INSTALLED 20' OF 2" SCH. 40
F. J. RISER.

TERRA TESTING, INC.
WASHINGTON, PA. 15301

# TEST BORING RECORD

WATER LEVELS:
BEFORE USING WATER ... -
AT COMPLETION ... - ... 24 hrs ... n/a
ENCOUNTERED ... 15.5'
LOSS ... -
OTHER ... -
CASING HAMMER WT. ... - lbs. DROP - in.
SAMPLER HAMMER WT. ... - lbs. DROP - in.
CASING SIZE ... - in. SPOON SIZE ... - in.
HOLLOW STEM AUGERS ... 3-1/4" I.D.
RIG USED ... CME 55
DRILLER ... W. Everett ... HELPER ... D. Novotny

PROJECT: Molycorp, Inc.
Washington, PA

CLIENT ... MOLYCORP, INC.
CLIENT PROJECT NO. ...
SURFACE ELEVATION ...
STARTED ... 8-1-90 ... COMPLETED ... 8-1-90
JOB NO. ... 90666
HOLE NO. ... 8 ... SHEET ... 1 ... OF ... 1

| SAMPLE NO. | HAMMER BLOWS ON SAMPLER/6" 1st | 2nd | 3rd | CASING BLOWS PER FT. | ELEV. (feet) | MATERIAL DEPTH (feet) 0.0 | DESCRIPTION | DEPTH DRILLED (feet) | CORE REC. (feet) |
|---|---|---|---|---|---|---|---|---|---|
| | | | | | | 3.0 | Gravel and slag with some clay-humid. | | |
| | | | | | | 17.6 | Gray silty clay with rock fragments-moist to wet. | | |
| | | | | | | 19.5 | Gray claystone-dry. | | |

AUGER (0.0–19.5)

BOTTOM OF BORING @ 19.5'

NOTE: INSTALLED 20' OF 2" SCH. 40
F.J. RISER.

TERRA TESTING, INC.
WASHINGTON, PA. 15301

# TEST BORING RECORD

WATER LEVELS:
- [BEFO]RE USING WATER ... -
- [CO]MPLETION ... - ..... 24 hrs ..... n/a
- ENCOUNTERED ... 15.0'
- LOSS ... -
- OTHER ... -

CASING HAMMER WT. ... - ... lbs. DROP - ... in.
SAMPLER HAMMER WT. - ... lbs. DROP - ... in.
CASING SIZE ... - in. SPOON SIZE ... - ... in.
HOLLOW STEM AUGERS 3-1/4" ... I.D.
RIG USED ... CME 55
DRILLER W. Everett ... HELPER D. Novotny

PROJECT: Molycorp, Inc.
Washington, PA

CLIENT: MOLYCORP, INC.
CLIENT PROJECT NO. ...
SURFACE ELEVATION ...
STARTED 8-1-90 ... COMPLETED 8-1-90
JOB NO. 90666
HOLE NO. 9 ... SHEET 1 ... OF 1

| [DEPT]H | | SAMPLE NO. | HAMMER BLOWS ON SAMPLER/6" 1st | 2nd | 3rd | CASING BLOWS PER FT. | ELEV. (feet) | MATERIAL DEPTH (feet) 0.0 | DESCRIPTION | DEPTH DRILLED (feet) | CORE REC (feet) |
|---|---|---|---|---|---|---|---|---|---|---|---|
| | AUGERED | | | | | | | 3.0 | Gray slag and gravel with some clay-humid. | | |
| | | | | | | | | 17.0 | Gray silty clay with rock fragments-moist to wet. | | |
| | | | | | | | | 20.0 | Claystone-dry. | | |

BOTTOM OF BORING @ 20.0'

NOTE: INSTALLED 20' OF 2" SCH 40
F. J. RISER.

TERRA TESTING, INC.
WASHINGTON, PA. 15301

# TEST BORING RECORD

WATER LEVELS:
BEFORE USING WATER ... -
AT COMPLETION ... - ... 24 hrs ... n/a
ENCOUNTERED ... 18.5'
LOSS ... -
OTHER ... -
CASING HAMMER WT. ... - ... lbs. DROP - ... in.
SAMPLER HAMMER WT. - ... lbs. DROP - ... in.
CASING SIZE ... - ... in. SPOON SIZE ... - ... in.
HOLLOW STEM AUGERS ... 3-1/4" I.D.
RIG USED ... CME 55
DRILLER ... W. Everett ... HELPER ... D. Novotny

PROJECT: Molycorp, Inc.
Washington, PA

CLIENT ... MOLYCORP, INC.
CLIENT PROJECT NO. ...
SURFACE ELEVATION ...
STARTED ... 8-1-90 ... COMPLETED ... 8-1-90
JOB NO. ... 90666
HOLE NO. ... 10 ... SHEET ... 1 ... OF ... 1

| DEPTH (feet) 0.0 | | SAMPLE NO. | HAMMER BLOWS ON SAMPLER/6" 1st | 2nd | 3rd | CASING BLOWS PER FT | ELEV. (feet) | MATERIAL DEPTH (feet) 0.0 | DESCRIPTION | DEPTH DRILLED (feet) |
|---|---|---|---|---|---|---|---|---|---|---|
| | AUGERED | | | | | | | | Brown silty clay with rock fragments-moist. | |
| | | | | | | | | 9.0 | | |
| | | | | | | | | | Gray silty clay-moist. | |
| | | | | | | | | 18.5 | | |
| | | | | | | | | | Gray claystone-dry. | |
| 20.0 | | | | | | | | 20.0 | | |
| | | | | | | | | | BOTTOM OF BORING @ 20.0' | |
| | | | | | | | | | NOTE: INSTALLED 20.0' of 2" SCH 40 F. J. RISER. | |

TERRA TESTING, INC.
WASHINGTON, PA. 15301

# TEST BORING RECORD

WATER LEVELS:
- WHILE USING WATER ... -
- AT COMPLETION ... - ... 24 hrs ... n/a
- ENCOUNTERED ... 18.0'
- LOSS ... -
- OTHER ... -

CASING HAMMER WT. ... - ... lbs. DROP - ... in.
SAMPLER HAMMER WT. ... - ... lbs. DROP - ... in.
CASING SIZE ... - in. SPOON SIZE ... - ... in.
HOLLOW STEM AUGERS. 3-1/4" ... I.D.
RIG USED ... CME 55
DRILLER. W. Everett ... HELPER. D. Novotny

PROJECT: Molycorp, Inc.
Washington, PA

CLIENT: MOLYCORP, INC.
CLIENT PROJECT NO. ...
SURFACE ELEVATION ...
STARTED 8-1-90 COMPLETED 8-1-90
JOB NO. 90666
HOLE NO. 11 SHEET 1 OF 1

| | SAMPLE NO. | HAMMER BLOWS ON SAMPLER/6" 1st | 2nd | 3rd | CASING BLOWS PER FT. | ELEV. (feet) | MATERIAL DEPTH (feet) 0.0 | DESCRIPTION | DEPTH DRILLED (feet) | CORE REC. (feet) |
|---|---|---|---|---|---|---|---|---|---|---|
| AUGERED | | | | | | | 6.0 | Brown silty clay with rock fragments-humid. | | |
| | | | | | | | 18.0 | Gray silty clay with some rock fragments-moist. | | |
| | | | | | | | 19.0 | Gray claystone-dry. | | |

BOTTOM OF BORING @ 19.0'

NOTE: INSTALLED 20' OF 2" SCH 40
F. J. RISER.

TERRA TESTING, INC.
WASHINGTON, PA. 15301

# TEST BORING RECORD

WATER LEVELS:
(BE)FORE USING WATER ... -
COMPLETION ... - ... 24 hrs ... n/a
ENCOUNTERED ... 14.0'
LOSS ... -
OTHER ... -
CASING HAMMER WT. ... - lbs. DROP - in.
SAMPLER HAMMER WT. - lbs. DROP - in.
CASING SIZE ... - in. SPOON SIZE ... - in.
HOLLOW STEM AUGERS CME 55 ... I.D.
RIG USED ...
DRILLER W. Everett HELPER D. Novotny

PROJECT: Molycorp, Inc.
Washington, PA

CLIENT MOLYCORP, INC.
CLIENT PROJECT NO. ...
SURFACE ELEVATION ...
STARTED 8-2-90 COMPLETED 8-2-90
JOB NO. 90666
HOLE NO. 12 SHEET 1 OF 1

| (D)EPTH (feet) 0.0 | | SAMPLE NO. | HAMMER BLOWS ON SAMPLER/6" 1st | 2nd | 3rd | CASING BLOWS PER FT. | ELEV. (feet) | MATERIAL DEPTH (feet) 0.0 | DESCRIPTION | DEPTH DRILLED (feet) |
|---|---|---|---|---|---|---|---|---|---|---|
| | AUGERED | | | | | | | 2.0 | Brown silty clay with rock and gravel fragments-humid. | |
| | | | | | | | | 17.0 | Gray silty clay-moist to wet. | |
| (2)0.0 | | | | | | | | 20.0 | Gray weathered claystone-dry. | |
| | | | | | | | | | BOTTOM OF BORING @ 20.0' | |
| | | | | | | | | | NOTE: INSTALLED 20' OF 2" SCH 40 F. J. RISER. | |

TERRA TESTING, INC.
WASHINGTON, PA. 15301

# TEST BORING RECORD

WATER LEVELS:
B... USING WATER -
A... COMPLETION ... - ... 24 hrs ... n/a
ENCOUNTERED ... 17.0'
LOSS ... -
OTHER ... -
CASING HAMMER WT. ... - lbs. DROP - in.
SAMPLER HAMMER WT. ... - lbs. DROP - in.
CASING SIZE ... - in. SPOON SIZE ... - in.
HOLLOW STEM AUGERS ... 3-1/4" I.D.
RIG USED ... CME 55
DRILLER W. Everett HELPER D. Novotny

PROJECT: Molycorp, Inc.
Washington, PA

CLIENT ... MOLYCORP, INC.
CLIENT PROJECT NO. ...
SURFACE ELEVATION ...
STARTED 8-2-90 COMPLETED 8-2-90
JOB NO. 90666
HOLE NO. 13 SHEET 1 OF 1

| | SAMPLE NO. | HAMMER BLOWS ON SAMPLER/6" 1st | 2nd | 3rd | CASING BLOWS PER FT. | ELEV. (feet) | MATERIAL DEPTH (feet) 0.0 | DESCRIPTION | DEPTH DRILLED (feet) | CORE REC'Y (feet) |
|---|---|---|---|---|---|---|---|---|---|---|
| AUGERED | | | | | | | 5.0 | Brown silty clay with rock and slag fragments-humid. | | |
| | | | | | | | 20.0 | Gray silty clay-moist to wet. | | |
| | | | | | | | | BOTTOM OF BORING @ 20.0' | | |
| | | | | | | | | NOTE: INSTALLED 20' OF 2" SCH 40 F. J. RISER. | | |

TERRA TESTING, INC.
WASHINGTON, PA. 15301

# TEST BORING RECORD

WATER LEVELS:
RE USING WATER -
MPLETION - 24 hrs. n/a
ENCOUNTERED 15.0'
LOSS -
OTHER -
CASING HAMMER WT. - lbs. DROP - in.
SAMPLER HAMMER WT. - lbs. DROP - in.
CASING SIZE - in. SPOON SIZE - in.
HOLLOW STEM AUGERS 3-1/4" I.D.
RIG USED CME 55
DRILLER W. Everett HELPER D. Novotny

PROJECT: Molycorp, Inc.
Washington, PA
CLIENT MOLYCORP, INC.
CLIENT PROJECT NO.
SURFACE ELEVATION
STARTED 8-2-90 COMPLETED 8-2-90
JOB NO. 90666
HOLE NO. 14 SHEET 1 OF 1

| DEPTH | | SAMPLE NO. | HAMMER BLOWS ON SAMPLER/6" 1st | 2nd | 3rd | CASING BLOWS PER FT. | ELEV. (feet) | MATERIAL DEPTH (feet) 0.0 | DESCRIPTION | DEPTH DRILLED (feet) | CORE REC (feet) |
|---|---|---|---|---|---|---|---|---|---|---|---|
| | AUGERED | | | | | | | 4.0 | Black silty clay with rock and slag fragments-humid. | | |
| | | | | | | | | 10.0 | Gray and brown silty clay with rock fragments-humid. | | |
| | | | | | | | | 20.0 | Gray silty clay-moist to wet. | | |
| | | | | | | | | | BOTTOM OF BORING @ 20.0' | | |
| | | | | | | | | | NOTE: INSTALLED 20' OF 2" SCH 40 F. J. RISER. | | |

TERRA TESTING, INC.
WASHINGTON, PA 15301

# TEST BORING RECORD

WATER LEVELS:
[illegible]E USING WATER -
[illegible]MPLETION - 24 hrs n/a
ENCOUNTERED 17.0'
LOSS -
OTHER -
CASING HAMMER WT. - lbs. DROP - in.
SAMPLER HAMMER WT. - lbs. DROP - in.
CASING SIZE - in. SPOON SIZE - in.
HOLLOW STEM AUGERS 3-1/4" I.D.
RIG USED CME 55
DRILLER W. Everett HELPER D. Novotny

PROJECT: Molycorp, Inc.
Washington, PA
CLIENT MOLYCORP, INC.
CLIENT PROJECT NO.
SURFACE ELEVATION
STARTED 8-3-90 COMPLETED 8-3-90
JOB NO. 90666
HOLE NO. 15 SHEET 1 OF 1

| H | | SAMPLE NO. | HAMMER BLOWS ON SAMPLER/6" 1st | 2nd | 3rd | CASING BLOWS PER FT. | ELEV. (feet) | MATERIAL DEPTH (feet) 0.0 | DESCRIPTION | DEPTH DRILLED (feet) | COR[illegible] REC[illegible] (feet) |
|---|---|---|---|---|---|---|---|---|---|---|---|
| | AUGERED | | | | | | | | Gray slag, gravel and rock fragments with some clay-moist. | | |
| | | | | | | | | 10.0 | | | |
| | | | | | | | | | Gray and brown silty clay-moist to wet. | | |
| 0 | | | | | | | | 20.0 | | | |
| | | | | | | | | | BOTTOM OF BORING @ 20.0' | | |
| | | | | | | | | | NOTE: INSTALLED 20' OF 2" SCH. 40 F. J. RISER. | | |

TERRA TESTING, INC.
WASHINGTON, PA. 15301

# TEST BORING RECORD

WATER LEVELS:
WHILE USING WATER -
AT COMPLETION - 24 hrs. n/a
ENCOUNTERED 15.0'
LOSS -
OTHER -
CASING HAMMER WT. - lbs. DROP - in.
SAMPLER HAMMER WT. - lbs. DROP - in.
CASING SIZE - in. SPOON SIZE - in.
HOLLOW STEM AUGERS 3-1/4" I.D.
RIG USED CME 55
DRILLER W. Everett HELPER D. Novotny

PROJECT: Molycorp, Inc.
Washington, PA

CLIENT MOLYCORP, INC.
CLIENT PROJECT NO
SURFACE ELEVATION
STARTED 8-3-90 COMPLETED 8-3-90
JOB NO. 90666
HOLE NO. 16 SHEET 1 OF 1

| | SAMPLE NO. | HAMMER BLOWS ON SAMPLER/6" 1st | 2nd | 3rd | CASING BLOWS PER FT. | ELEV. (feet) | MATERIAL DEPTH (feet) 0.0 | DESCRIPTION | DEPTH DRILLED (feet) | CORE REC'Y (feet) |
|---|---|---|---|---|---|---|---|---|---|---|
| AUGERED | | | | | | | 7.0 | Gray slag and gravel with some clay-humid to moist. | | |
| AUGERED | | | | | | | 20.0 | Gray silty clay-moist to wet. | | |
| | | | | | | | | BOTTOM OF BORING @ 20.0'<br><br>NOTE: INSTALLED 20' OF 2" SCH. 40 F. J. RISER. | | |

TERRA TESTING, INC.
WASHINGTON, PA. 15301

# TEST BORING RECORD

WATER LEVELS:
WHILE USING WATER -
AFTER COMPLETION - 24 hrs. -
ENCOUNTERED none
LOSS -
OTHER -
CASING HAMMER WT. - lbs. DROP - in.
SAMPLER HAMMER WT. - lbs. DROP - in.
CASING SIZE - in. SPOON SIZE - in.
HOLLOW STEM AUGERS 3-1/4" I.D.
RIG USED CME 55
DRILLER W. Everett HELPER D. Novotny

PROJECT: Molycorp, Inc.
Washington, PA

CLIENT MOLYCORP, INC.
CLIENT PROJECT NO.
SURFACE ELEVATION
STARTED 8-2-90 COMPLETED 8-2-90
JOB NO. 90666
HOLE NO. 17 SHEET 1 OF 1

| DEPTH (feet) | | SAMPLE NO. | HAMMER BLOWS ON SAMPLER/6" 1st | 2nd | 3rd | CASING BLOWS PER FT. | ELEV. (feet) | MATERIAL DEPTH (feet) 0.0 | DESCRIPTION | DEPTH DRILLED (feet) | CORE REC. (feet) |
|---|---|---|---|---|---|---|---|---|---|---|---|
| | AUGERED | | | | | | | 4.0 | Gray silty clay with rock, slag and reddog fragments-humid. | | |
| | | | | | | | | 18.0 | Gray silty clay-moist. | | |
| 20 | | | | | | | | 20.0 | Gray claystone-dry. | | |
| | | | | | | | | | BOTTOM OF BORING @ 20.0' | | |
| | | | | | | | | | NOTE: INSTALLED 20' OF 2" SCH 40 F. J. RISER. | | |

TERRA TESTING, INC.
WASHINGTON, PA. 15301

# TEST BORING RECORD

WATER LEVELS:
B[illegible] USING WATER -
A[illegible] COMPLETION - 24 hrs n/a
ENCOUNTERED 16.0'
LOSS -
OTHER -
CASING HAMMER WT. - lbs. DROP - in.
SAMPLER HAMMER WT. - lbs. DROP - in.
CASING SIZE - in. SPOON SIZE - in.
HOLLOW STEM AUGERS 3-1/4" I.D.
RIG USED CME 55
DRILLER W. Everett HELPER D. Novotny

PROJECT: Molycorp, Inc.
Washington, PA

CLIENT MOLYCORP, INC.
CLIENT PROJECT NO.
SURFACE ELEVATION
STARTED 8-3-90 COMPLETED 8-3-90
JOB NO. 90666
HOLE NO. 18 SHEET 1 OF 1

| | SAMPLE NO. | HAMMER BLOWS ON SAMPLER/6" 1st | 2nd | 3rd | CASING BLOWS PER FT. | ELEV. (feet) | MATERIAL DEPTH (feet) 0.0 | DESCRIPTION | DEPTH DRILLED (feet) | CORE REC'Y (feet) |
|---|---|---|---|---|---|---|---|---|---|---|
| AUGERED (0.0–20.0) | | | | | | | 8.0 | Gray silty clay with rock and slag fragments-humid. | | |
| | | | | | | | 20.0 | Gray silty clay-moist to wet. | | |
| | | | | | | | | BOTTOM OF BORING @ 20.0' | | |
| | | | | | | | | NOTE: INSTALLED 20' OF 2" SCH 40 F. J. RISER. | | |

TERRA TESTING, INC.
WASHINGTON, PA. 15301

# TEST BORING RECORD

WATER LEVELS:
- (BEFO)RE USING WATER -
- (CO)MPLETION - 24 hrs. n/a
- ENCOUNTERED 18.0'
- LOSS -
- OTHER -

CASING HAMMER WT. - lbs. DROP - in.
SAMPLER HAMMER WT. - lbs. DROP - in.
CASING SIZE - in. SPOON SIZE - in.
HOLLOW STEM AUGERS 3-1/4" I.D.
RIG USED CME 55
DRILLER W. Everett HELPER D. Novotny

PROJECT: Molycorp, Inc.
Washington, PA
CLIENT MOLYCORP, INC.
CLIENT PROJECT NO.
SURFACE ELEVATION
STARTED 8-2-90 COMPLETED 8-2-90
JOB NO. 90666
HOLE NO. 19 SHEET 1 OF 1

| (DEPT)H (feet) | | SAMPLE NO. | HAMMER BLOWS ON SAMPLER/6" 1st | 2nd | 3rd | CASING BLOWS PER FT. | ELEV. (feet) | MATERIAL DEPTH (feet) 0.0 | DESCRIPTION | DEPTH DRILLED (feet) | CORE REC'Y (feet) |
|---|---|---|---|---|---|---|---|---|---|---|---|
| | AUGERED | | | | | | | 5.0 | Gray and brown silty clay with rock and slag fragments-humid. | | |
| (2)0 | | | | | | | | 20.0 | Gray silty clay-moist to wet. | | |
| | | | | | | | | | BOTTOM OF BORING @ 20.0' | | |
| | | | | | | | | | NOTE: INSTALLED 20' OF 2" SCH 40 F. J. RISER. | | |

TERRA TESTING, INC.
WASHINGTON, PA. 15301

# TEST BORING RECORD

WATER LEVELS:
- [illegible]RE USING WATER .. -
- [illegible]MPLETION .. - .. 24 hrs .. n/a
- ENCOUNTERED .. 18.0'
- LOSS .. -
- OTHER .. -

CASING HAMMER WT. .. - .. lbs. DROP - .. in.
SAMPLER HAMMER WT. .. - .. lbs. DROP - .. in.
CASING SIZE .. - .. in. SPOON SIZE .. - .. in.
HOLLOW STEM AUGERS .. 3-1/4" .. I.D.
RIG USED .. CME 55
DRILLER .. W. Everett .. HELPER .. D. Novotny

PROJECT: Molycorp, Inc.
Washington, PA

CLIENT .. MOLYCORP, INC.
CLIENT PROJECT NO. ..
SURFACE ELEVATION ..
STARTED .. 8-3-90 .. COMPLETED .. 8-3-90
JOB NO. .. 90666
HOLE NO. .. 20 .. SHEET .. 1 .. OF .. 1

| [illegible]H | | SAMPLE NO. | HAMMER BLOWS ON SAMPLER/6" 1st | 2nd | 3rd | CASING BLOWS PER FT. | ELEV. (feet) | MATERIAL DEPTH (feet) 0.0 | DESCRIPTION | DEPTH DRILLED (feet) | COR[illegible] REC[illegible] (feet) |
|---|---|---|---|---|---|---|---|---|---|---|---|
| | AUGERED | | | | | | | 10.0 | Gray slag and gravel with some clay-humid to moist. | | |
| [illegible]0 | | | | | | | | 20.0 | Gray silty clay with rock fragments-moist to wet. | | |
| | | | | | | | | | BOTTOM OF BORING @ 20.0'<br><br>NOTE: INSTALLED 20' OF 2" SCH 40 F. J. RISER. | | |

ERRA TESTING, INC.
ASHINGTON, PA. 15301

# TEST BORING RECORD

TER LEVELS:
BEF... JSING WATER .. -
AT ... LETION ... - ... 24 hrs. ... n/a
ENCOUNTERED ... 17.0'
LOSS ... -
OTHER ... -
SING HAMMER WT. ... - ... lbs. DROP - ... in.
MPLER HAMMER WT. - ... lbs. DROP - ... in.
SING SIZE ... - in. SPOON SIZE ... - ... in.
LLOW STEM AUGERS ... 3-1/4" ... I.D.
USED ... CME 55
ILLER W. Everett ... HELPER D. Novotny

PROJECT: Molycorp, Inc.
Washington, PA

CLIENT MOLYCORP, INC.
CLIENT PROJECT NO.
SURFACE ELEVATION
STARTED 8-3-90 COMPLETED 8-3-90
JOB NO. 90666
HOLE NO. 21 SHEET 1 OF 1

| | SAMPLE NO. | HAMMER BLOWS ON SAMPLER/6" 1st | 2nd | 3rd | CASING BLOWS PER FT. | ELEV. (feet) | MATERIAL DEPTH (feet) 0.0 | DESCRIPTION | DEPTH DRILLED (feet) | CORE REC'Y (feet) |
|---|---|---|---|---|---|---|---|---|---|---|
| AUGERED | | | | | | | 3.0 | Gray silty clay with rock and slag fragments-humid. | | |
| | | | | | | | 20.0 | Brown and gray silty clay-moist to wet. | | |
| | | | | | | | | BOTTOM OF BORING @ 20.0' | | |
| | | | | | | | | NOTE: INSTALLED 20' OF 2" SCH 40 F. J. RISER. | | |

TERRA TESTING, INC.
WASHINGTON, PA. 15301

# TEST BORING RECORD

WATER LEVELS:
BEFORE USING WATER ...-...
AT COMPLETION ...-... 24 hrs ... n/a ...
ENCOUNTERED ... 16.0' ...
LOSS ...-...
OTHER ...-...
CASING HAMMER WT. ...-... lbs. DROP -... in.
SAMPLER HAMMER WT. -... lbs. DROP -... in.
CASING SIZE ...-. in. SPOON SIZE ...-...in.
HOLLOW STEM AUGERS. 3-1/4"... I.D.
RIG USED ... CME 55 ...
DRILLER W. Everett ... HELPER D. Novotny ...

PROJECT: Molycorp., Inc.
Washington, PA

CLIENT ... MOLYCORP, INC. ...
CLIENT PROJECT NO. ...
SURFACE ELEVATION ...
STARTED 8-3-90 ... COMPLETED 8-3-90 ...
JOB NO. 90666
HOLE NO. 22 ... SHEET 1 ... OF 1 ...

| DEPTH (feet) 0.0 | | SAMPLE NO. | HAMMER BLOWS ON SAMPLER/6" 1st | 2nd | 3rd | CASING BLOWS PER FT. | ELEV. (feet) | MATERIAL DEPTH (feet) 0.0 | DESCRIPTION | DEPTH DRILLED (feet) |
|---|---|---|---|---|---|---|---|---|---|---|
| | AUGERED | | | | | | | | Gray silty clay with slag fragments-humid. | |
| | | | | | | | | 5.0 | | |
| | | | | | | | | | Brown and gray silty clay-moist to wet. | |
| 20.0 | | | | | | | | 20.0 | | |
| | | | | | | | | | BOTTOM OF BORING @ 20.0' | |
| | | | | | | | | | NOTE: INSTALLED 20' OF 2" SCH 40 F. J. RISER. | |

'ERRA TESTING, INC.
/ASHINGTON, PA. 15301

# TEST BORING RECORD

/ATE[illegible] 'ELS:
BL[illegible] USING WATER -
AT COMPLETION - 24 hrs n/a
ENCOUNTERED 18.0'
LOSS -
OTHER -
:ASING HAMMER WT. - lbs. DROP - in.
AMPLER HAMMER WT. - lbs. DROP - in.
:ASING SIZE - in. SPOON SIZE - in.
IOLLOW STEM AUGERS 3-1/4" I.D.
:IG USED CME 55
IRILLER W. Everett HELPER D. Novotny

PROJECT: Molycorp, Inc.
Washington, PA

CLIENT MOLYCORP, INC.
CLIENT PROJECT NO.
SURFACE ELEVATION
STARTED 8-2-90 COMPLETED 8-2-90
JOB NO. 90666
HOLE NO. 23 SHEET 1 OF 1

| | SAMPLE NO. | HAMMER BLOWS ON SAMPLER/6" 1st | 2nd | 3rd | CASING BLOWS PER FT. | ELEV. (feet) | MATERIAL DEPTH (feet) 0.0 | DESCRIPTION | DEPTH DRILLED (feet) | CORE REC" (feet) |
|---|---|---|---|---|---|---|---|---|---|---|
| AUGERED | | | | | | | 5.0 | Black silty clay with rock and slag fragments-humid. | | |
| | | | | | | | 20.0 | Gray silty clay-moist to wet. | | |
| | | | | | | | | BOTTOM OF BORING @ 20.0'<br><br>NOTE: INSTALLED 20' OF 2" SCH 40 F. J. RISER. | | |

TERRA TESTING, INC.
WASHINGTON, PA. 15301

# TEST BORING RECORD

WATER LEVELS:
BEFORE USING WATER .... -
AT COMPLETION .... - .... 24 hrs. .... n/a
ENCOUNTERED .... 15.5'
LOSS .... -
OTHER .... -
CASING HAMMER WT. .... - .... lbs. DROP .... - .... in.
SAMPLER HAMMER WT. .... - .... lbs. DROP .... - .... in.
CASING SIZE .... - .... in. SPOON SIZE .... - .... in.
HOLLOW STEM AUGERS .... 3-1/4" .... I.D.
RIG USED .... CME 55
DRILLER .... W. Everett .... HELPER .... D. Novotny

PROJECT: Molycorp, Inc.
Washington, PA

CLIENT .... MOLYCORP, INC.
CLIENT PROJECT NO. ....
SURFACE ELEVATION ....
STARTED .... 8-2-90 .... COMPLETED .... 8-2-90
JOB NO. .... 90666
HOLE NO. .... 24 .... SHEET .... 1 .... OF .... 1

| | Sample No. | Hammer Blows on Sampler/6" 1st | 2nd | 3rd | Casing Blows per Ft. | Elev. (feet) | Material Depth (feet) 0.0 | Description | Depth Drilled (feet) | Core Rec. (feet) |
|---|---|---|---|---|---|---|---|---|---|---|
| AUGERED | | | | | | | 5.0 | Brown silty clay with rock and slag fragments-humid. | | |
| | | | | | | | 18.0 | Gray silty clay-moist to wet. | | |
| | | | | | | | 19.3 | Gray claystone-dry. | | |
| | | | | | | | | BOTTOM OF BORING @ 19.3' | | |
| | | | | | | | | NOTE: INSTALLED 20' OF 2" SCH 40 F. J. RISER. | | |

TERRA TESTING, INC.
WASHINGTON, PA. 15301

# TEST BORING RECORD

WATER LEVELS:
WHILE USING WATER ...-...
AFTER COMPLETION ...-... 24 hrs. ...n/a...
ENCOUNTERED ...15.0'...
LOSS ...-...
OTHER ...-...
CASING HAMMER WT. ...-... lbs. DROP -... in.
SAMPLER HAMMER WT. -... lbs. DROP -... in.
CASING SIZE ...-... in. SPOON SIZE ...-... in.
HOLLOW STEM AUGERS ...3-1/4"... I.D.
RIG USED ...CME 55...
DRILLER ...W. Everett... HELPER ...D. Novotny...

PROJECT: Molycorp, Inc.
Washington, PA

CLIENT ...MOLYCORP, INC....
CLIENT PROJECT NO. ...
SURFACE ELEVATION ...
STARTED ...8-2-90... COMPLETED ...8-2-90...
JOB NO. ...90666...
HOLE NO. ...25... SHEET ...1... OF ...1...

| | SAMPLE NO. | HAMMER BLOWS ON SAMPLER/6" 1st | 2nd | 3rd | CASING BLOWS PER FT. | ELEV. (feet) | MATERIAL DEPTH (feet) 0.0 | DESCRIPTION | DEPTH DRILLED (feet) | CORE REC'Y (feet) |
|---|---|---|---|---|---|---|---|---|---|---|
| AUGERED | | | | | | | | Brown silty clay with rock fragments-humid. | | |
| | | | | | | | 6.0 | Gray silty clay-moist to wet. | | |
| | | | | | | | 16.0 | Brown sand and gravel-moist. | | |
| | | | | | | | 17.5 | Gray claystone-dry. | | |
| | | | | | | | 19.0 | | | |

BOTTOM OF BORING @ 19.0'

NOTE: INSTALLED 20' OF 2" SCH 40
F. J. RISER.

TERRA TESTING, INC.
WASHINGTON, PA 15301

# TEST BORING RECORD

WATER LEVELS:
- [WHIL]E USING WATER .. -
- [CO]MPLETION ... - ..... 24 hrs ........ n/a
- ENCOUNTERED .... 15.0'
- LOSS ........ -
- OTHER ........ -

CASING HAMMER WT. ... - ... lbs. DROP - ... in.
SAMPLER HAMMER WT. - ... lbs. DROP - ... in.
CASING SIZE ..... - .. in. SPOON SIZE ... - ... in.
HOLLOW STEM AUGERS ... 3-1/4" .. I.D.
RIG USED ....... CME 55
DRILLER .. W. Everett ... HELPER .. D. Novotny

PROJECT: Molycorp, Inc.
Washington, PA

CLIENT ... MOLYCORP, INC.
CLIENT PROJECT NO. ......
SURFACE ELEVATION ......
STARTED .. 8-2-90 ....... COMPLETED ... 8-2-90
JOB NO. .. 90666
HOLE NO. .. 26 ...... SHEET ... 1 ..... OF .. 1

| [DEPT]H | | SAMPLE NO. | HAMMER BLOWS ON SAMPLER/6" 1st | 2nd | 3rd | CASING BLOWS PER FT. | ELEV. (feet) | MATERIAL DEPTH (feet) 0.0 | DESCRIPTION | DEPTH DRILLED (feet) | CORE REC. (feet) |
|---|---|---|---|---|---|---|---|---|---|---|---|
| | AUGERED (0.0–20.0) | | | | | | | 3.0 | Brown silty clay with rock and reddog fragments-humid. | | |
| | | | | | | | | 6.0 | Gray silty clay with rock fragments-humid. | | |
| | | | | | | | | 18.0 | Gray silty clay-moist to wet. | | |
| | | | | | | | | 20.0 | Claystone-dry. | | |

BOTTOM OF BORING @ 20.'

NOTE: INSTALLED 20' OF 2" SCH 40
F. J. RISER.

TERRA TESTING, INC.
WASHINGTON, PA 15301

# TEST BORING RECORD

WATER LEVELS:
- WHILE USING WATER: -
- COMPLETION: - 24 hrs: n/a
- ENCOUNTERED: none
- LOSS: -
- OTHER: -

CASING HAMMER WT. - lbs. DROP - in.
SAMPLER HAMMER WT. - lbs. DROP - in.
CASING SIZE - in. SPOON SIZE - in.
HOLLOW STEM AUGERS 3-1/4" I.D.
RIG USED CME 55
DRILLER W. Everett HELPER D. Novotny

PROJECT: Molycorp, Inc.
Washington, PA

CLIENT MOLYCORP, INC.
CLIENT PROJECT NO.
SURFACE ELEVATION
STARTED 8-2-90 COMPLETED 8-2-90
JOB NO. 90666
HOLE NO. 27 SHEET 1 OF 1

| DEPTH (feet) | | SAMPLE NO. | HAMMER BLOWS ON SAMPLER/6" 1st | 2nd | 3rd | CASING BLOWS PER FT. | ELEV. (feet) | MATERIAL DEPTH (feet) 0.0 | DESCRIPTION | DEPTH DRILLED (feet) | CORE REC'Y (feet) |
|---|---|---|---|---|---|---|---|---|---|---|---|
| | AUGERED | | | | | | | 3.0 | Brown silty clay with rock fragments-dry. | | |
| 0 | | | | | | | | 8.0 | Brown weathered sandy shale-dry. | | |
| | | | | | | | | | BOTTOM OF BORING @ 8.0' | | |
| | | | | | | | | | NOTE: INSTALLED 10' OF 2" SCH 40 F. J. RISER. | | |

TERRA TESTING, INC.
WASHINGTON, PA. 15301

# TEST BORING RECORD

WATER LEVELS:
'RE USING WATER .. -
OMPLETION .. - .. 24 hrs .. n/a
ENCOUNTERED .. 17.0'
LOSS .. -
OTHER .. -
CASING HAMMER WT. .. - .. lbs. DROP - .. in.
SAMPLER HAMMER WT. - .. lbs. DROP - .. in.
CASING SIZE .. - .. in. SPOON SIZE .. - .. in.
HOLLOW STEM AUGERS .. 3-1/4" .. I.D.
RIG USED .. CME 55
DRILLER. W. Everett ... HELPER. D. Novotny

PROJECT: Molycorp, Inc.
Washington, PA
CLIENT .. MOLYCORP, INC.
CLIENT PROJECT NO. ..
SURFACE ELEVATION ..
STARTED .. 8-2-90 .. COMPLETED .. 8-2-90
JOB NO. .. 90666
HOLE NO. .. 28 .. SHEET .. 1 .. OF .. 1

| TH (t) | | SAMPLE NO. | HAMMER BLOWS ON SAMPLER/6" 1st | 2nd | 3rd | CASING BLOWS PER FT. | ELEV. (feet) | MATERIAL DEPTH (feet) 0.0 | DESCRIPTION | DEPTH DRILLED (feet) | CORE REC'Y (feet) |
|---|---|---|---|---|---|---|---|---|---|---|---|
| | AUGERED | | | | | | | 7.0 | Rock, slag, brick and glass fragments with some silty clay-humid. | | |
| | | | | | | | | 14.0 | Brown silty clay with rock fragments-humid. | | |
| 0 | | | | | | | | 19.0 | Brown to gray clayshale-dry. | | |
| | | | | | | | | | BOTTOM OF BORING @ 19.0' | | |
| | | | | | | | | | NOTE: INSTALLED 20' OF 2" SCH 40 F. J. RISER. | | |

TERRA TESTING, INC.
WASHINGTON, PA. 15301

# TEST BORING RECORD

WATER LEVELS:
(BEFO)RE USING WATER ... -
(C)OMPLETION ... 11.8' 24 hrs ... n/a
ENCOUNTERED ... 6.0'
LOSS ... -
OTHER ... -
CASING HAMMER WT. ... - lbs. DROP - in.
SAMPLER HAMMER WT. 140 lbs. DROP 30 in.
CASING SIZE ... - in. SPOON SIZE ... 2 in.
HOLLOW STEM AUGERS ... 3-1/4" I.D.
RIG USED ... CME 45-C
DRILLER ... W. Everett HELPER ... D. Novotny

PROJECT: Molycorp, Inc.
Washington, PA

CLIENT ... MOLYCORP, INC.
CLIENT PROJECT NO. ...
SURFACE ELEVATION ...
STARTED 8-29-90 COMPLETED 8-29-90
JOB NO. 90690
HOLE NO. 29 SHEET 1 OF 1

| SAMPLE NO. | HAMMER BLOWS ON SAMPLER/6" 1st | 2nd | 3rd | CASING BLOWS PER FT. | ELEV. (feet) | MATERIAL DEPTH (feet) 0.0 | DESCRIPTION | DEPTH DRILLED (feet) | CORE REC'Y (feet) |
|---|---|---|---|---|---|---|---|---|---|
| 1 | 3 | 5 | 7 | | | | | | |
| | | | | | | | Gray slag and gravel with brick fragments-humid to wet, medium dense. | | |
| 2 | 7 | 4 | 3 | | | | | | |
| 3 | 4 | 16 | 19 | | | | | | |
| | | | | | | 5.0 | | | |
| 4 | 20 | 8 | 4 | | | | Gray and brown silty clay with rock fragments-wet, medium dense. | | |
| 5 | 16 | 8 | 5 | | | | | | |
| 6 | 1 | 2 | 2 | | | | | | |
| 7 | 2 | 3 | 3 | | | | | | |
| [illegible] | 2 | 3 | 5 | | | 12.0 | | | |
| 9 | 4 | 5 | 5 | | | | | | |
| | | | | | | | Brown silty clay with rock fragments-wet, medium dense. | | |
| 10 | 4 | 4 | 4 | | | 15.0 | | | |
| 11 | 3 | 5 | 9 | | | | Gray sand and gravel with some clay-wet, medium dense. | | |
| 12 | 11 | 6 | 7 | | | | | | |
| 13 | 5 | 13 | 27 | | | 19.0 | | | |
| | | | | | | 19.5 | Gray clayshale-damp, dense. | | |
| | | | | | | | BOTTOM OF BORING @ 19.5' | | |
| | | | | | | | NOTE: INSTALLED 20' OF 2" SCH 40 F.J. PVC RISER. | | |

TERRA TESTING, INC.
WASHINGTON, PA. 15301

# TEST BORING RECORD

WATER LEVELS:
'RE USING WATER ... -
COMPLETION ... 5.6' 24 hrs. ... n/a
ENCOUNTERED ... 10.0'
LOSS ... -
OTHER ... -
CASING HAMMER WT. ... - lbs. DROP - in.
SAMPLER HAMMER WT. - lbs. DROP - in.
CASING SIZE ... - in. SPOON SIZE - in.
HOLLOW STEM AUGERS ... 3-1/4" I.D.
RIG USED ... CME 45-C
DRILLER W. Everett ... HELPER D. Novotny

PROJECT: Molycorp, Inc.
Washington, PA

CLIENT ... MOLYCORP, INC.
CLIENT PROJECT NO. ...
SURFACE ELEVATION ...
STARTED 8-30-90 ... COMPLETED 8-30-90
JOB NO. 90690
HOLE NO. 30 SHEET 1 OF 1

| TH (ft) | | SAMPLE NO. | HAMMER BLOWS ON SAMPLER/6" 1st | 2nd | 3rd | CASING BLOWS PER FT. | ELEV. (feet) | MATERIAL DEPTH (feet) 0.0 | DESCRIPTION | DEPTH DRILLED (feet) | CORE REC'Y (feet) |
|---|---|---|---|---|---|---|---|---|---|---|---|
| | AUGER | | | | | | | 5.0 | Gray slag and gravel-moist. | | |
| | | | | | | | | 18.0 | Gray and brown silty clay with rock fragments-moist to wet. | | |
| | | | | | | | | 19.0 | Gray sand and gravel-wet. | | |
| | | | | | | | | | BOTTOM OF BORING @ 19.0' | | |
| | | | | | | | | | NOTE: INSTALLED 20' OF 2" SCH 40 F.J. PVC RISER. | | |

TERRA TESTING, INC.
WASHINGTON, PA. 15301

# TEST BORING RECORD

WATER LEVELS:
- USING WATER: -
- AT COMPLETION: 7.4' 24 hrs: n/a
- ENCOUNTERED: 11.0'
- LOSS: -
- OTHER: -

CASING HAMMER WT. - lbs. DROP - in.
SAMPLER HAMMER WT. - lbs. DROP - in.
CASING SIZE - in. SPOON SIZE - in.
HOLLOW STEM AUGERS 3-1/4" I.D.
RIG USED CME 45-C
DRILLER W. Everett HELPER D. Novotny

PROJECT: Molycorp, Inc.
Washington, PA

CLIENT: MOLYCORP, INC.
CLIENT PROJECT NO.
SURFACE ELEVATION
STARTED 8-30-90 COMPLETED 8-3-90
JOB NO. 90690
HOLE NO. 31 SHEET 1 OF 1

| SAMPLE NO. | HAMMER BLOWS ON SAMPLER/6" 1st | 2nd | 3rd | CASING BLOWS PER FT. | ELEV. (feet) | MATERIAL DEPTH (feet) 0.0 | DESCRIPTION | DEPTH DRILLED (feet) | CORE REC'Y (feet) |
|---|---|---|---|---|---|---|---|---|---|
| | | | | | | 6.0 | Gray gravel and slag-humid, loose. | | |
| | | | | | | 19.0 | Gray silty clay with rock fragments-moist to wet. | | |
| | | | | | | | BOTTOM OF BORING @ 19.0'<br><br>NOTE: INSTALLED 20' OF 2" SCH 40 F.J. PVC RISER. | | |

AUGER REF. (0.0–19.0)

TERRA TESTING, INC.
WASHINGTON, PA. 15301

# TEST BORING RECORD

WATER LEVELS:
WHILE USING WATER ... -
AT COMPLETION ... 13.8' 24 hrs. ... n/a
ENCOUNTERED ... 11.0'
LOSS ... -
OTHER ... -
CASING HAMMER WT. ... - lbs. DROP - in.
SAMPLER HAMMER WT. 140 lbs. DROP 30 in.
CASING SIZE ... - in. SPOON SIZE ... 2 in.
HOLLOW STEM AUGERS 3-1/4" I.D.
RIG USED ... CME 45-C
DRILLER W. Everett HELPER D. Novotny

PROJECT: Molycorp, Inc.
Washington, PA

CLIENT MOLYCORP, INC.
CLIENT PROJECT NO.
SURFACE ELEVATION
STARTED 8-29-90 COMPLETED 8-29-90
JOB NO. 90690
HOLE NO. 32 SHEET 1 OF 1

| SAMPLE NO. | HAMMER BLOWS ON SAMPLER/6" 1st | 2nd | 3rd | CASING BLOWS PER FT. | ELEV. (feet) | MATERIAL DEPTH (feet) 0.0 | DESCRIPTION | DEPTH DRILLED (feet) | CORE REC'Y (feet) |
|---|---|---|---|---|---|---|---|---|---|
| 1 | 6 | 13 | 18 | | | | Gray slag and gravel-damp, very dense. | | |
| 2 | 14 | 13 | 19 | | | | | | |
| 3 | 50/0.2 | | | | | | | | |
| 4 | 1 | 2 | 2 | | | 6.0 | | | |
| 5 | 3 | 6 | 5 | | | | Gray sand-moist, medium dense. | | |
| 6 | 2 | 3 | 18 | | | 9.0 | | | |
| 7 | 23 | 7 | 5 | | | | Gray silty clay with rock fragments-wet, loose. | | |
| 8 | 1 | 2 | 3 | | | | | | |
| 9 | 2 | 2 | 4 | | | | | | |
| 10 | 4 | 3 | 9 | | | | | | |
| 11 | 3 | 3 | 5 | | | 16.5 | | | |
| 12 | 4 | 3 | 4 | | | | Brown silty clay with rock fragments-wet, loose. | | |
| 13 | 3 | 3 | 4 | | | 19.5 | | | |
| | | | | | | | BOTTOM OF BORING @ 19.5' | | |
| | | | | | | | NOTE: INSTALLED 20' OF 2" SCH 40 F. J. PVC RISER. | | |

Water Well 1

TERRA TESTING CO.
PITTSBURGH, PA. 412 / 787-1254

# TEST BORING RECORD

DEPTH TO WATER 0 hrs. 10.0 ft. 24 hrs. - ft.
GROUNDWATER ENCOUNTERED 10.0 ft.
LOSS - ft.
CASING HAMMER Wt. - lbs. DROP - in.
SAMPLER HAMMER Wt. - lbs. DROP - in.
CASING SIZE Hollow Stem in. SAMPLER SIZE - in.
DRILLER E. Bright HELPER R. Lawrence

PROJECT Molycorp Inc. Washington, Pa
CLIENT SRW Associates, Inc.
CLIENT PROJ. NO.
SURFACE ELEVATION
STARTED 3-3-83 COMPLETED 3-4-83
JOB NO. 83524

| ELEVATION | DEPTH | SAMPLE NO. | HAMMER BLOWS/6" ON SAMPLER 1st 6" | 2nd 6" | 3rd 6" | HAMMER BLOWS CASING | DESCRIPTION | DEPTH DRILLED | CORE REC. |
|---|---|---|---|---|---|---|---|---|---|
| | 0.0 | AUGERED | | | | | 0.0'-15.0': Fill-slag, gravel, cinders, glass, metal-very loose, damp. | | |
| | | | | | | | 15.0'-17.0': Fill-gray silty sandy clay cinders-soft, loose, wet. | | |
| | | | | | | | 17.0'-22.0': Brown silty, sandy clay-stiff, moist. | | |
| | 22.0 | | | | | | REFUSAL @ 22.0' | | |
| | | | | | | | BOTTOM OF BORING @ 22.0' | | |
| | | | | | | | NOTE: Installed 4" PVC, .040 screen and sanded, Bentonite seal and cemented in a locking steel cap. | | |

HOLE NO. M1 SHEET 1 OF 1

11D Gm...t Well M-1

Water well –

TERRA TESTING CO.
PITTSBURGH, PA. 412 / 787-1254

# TEST BORING RECORD

DEPTH TO WATER 0 hrs. 9.3 ft. 24 hrs. – ft.
GROUNDWATER ENCOUNTERED 10.0 ft.
WATER LOSS – ft.
CASING HAMMER Wt. – lbs. DROP – in.
SAMPLER HAMMER Wt. – lbs. DROP – in.
CASING SIZE Hollow Stem in. SAMPLER SIZE – in.

DRILLER E. Bright HELPER R. Lawrence

PROJECT Molycorp Inc.
Washington, Pa.
CLIENT SRW Associates, Inc.
CLIENT PROJ. NO.
SURFACE ELEVATION
STARTED 3-3-83 COMPLETED 3-3-83
JOB NO. 83524

| ELEVATION | DEPTH | SAMPLE NO. | HAMMER BLOWS/6" ON SAMPLER 1st 6" | 2nd 6" | 3rd 6" | HAMMER BLOWS CASING | DESCRIPTION | DEPTH DRILLED | CORE REC'Y. |
|---|---|---|---|---|---|---|---|---|---|
| | 0.0 | AUGERED (0.0–16.0) | | | | | 0.0'- 3.0': Fill-slag, cinders, glass, wood-loose, damp. | | |
| | | | | | | | 3.0'-10.0': Fill-brown silty sandy gravel, wood, cinders-loose, moist. | | |
| | | | | | | | 10.0'-12.0': Brown sandy silt-soft, wet. | | |
| | | | | | | | 12.0'-16.0': Gray sandy silt-soft, wet. | | |
| | 16.0 | | | | | | REFUSAL @ 16.0' | | |
| | | | | | | | BOTTOM OF BORING @ 16.0' | | |
| | | | | | | | NOTE: Installed 4" PVC, .040 screen and sanded, Bentonite seal and cemented in a locking steel cap. | | |

HOLE NO. M 2 SHEET 1 OF 1

Well M-2

Water Well 2

TERRA TESTING CO.
PITTSBURGH, PA. 412 / 787-1254

# TEST BORING RECORD

DEPTH WATER 0 hrs. 12.0 ft. 24 hrs. - ft.
GROUNDWATER ENCOUNTERED 12.0 ft.
WATER LOSS - ft.
CASING HAMMER Wt. - lbs. DROP - in.
SAMPLER HAMMER Wt. - lbs. DROP - in.
CASING SIZE Hollow Stem in. SAMPLER SIZE - in.
DRILLER E. Bright HELPER R. Lawrence

PROJECT Molycorp
Washington, Pa.
CLIENT SRW Associates, Inc.
CLIENT PROJ. NO.
SURFACE ELEVATION
STARTED 3-3-83 COMPLETED 3-3-83
JOB NO. 83524

| ELEVATION | DEPTH | SAMPLE NO. | HAMMER BLOWS/6" ON SAMPLER 1st 6" | 2nd 6" | 3rd 6" | HAMMER BLOWS CASING | DESCRIPTION | DEPTH DRILLED | CORE REC'Y. |
|---|---|---|---|---|---|---|---|---|---|
| | 0.0 | AUGERED | | | | | 0.0'- 3.0': Fill-slag, sand, glass, wood-loose, damp. | | |
| | | | | | | | 3.0'- 7.0': Fill-gray silty sandy clay, wood-soft, moist. | | |
| | | | | | | | 7.0'-17.0': Gray sandy silt--soft, moist to wet. | | |
| | 17.0 | | | | | | REFUSAL @ 17.0' | | |
| | | | | | | | BOTTOM OF BORING @ 17.0' | | |
| | | | | | | | NOTE: Installed 4" PVC, .040 screen and sanded, Bentonite seal and cemented in a locking steel cap. | | |

Water well 7

TERRA TESTING CO.
PITTSBURGH, PA. 412/787-1254

# TEST BORING RECORD

DEPTH WATER 0 hrs. 9.0 ft. 24 hrs. - ft.
GROUND WATER ENCOUNTERED 11.0 ft.
WATER LOSS - ft.
CASING HAMMER Wt. - lbs. DROP - in.
SAMPLER HAMMER Wt. - lbs. DROP - in.
CASING SIZE Hollow Stemin. SAMPLER SIZE - in.
DRILLER E. Bright HELPER R. Lawrence

PROJECT Molycorp Inc.
Washington, Pa.
CLIENT SRW Associates, Inc.
CLIENT PROJ. NO.
SURFACE ELEVATION
STARTED 3-2-83 COMPLETED 3-2-83
JOB NO. 83524

| ELEVATION | DEPTH | SAMPLE NO. | HAMMER BLOWS/6" ON SAMPLER 1st 6" | 2nd 6" | 3rd 6" | HAMMER BLOWS CASING | DESCRIPTION | DEPTH DRILLED | CORE REC'Y. |
|---|---|---|---|---|---|---|---|---|---|
| | 0.0 | AUGERED | | | | | 0.0'- 6.0': Fill-slag, cinders, brick, sand, glass-loose, damp. | | |
| | | | | | | | 6.0'-18.7': Gray sandy silt-soft, moist to wet. | | |
| | 18.7 | | | | | | REFUSAL @ 18.7' | | |
| | | | | | | | BOTTOM OF BORING @ 18.7' | | |
| | | | | | | | NOTE: Installed 4" PVC, .040 screen and sanded. Bentonite seal and cemented in a locking steel cap. | | |

# Appendix E: Scintillometer Survey

**Quadr[illegible]: Scintillometer Survey, μR/hr indicated by survey instrument**

| Y-axis (feet) | | | | | | | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| 280.0 | 40.0 | 45.0 | 55.0 | 55.0 | 55.0 | 121.0 | 150.0 | 170.0 | 150.0 | 44.0 | 23.0 | 21.0 | |
| 260.0 | 23.0 | 23.0 | 22.0 | 32.0 | 75.0 | 255.0 | 200.0 | 160.0 | 90.0 | 75.0 | 65.0 | 32.0 | |
| 240.0 | 13.5 | 15.0 | 19.5 | 22.0 | 112.0 | 330.0 | 310.0 | 160.0 | 50.0 | 65.0 | 75.0 | 44.0 | |
| 220.0 | 16.0 | 16.0 | 20.0 | 52.0 | 155.0 | 150.0 | 160.0 | 65.0 | | 40.0 | 55.0 | | |
| 200.0 | 17.5 | 18.5 | 29.0 | 48.0 | 110.0 | 71.0 | 34.5 | 25.0 | 15.0 | 15.0 | 20.0 | 18.0 | |
| 180.0 | 16.5 | 17.5 | 17.5 | 24.0 | 21.5 | 18.0 | 16.5 | 14.5 | 13.5 | 13.0 | 16.0 | 15.5 | |
| 160.0 | 16.0 | 16.0 | 16.5 | 19.0 | 20.5 | 19.5 | 17.5 | 19.5 | 14.5 | 13.5 | 19.5 | 17.5 | |
| 140.0 | 15.5 | 16.0 | 15.0 | 16.5 | 42.0 | 16.0 | 22.0 | 41.0 | 110.0 | | | 12.5 | |
| 120.0 | 15.0 | 16.5 | 13.5 | 15.0 | 40.0 | 26.0 | 26.5 | 47.0 | | | | 10.5 | |
| 100.0 | 16.0 | 17.5 | 18.5 | 16.5 | 23.0 | 34.5 | 30.0 | 75.0 | | | | 13.5 | |
| 80.0 | 22.5 | 21.0 | 27.0 | 22.0 | 30.0 | 31.5 | 25.0 | 24.0 | 19.0 | | | | |
| 60.0 | 20.5 | 20.5 | 16.5 | 17.0 | 22.0 | 21.0 | 20.5 | 21.0 | | | | | |
| 40.0 | 22.0 | 20.5 | 25.0 | 19.5 | 21.0 | 21.5 | 19.0 | 28.0 | | | | | |
| 20.0 | 17.5 | 15.5 | 22.0 | 26.0 | 29.5 | 19.0 | 16.5 | 15.5 | 12.5 | 12.0 | 13.5 | 18.0 | |
| 0.0 | 14.5 | 12.5 | 32.5 | 37.0 | 58.0 | 24.5 | 13.5 | | | | | | X-axis |
| **0.0** | **20.0** | **40.0** | **60.0** | **80.0** | **100.0** | **120.0** | **140.0** | **160.0** | **180.0** | **200.0** | **220.0** | **240.0** | (feet) |

**Quadrant 1: Scintillometer Survey, μR/hr true gamma**

| Y-axis (feet) | | | | | | | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| 280.0 | 29.1 | 32.8 | 40.0 | 40.0 | 40.0 | 88.1 | 109.2 | 123.8 | 109.2 | 32.0 | 16.7 | 15.3 | |
| 260.0 | 16.7 | 16.7 | 16.0 | 23.3 | 54.6 | 185.6 | 145.6 | 116.5 | 65.5 | 54.6 | 47.3 | 23.3 | |
| 240.0 | 9.8 | 10.9 | 14.2 | 16.0 | 81.5 | 240.2 | 225.7 | 116.5 | 36.4 | 47.3 | 54.6 | 32.0 | |
| 220.0 | 11.6 | 11.6 | 14.6 | 37.9 | 112.8 | 109.2 | 116.5 | 47.3 | | 29.1 | 40.0 | | |
| 200.0 | 12.7 | 13.5 | 21.1 | 34.9 | 80.1 | 51.7 | 25.1 | 18.2 | 10.9 | 10.9 | 14.6 | 13.1 | |
| 180.0 | 12.0 | 12.7 | 12.7 | 17.5 | 15.7 | 13.1 | 12.0 | 10.6 | 9.8 | 9.5 | 11.6 | 11.3 | |
| 160.0 | 11.6 | 11.6 | 12.0 | 13.8 | 14.9 | 14.2 | 12.7 | 14.2 | 10.6 | 9.8 | 14.2 | 12.7 | |
| 140.0 | 11.3 | 11.6 | 10.9 | 12.0 | 30.6 | 11.6 | 16.0 | 29.8 | 80.1 | | | 9.1 | |
| 120.0 | 10.9 | 12.0 | 9.8 | 10.9 | 29.1 | 18.9 | 19.3 | 34.2 | | | | 7.6 | |
| 100.0 | 11.6 | 12.7 | 13.5 | 12.0 | 16.7 | 25.1 | 21.8 | 54.6 | | | | 9.8 | |
| 80.0 | 16.4 | 15.3 | 19.7 | 16.0 | 21.8 | 22.9 | 18.2 | 17.5 | 13.8 | | | | |
| 60.0 | 14.9 | 14.9 | 12.0 | 12.4 | 16.0 | 15.3 | 14.9 | 15.3 | 0.0 | | | | |
| 40.0 | 16.0 | 14.9 | 18.2 | 14.2 | 15.3 | 15.7 | 13.8 | 20.4 | 0.0 | | | | |
| 20.0 | 12.7 | 11.3 | 16.0 | 18.9 | 21.5 | 13.8 | 12.0 | 11.3 | 9.1 | 8.7 | 9.8 | 13.1 | |
| 0.0 | 10.6 | 9.1 | 23.7 | 26.9 | 42.2 | 17.8 | 9.8 | | | | | | X-axis |
| **0.0** | **20.0** | **40.0** | **60.0** | **80.0** | **100.0** | **120.0** | **140.0** | **160.0** | **180.0** | **200.0** | **220.0** | **240.0** | (feet) |

Quadrant 2: Scintillometer Survey, µR/hr indicated by survey instrument

| | | | | | | | | | | | | | | | Y-axis (feet) |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| | | | | | | | | | | | | | | | 280.0 |
| | | | | | | | | | | | | 23.0 | 25.0 | 20.0 | 260.0 |
| | | | | | | | | | | | | 22.0 | 21.5 | 14.5 | 240.0 |
| | | | | | | | | | | | 28.0 | 23.0 | 18.5 | 18.0 | 220.0 |
| | | | | | | | | | | 17.5 | 19.5 | 15.0 | 16.5 | 17.5 | 200.0 |
| | | | | | | | | | | 18.0 | 16.0 | 14.0 | 13.5 | 16.0 | 180.0 |
| | | | | | | | | | 18.0 | 16.5 | 15.5 | 15.5 | 15.0 | 15.0 | 160.0 |
| | | | | | | | | 18.5 | 21.5 | 22.5 | 17.5 | 15.0 | 15.0 | 16.5 | 140.0 |
| | | | | | | 19.0 | 20.0 | 22.0 | 25.0 | 55.0 | 42.0 | 33.0 | 17.0 | 19.5 | 120.0 |
| | | | | | | 21.0 | 20.0 | 36.0 | | | | | 22.0 | 21.0 | 100.0 |
| | | | | | 19.5 | 20.0 | 30.0 | 30.0 | 33.0 | 31.0 | 26.0 | 24.0 | 23.0 | 23.0 | 80.0 |
| | | | | | 19.5 | 18.0 | 20.0 | | | | | | 19.0 | 21.0 | 60.0 |
| | | | | 18.0 | 18.0 | 22.0 | 20.0 | 18.0 | 19.0 | 23.0 | 21.0 | 22.0 | 21.5 | 20.5 | 40.0 |
| | | | | 18.0 | 22.0 | 23.0 | 18.0 | 19.0 | | | | | 26.5 | 21.5 | 20.0 |
| | | | | 26.0 | 32.0 | 36.0 | 18.0 | 18.0 | 20.0 | | | | | 28.0 | 0.0 |
| X-axis (feet) | -260.0 | -240.0 | -220.0 | -200.0 | -180.0 | -160.0 | -140.0 | -120.0 | -100.0 | -80.0 | -60.0 | -40.0 | -20.0 | 0.0 | 0.0 |

Quadrant 2: Scintillometer Survey, µR/hr true gamma

| | | | | | | | | | | | | | | | Y-axis (feet) |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| | | | | | | | | | | | | | | | 280.0 |
| | | | | | | | | | | | | 16.7 | 18.2 | 14.6 | 260.0 |
| | | | | | | | | | | | | 16.0 | 15.7 | 10.6 | 240.0 |
| | | | | | | | | | | | 20.4 | 16.7 | 13.5 | 13.1 | 220.0 |
| | | | | | | | | | | 12.7 | 14.2 | 10.9 | 12.0 | 12.7 | 200.0 |
| | | | | | | | | | | 13.1 | 11.6 | 10.2 | 9.8 | 11.6 | 180.0 |
| | | | | | | | | | 13.1 | 12.0 | 11.3 | 11.3 | 10.9 | 10.9 | 160.0 |
| | | | | | | | | 13.5 | 15.7 | 16.4 | 12.7 | 10.9 | 10.9 | 12.0 | 140.0 |
| | | | | | | 13.8 | 14.6 | 16.0 | 18.2 | 40.0 | 30.6 | 24.0 | 12.4 | 14.2 | 120.0 |
| | | | | | | 15.3 | 14.6 | 26.2 | | | | | 16.0 | 15.3 | 100.0 |
| | | | | | 14.2 | 14.6 | 21.8 | 21.8 | 24.0 | 22.6 | 18.9 | 17.5 | 16.7 | 16.7 | 80.0 |
| | | | | | 14.2 | 13.1 | 14.6 | | | | | | 13.8 | 15.3 | 60.0 |
| | | | | 13.1 | 13.1 | 16.0 | 14.6 | 13.1 | 13.8 | 16.7 | 15.3 | 16.0 | 15.7 | 14.9 | 40.0 |
| | | | | 13.1 | 16.0 | 16.7 | 13.1 | 13.8 | | | | | 19.3 | 15.7 | 20.0 |
| | | | | 18.9 | 23.3 | 26.2 | 13.1 | 13.1 | 14.6 | | | | | 20.4 | 0.0 |
| X-axis (feet) | -260.0 | -240.0 | -220.0 | -200.0 | -180.0 | -160.0 | -140.0 | -120.0 | -100.0 | -80.0 | -60.0 | -40.0 | -20.0 | 0.0 | 0.0 |

Quadrant 3: Scintillometer Survey, µR/hr indicated by survey instrument

| X-ax (fee | !60.0 | -240.0 | -220.0 | -200.0 | -180.0 | -160.0 | -140.0 | 0.0 | -100.0 | -80.0 | -60.0 | -40.0 | -20.0 | 0.0 | .0 |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| | | | 45.0 | 105.0 | 24.0 | 18.0 | 20.0 | .0 | 27.0 | 26.0 | 44.0 | 27.0 | 22.0 | 25.0 | ).0 |
| | | | 65.0 | 85.0 | 20.0 | 17.0 | 16.0 | _1.0 | | | | | 18.0 | 24.0 | 0.0 |
| | 18.0 | 22.0 | 65.0 | 28.0 | 19.0 | 17.5 | 17.5 | 20.0 | 17.0 | 18.0 | 19.0 | 22.0 | 15.5 | 22.0 | -60.0 |
| | | 27.0 | 27.0 | 22.0 | 18.0 | 17.0 | 16.0 | 20.0 | | | | | 16.0 | 18.0 | -80.0 |
| | | 24.0 | 26.0 | 20.0 | 21.0 | 18.0 | 19.0 | 21.0 | 24.0 | 24.0 | 20.0 | 16.0 | 15.5 | 14.0 | -100.0 |
| | | 26.0 | 45.0 | 31.0 | 19.0 | 17.0 | 22.0 | 22.0 | | | | | 16.5 | 14.0 | -120.0 |
| | | 24.0 | 49.0 | 38.0 | 20.0 | 15.5 | 18.0 | 18.5 | | | | | 17.0 | 13.0 | -140.0 |
| | | | 27.0 | 54.0 | 20.0 | 17.5 | 18.0 | 19.0 | 23.0 | 30.0 | 28.0 | 27.0 | 17.0 | 13.0 | -160.0 |
| | | | | 31.0 | 36.0 | 20.0 | 17.0 | 18.0 | | | | | 17.0 | 12.0 | -180.0 |
| | | | | 31.0 | 29.0 | 22.0 | 20.0 | 18.0 | 28.0 | 28.0 | 27.0 | 24.0 | 20.0 | 12.0 | -200.0 |
| | | | | | 30.0 | 30.0 | 18.0 | 20.0 | 60.0 | | | | 19.0 | 13.0 | -220.0 |
| | | | | | 32.0 | 30.0 | 17.0 | 21.0 | 49.0 | | | | 21.0 | 13.0 | -240.0 |
| | | | | | | 30.0 | 26.0 | 25.0 | 35.0 | 60.0 | 35.5 | 39.0 | 23.0 | 14.0 | -260.0 |
| | | | | | | 26.0 | 27.0 | 29.0 | 32.0 | 25.0 | 26.0 | 30.0 | 24.5 | 17.0 | -280.0 |
| | | | | | | | 28.0 | 38.0 | 47.0 | 30.0 | 24.0 | 34.0 | 24.0 | 20.5 | -300.0 |
| | | | | | | | 30.0 | 31.0 | 37.0 | 28.0 | 26.0 | 47.0 | 25.0 | 24.0 | -320.0 |
| | | | | | | | | 45.0 | 38.0 | 32.0 | 30.0 | 30.0 | 31.0 | 26.5 | -340.0 |

Y-axis (feet)

Quadrant3: Scintillometer Survey, µR/hr true gamma

| X-axis (feet) | -260.0 | -240.0 | -220.0 | -200.0 | -180.0 | -160.0 | -140.0 | -120.0 | -100.0 | -80.0 | -60.0 | -40.0 | -20.0 | 0.0 | 0.0 |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| | | | 32.8 | 76.4 | 17.5 | 13.1 | 14.6 | 18.2 | 19.7 | 18.9 | 32.0 | 19.7 | 16.0 | 18.2 | -20.0 |
| | | | 47.3 | 61.9 | 14.6 | 12.4 | 11.6 | 15.3 | | | | | 13.1 | 17.5 | -40.0 |
| | 13.1 | 16.0 | 47.3 | 20.4 | 13.8 | 12.7 | 12.7 | 14.6 | 12.4 | 13.1 | 13.8 | 16.0 | 11.3 | 16.0 | -60.0 |
| | | 19.7 | 19.7 | 16.0 | 13.1 | 12.4 | 11.6 | 14.6 | | | | | 11.6 | 13.1 | -80.0 |
| | | 17.5 | 18.9 | 14.6 | 15.3 | 13.1 | 13.8 | 15.3 | 17.5 | 17.5 | 14.6 | 11.6 | 11.3 | 10.2 | -100.0 |
| | | 18.9 | 32.8 | 22.6 | 13.8 | 12.4 | 16.0 | 16.0 | | | | | 12.0 | 10.2 | -120.0 |
| | | 17.5 | 35.7 | 27.7 | 14.6 | 11.3 | 13.1 | 13.5 | | | | | 12.4 | 9.5 | -140.0 |
| | | | 19.7 | 39.3 | 14.6 | 12.7 | 13.1 | 13.8 | 16.7 | 21.8 | 20.4 | 19.7 | 12.4 | 9.5 | -160.0 |
| | | | | 22.6 | 26.2 | 14.6 | 12.4 | 13.1 | | | | | 12.4 | 8.7 | -180.0 |
| | | | | 22.6 | 21.1 | 16.0 | 14.6 | 13.1 | 20.4 | 20.4 | 19.7 | 17.5 | 14.6 | 8.7 | -200.0 |
| | | | | | 21.8 | 21.8 | 13.1 | 14.6 | 43.7 | 0.0 | 0.0 | 0.0 | 13.8 | 9.5 | -220.0 |
| | | | | | 23.3 | 21.8 | 12.4 | 15.3 | 35.7 | 0.0 | 0.0 | 0.0 | 15.3 | 9.5 | -240.0 |
| | | | | | | 21.8 | 18.9 | 18.2 | 25.5 | 43.7 | 25.8 | 28.4 | 16.7 | 10.2 | -260.0 |
| | | | | | | 18.9 | 19.7 | 21.1 | 23.3 | 18.2 | 18.9 | 21.8 | 17.8 | 12.4 | -280.0 |
| | | | | | | | 20.4 | 27.7 | 34.2 | 21.8 | 17.5 | 24.8 | 17.5 | 14.9 | -300.0 |
| | | | | | | | 21.8 | 22.6 | 26.9 | 20.4 | 18.9 | 34.2 | 18.2 | 17.5 | -320.0 |
| | | | | | | | | 32.8 | 27.7 | 23.3 | 21.8 | 21.8 | 22.6 | 20.7 | -340.0 |

Y-axis (feet)

**Quadrant 4: Scintillometer Survey, μR/hr indicated by survey instrument**

| 0.0 | 20.0 | 40.0 | 60.0 | 80.0 | 100.0 | 120.0 | 140.0 | 160.0 | 180.0 | 200.0 | 220.0 | 240.0 | X-axis (feet) |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| -20.0 | 16.5 | | | 48.0 | | | | | | | | | |
| -40.0 | 15.5 | 38.0 | 85.0 | 62.0 | 20.0 | | | | | | | | |
| -60.0 | 18.5 | 41.0 | 75.0 | 75.0 | 26.0 | | | | | | | | |
| -80.0 | 14.0 | | 21.0 | 32.0 | 25.0 | | | | | | | | |
| -100.0 | 12.5 | 9.0 | 12.5 | 11.0 | 10.0 | | | | | | | | |
| -120.0 | 11.0 | | | | 11.0 | | | | | | | | |
| -140.0 | | | | | | | | | | | | | |
| -160.0 | | | | | | | | | | | | | |
| -180.0 | | | | | | | | | | | | | |
| -200.0 | | | | | | | | | | | | | |
| -220.0 | | | | | | | | | | | | | |
| -240.0 | | | | | | | | | | | | | |
| -260.0 | | | | | | | | | | | | | |
| -280.0 | | | | | | | | | | | | | |
| -300.0 | | | | | | | | | | | | | |
| -320.0 | | | | | | | | | | | | | |
| -340.0 | | | | | | | | | | | | | |

Y-axis (feet)

**Quadrant 4: Scintillometer Survey, μR/hr true gamma**

| 0.0 | 20.0 | 40.0 | 60.0 | 80.0 | 100.0 | 120.0 | 140.0 | 160.0 | 180.0 | 200.0 | 220.0 | 240.0 | X-axis (feet) |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| -20.0 | 12.0 | | | 34.9 | | | | | | | | | |
| -40.0 | 11.3 | 27.7 | 61.9 | 45.1 | 14.6 | | | | | | | | |
| -60.0 | 13.5 | 29.8 | 54.6 | 54.6 | 18.9 | | | | | | | | |
| -80.0 | 10.2 | 0.0 | 15.3 | 23.3 | 18.2 | | | | | | | | |
| -100.0 | 9.1 | 6.6 | 9.1 | 8.0 | 7.3 | | | | | | | | |
| -120.0 | 8.0 | | | | 8.0 | | | | | | | | |
| -140.0 | | | | | | | | | | | | | |
| -160.0 | | | | | | | | | | | | | |
| -180.0 | | | | | | | | | | | | | |
| -200.0 | | | | | | | | | | | | | |
| -220.0 | | | | | | | | | | | | | |
| -240.0 | | | | | | | | | | | | | |
| -260.0 | | | | | | | | | | | | | |
| -280.0 | | | | | | | | | | | | | |
| -300.0 | | | | | | | | | | | | | |
| -320.0 | | | | | | | | | | | | | |
| -340.0 | | | | | | | | | | | | | |

Y-axis (feet)

## Appendix F: Calibration Certificates for the Instruments.

# reuter stokes

18530 South Miles Parkway, Cleveland, Ohio 44128 U.S.A. • Telephone (216) 581-9400, Telex 98-5253

reuter-stokes
WE HAVE MOVED
*Our new ship to & bill to address is:*
Edison Park, 8499 Darrow Rd.,
Twinsburg, Ohio 44087
phone: (216) 425-3755

CALIBRATION CERTIFICATION

We certify that the area Monitor, Model Number RSS-111-100, Listed below, has been calibrated for output using calibrated radiation sources traceable to the National Bureau of Standards.

SERIAL NUMBER =C6008

DATE OF CALIBRATION =6/6/86

REUTER-STOKES INSTRUMENTS, INC.

[signature]

DATE: 6/18/86

**************************************************

reuter RS stokes

18530 South Miles Parkway, Cleveland, Ohio 44128 U.S.A. • Telephone (216) 581-9400, Telex 98-5253

CALIBRATION DATA

DATE = 6/6/86

SERIAL NO C6008

| ISTANCE | P S A | S A | P | MV/UR |
|---|---|---|---|---|
| 04.8 | 1576.5 | 345.0 | 1231.5 | 19.35 |
| 65.8 | 1181.3 | 327.6 | 853.7 | 19.40 |
| 26. | 936.5 | 316.0 | 620.4 | 19.27 |
| 87.7 | 781.6 | 305.4 | 476.2 | 19.40 |
| 48.6 | 671.1 | 294.5 | 376.5 | 19.49 |

*************************************************************************

CO-60 AVERAGE=19.38

STANDARD DEV= .08

COFF OF VAR=.0042

CO(RA226)=19.81

CORRECTION VALUES

· S A = 1183.645
; A = 328.8675
'= 854.7775

IEW COBALT VALUE= 19.4400159199
IEW RADIUM VALUE= 19.8774162781

:** ******************* CALIBRATED BY Richard L. Wukofe______

FIELD STRENGTH AT 1 METER = 599.57 YEAR 86 DAY 6 MONTH 6

## REFERENCES


(1) NCRP Report No. 50, National Council on Radiation Protection and Measurements, Washington D.C., Dec. 27, 1976; pp. 30-31.

(2) Martin K.L., Radiological Survey of Molybdenum Corporation of America, Washington, Pennsylvania, Oak Ridge Associated Universities, Oak Ridge Tenn., June, 1985 (unpublished).

(3) Wrenn, McDonald E., Health Physics Evaluation of the Molycorp, Washington, PA, Site, August 7, 1986 (unpublished).

(4) NCRP Report No. 50, National Council on Radiation Protection and Measurements, Washington D.C., Dec. 27, 1976; pp. 39.

**Appendix J: 1992 Report by RSA, Inc., Entitled "Justification of the Calibration Factor Used for Borehole Measurements of Underground Radiation Exposure Rates and Average Th-232 Concentration"**

Radiation Surveillance Associates, Inc.
1771 South 900 West, Suite #10
Salt Lake City, Ut 84105

Report to

U.S. Nuclear Regulatory Commission
Regulatory Issues Section
Low Level Waste Management and Decommissioning

December 30, 1992
Revised February 10, 1993

Re: Molycorp, Washington, Pa. Facility and RSA Report,
"A Subsurface Survey for Thorium Content,"
Dated December 27, 1990.

# Justification of the Calibration Factor used for Borehole Measurements of Underground Radiation Exposure Rates and Average $^{232}$Th Concentration and Response to NRC Comments Dated October 29, 1992.

McDonald E. Wrenn, Ph.D., CHP
William Delaney, M.S.
Luiz Bertelli, Ph.D.
Narayani P. Singh, Ph.D.

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**INTRODUCTION:**

In 1990 RSA conducted a surface and subsurface radiation survey for gamma exposure rate around the pond area of the Molycorp Washington Pennsylvania site. The results were submitted to Molycorp in a report dated December 27, 1990 which has been recently reviewed by the NRC in a report entitled 'NRC Comments on Report Entitled, "A Sub-Surface Survey for Thorium Content at the Molycorp Plant Site in Washington, Pennsylvania,"' and transmitted to Ms. Barbara Dankmyer, Molycorp Resident Manager, in a letter from Chad Glenn, NRC Project manager dated October 29, 1992.

In this survey the surface gamma radiation measurements were made at a variety of places on site with particular attention to the pond area; 32 boreholes were drilled and logged with a sodium iodide probe to measure exposure rate, which is related to average concentration of gamma emitters in soils.

The original intent of the summary was to measure the extent of the subsurface concentration of radioactive materials and quantitatively assess the concentrations and amounts of $^{232}Th$ present, laterally and as a function of depth in the area of the ponds. In order to be quantitative, an extensive calibration program was undertaken to relate the ambient gamma background both on the surface and in the boreholes to the $^{232}Th$ content of the underlying soils. Whenever the gamma radiation measurements exceeded the background gamma levels substantially it could be assumed that the material responsible for that increase was $^{232}Th$ and its daughters in equilibrium. This assumption was quite reasonable based on the history of operation of the plant and previous measurements of thorium in slag from the Molycorp operations. Information presented later in this report shows ~~that the assumption of equilibrium~~ was justified.

The calibration procedure is described in great detail in the 1990 report but a brief summary will be given here. In a ground survey of external radiation in 1990, a set of external exposure measurements was made with a calibrated pressurized ionization chamber (PIC) traceable to NIST. At each location where absolute exposure rate measurements were made with the PIC measurements were also made with a sodium iodide scintillometer (model 19 Ludlum) and with a sodium iodide (NaI) probe and photomultiplier tube which was capable of being lowered into the ground inside the boreholes. The sodium iodide probe and scintillometer were cross calibrated against the pressurized ionization chamber on the surface and the calibration curves presented in that report. Thus the readout of both NaI instruments were calibrated against the exposure rate in μR/hr due to gamma rays from a distributed environmental source, predominantly due to $^{232}$Th and its daughters.

The basis for the conversion from the gamma exposure rate to the average concentration in surrounding soil was given by Beck (1972), and his conversion factor, which was subsequently adopted by the NCRP, (NCRP-50, 1976) gives the exposure rate due to a semi infinite slab of soil with uniformly distributed $^{232}$Th in equilibrium with its daughters as 2.82 $\mu R \cdot hr^{-1}/pCi \cdot g^{-1}$. This conversion factor is only applicable to distributed sources.

In a review of the 1990 RSA report the NRC indicated that they were not convinced that the calibration and subsequent interpretation relating exposure rate to average $^{232}$Th concentration in soil was a valid one. RSA points out that the use of external gamma exposure rate and gamma spectrometry to assess average concentration of thorium in soil is a technique recognized in both the scientific literature and the NCRP publications. Moreover gamma ray exposure rate measurements of this type result from the average radioactivity concentration over reasonably large volumes of soil, and are directly related to the potential for human exposure, since they result from direct radiation measurements.

In the report that follows we have laid out the rationale and additional information for accepting the calibration factors derived in the RSA 1990 Report and present additional information on the isotopic composition of the thorium in the slag pile. Additional information is also provided on thorium isotopes found underground in borehole #29 and #32, from which core samples were obtained and radiochemical analysis for the alpha emitting isotopes of thorium made.

## BACKGROUND RADIATION:

### Gamma Exposure Rates for Unit $^{232}Th$, $^{238}U$ and $^{40}K$ Sources in Soil

NCRP-50, based on the work of Beck, showed that the exposure rate at 1 meter above the soil for uniformly distributed natural emitters is 2.82 $\mu R \cdot hr^{-1}/pCi \cdot g^{-1}$ $^{232}Th$. Figure 1 shows graphically the exposure rate in air one meter above the ground for the major nuclides found in nature, the uranium series, thorium series, and $^{40}K$ under equilibrium conditions of uniform distribution in depth and lateral extent at a concentration of 1 pCi/g in soil.

### Fractional Gamma Exposure Rate In Surface Air Due to Natural Sources as a Function of Depth

NCRP-94 and Beck (1972) show the contribution to the exposure rate at 1 meter above the soil due to gamma emitting sources at various depths in soil for a typical natural emitter source composition. Although the gamma spectrum of energies from a typical natural emitter composition has a slightly lower average energy than that from $^{232}Th$ and its daughter products, the graph shown in Figure 2 can be used to illustrate a basic point about averaging. This graph has been reproduced from Beck (1972) with permission of the author. About 90% of the total exposure rate comes from radioactivity distributed in the top 20 centimeters (about 8 inches) of soil.

### Specific Activity of Thorium In Slag

Beck's work implies that underground most of the gamma ray exposure from $^{232}Th$ and its daughters which reaches a detector in a borehole will originate from within a sphere with a radius of approximately a foot, or alternatively with a diameter of 2 or more feet. This means that, although gamma ray measurement provide a reasonably local measure of the background, they average over a relatively large volume compared to the volume of a soil sample such as those taken from the cores from boreholes 29 and 32 (see page 12). Since the concentration of $^{232}Th$ in the slag pile is known to average 1250 pCi/g (see Table 1) (AHP, 1975,) and since pieces of slag are probably not uniformly distributed underground, increased backgrounds underground must result from combinations of thorium bearing slag mixed with other materials.

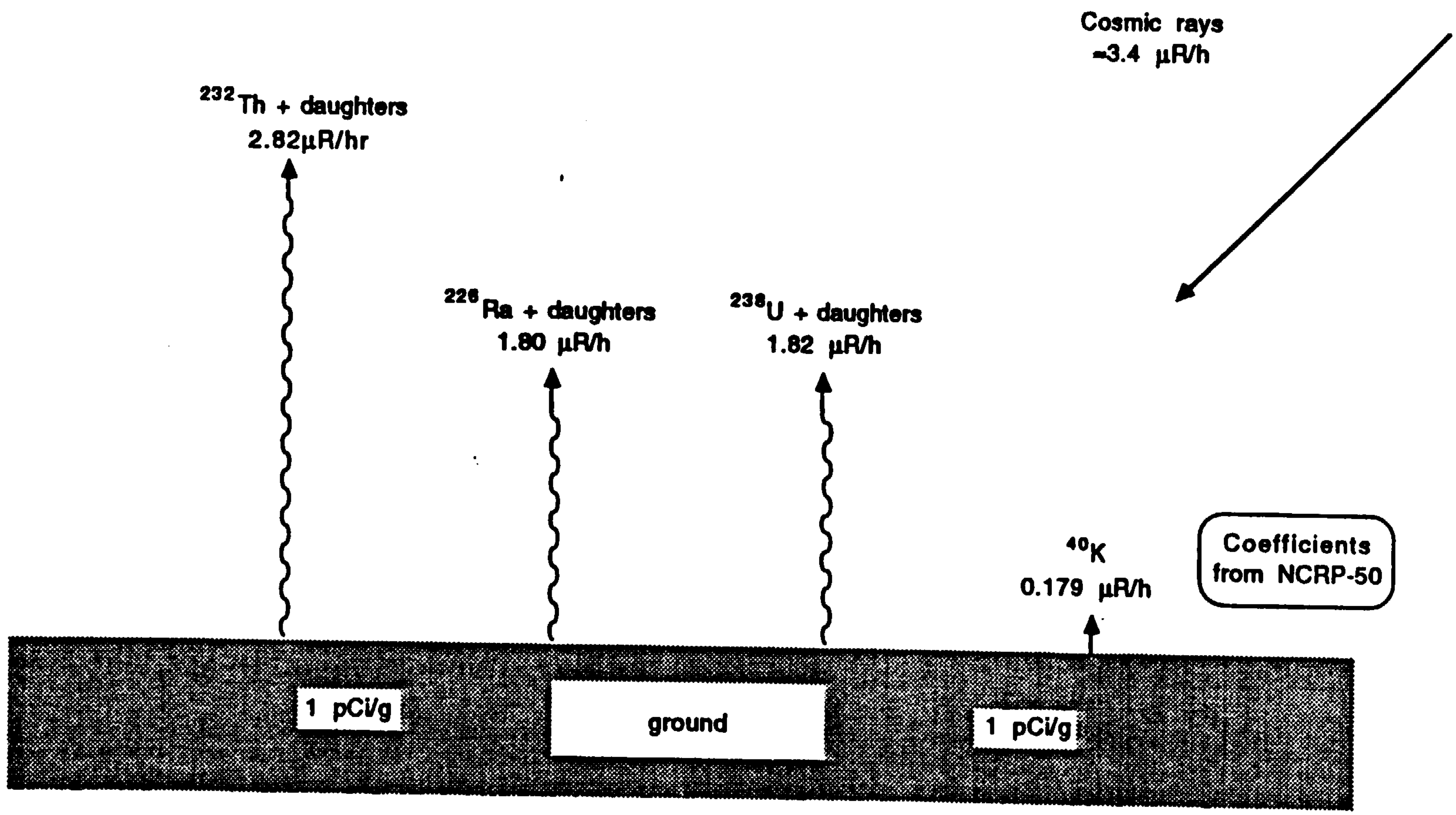



Figure1: Exposure rate at one meter above the ground for uniformly distributed natural emitters (at a concentration of 1 pCi/g)

RSA, 12/29/92

.·igure 2. Contribution of Total Exposure Rate at One Meter Above the Ground from Natural Sources as a Function of Soil Thickness.

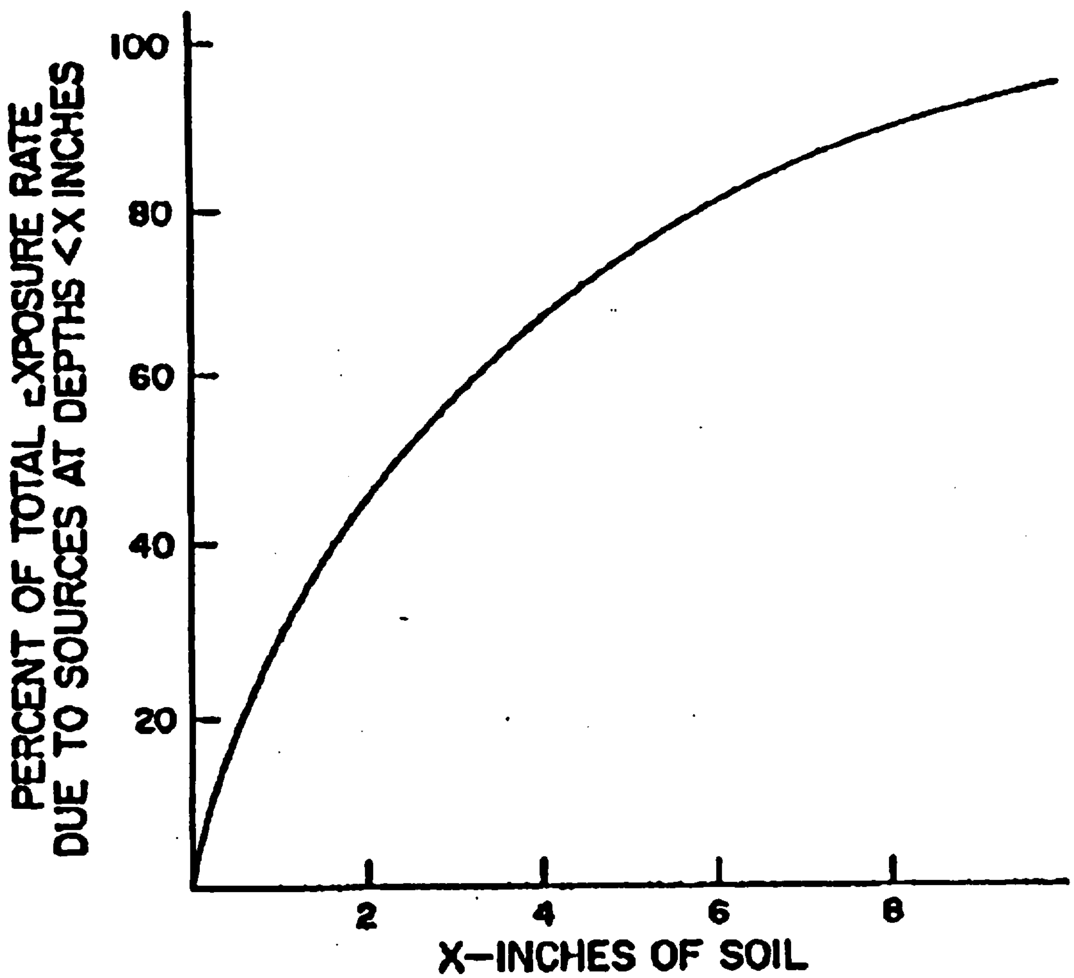


Table 1. **Information About the Slag Pile**

| | |
|---|---|
| Volume: | $2.494 \times 10^5\ ft^3$ |
| Mass: | $2.245 \times 10^7$ lbs |
| Density: | 90 $lbs/ft^3$ |
| Concentration of Th: | 11.4 ± 0.2 mg Th/g |
| or | 1.14% |
| or | 1250 pCi/g $^{232}Th$ |
| Degree of Equilibrium | $^{232}Th = {}^{228}Th$ (~100%) |
| Total Activity: | 12.7 Ci $^{232}Th$ |

- Applied Health Physics Report dated May 22, 1975

## SURFACE & SUBSURFACE CALIBRATION PROCEDURES:

### Summary of Procedures

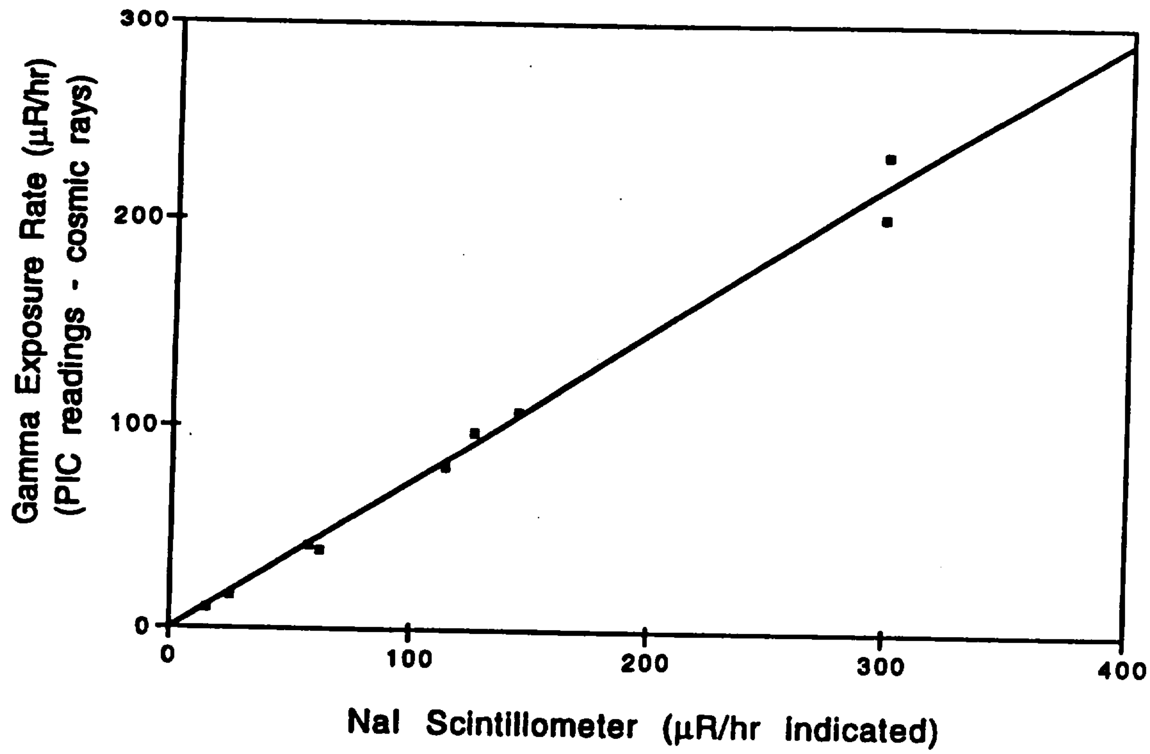
The RSA 1990 Report describes in detail the PIC calibration and the results of the pressurized ionization chamber (μR/hr) vs. in the response of the NaI scintillometer and cpm in the NaI well logging crystal (probe). For convenience the plot of the total ionization less that due to cosmic rays (i.e., due only to gamma rays) measured in the pressurized ionization chamber vs. the scintillometer readings are shown in Figure 3 (Figure 1 in the RSA Report, 1990). The correlation is very good over the range of exposure rates measured indicating that the scintillometer can be used for absolute gamma rays exposure measurements. In Figure 4 the results of the same calibration procedure are shown for the well logging probe inside PVC pipe in the configuration we used in the underground logging of boreholes 1-32.

Because the calibration coefficient was obtained in an area where the environmental radiation field is primarily due to thorium and its daughters distributed as volumetric sources in the surrounding material, the calibration factor derived is valid for $^{232}Th$ in a volumetric distribution We will show later in this report that most of the radioactivity responsible for the increased gamma background is from $^{232}Th$ and its daughters in equilibrium.

Since the boreholes were cased with 2 inch diameter PVC pipe and the probe lowered inside a 1 inch diameter PVC pipe the appropriate calibration factor is given in Graph 5 of Figure 2 (RSA 1990), which is reproduced here as Figure 4. The appropriate calibration and conversion factors are as follows:

### Summary of Calibration and Conversion Factors

| | |
|---|---|
| 12.6±0.3 μR/hr /1000 cpm | directly measured, Fig. 4, NaI Probe |
| 5.64 μR/hr /pCi/g | from NCRP-50,94, Beck, 72, adjusted for $4\pi$, $k_2$ in Appendix B |
| 448 cpm / pCi/g | inferred from the two above |
| 0.728 true/indicated | NaI Scintillometer, Fig. 3 (μR/hr) |




Least Squares Fit to a Line Constrained to Pass Through Zero:

Slope (compensation factor): 0.728 ± 0.018

y intercept = 0

(Computed using the statistical software package StatWorks on a Macintosh computer.)

**Figure 3: Least squares fit of the calibration factor for the NaI scintillometer gamma measurements.**

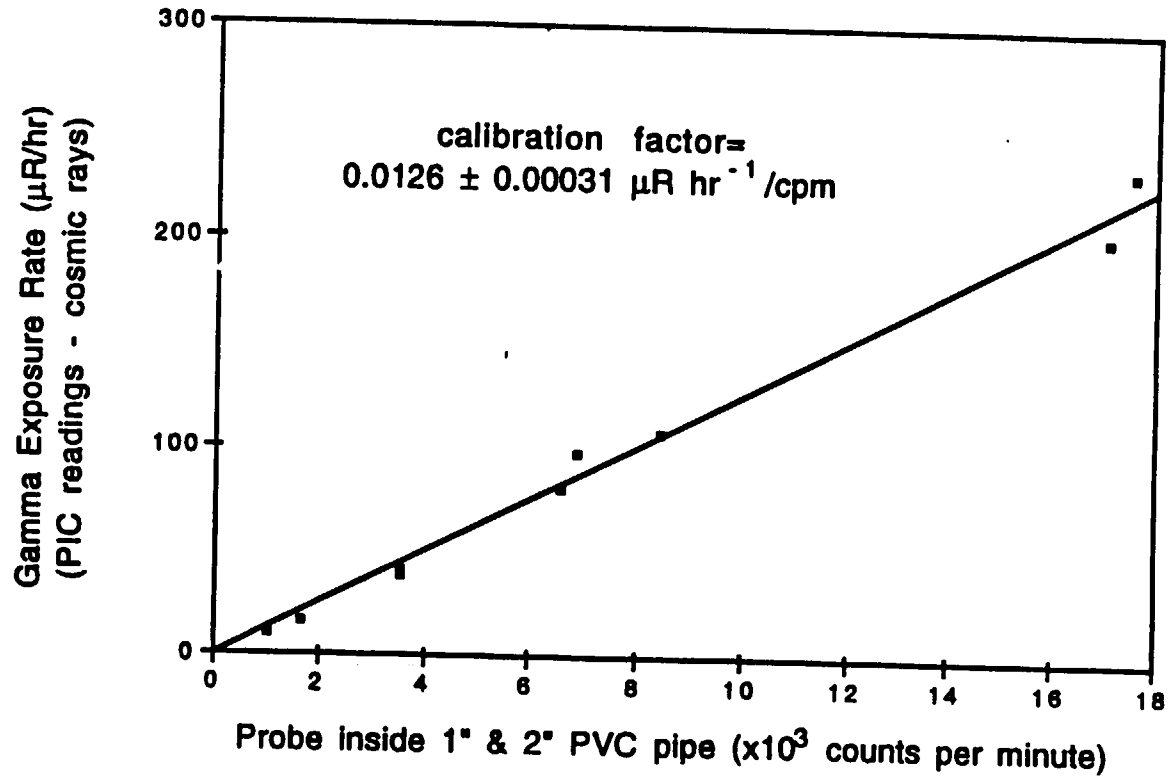



**Figure 4: Least squares fit of the calibration factor for the NaI probe over a $2\pi$ geometry for a volumetrically distributed source of Th-232 and daughters**

The calibration factor for 4 π geometry was obtained by multiplying the 2 π calibration factor by two. We have also made a correction for solid angle which did not appear in the RSA 1990 Report. (See Appendix C.) The RSA 1990 Report did not give estimates of average $^{232}$Th content in the first foot and one half of surface soil because a correction for the reduction in the expected response associated with the solid angle subtended by the top of the hole had not been made. This correction, although approximate, should be reasonably good for the shallow depth readings and we have included its derivation in this document so that concentrations of $^{232}$Th in the first several feet below the surface can be inferred from the results of gamma exposure rates established in the well logging conducted for the RSA 1990 Report. This correction is shown in the Appendix C.

**Derivation of Exposure Rate Underground from $^{232}$Th From First Principles**

The exposure rate produced in air in a borehole can also be derived from first principles as follows: The dose rate to any medium can be calculated for a radionuclide distributed uniformly in the medium at a concentration of C pCi/g with $f_i$ fractional gamma's emitted per disintegration where $E_i$ is the energy of gamma ray i as follows (Spiers 1968) :

$$\mu rad/hr = 2.13\ C \sum f_i E_i$$

The mean energy of the gamma rays emitted by the $^{232}$Th series in equilibrium is about 0.9 MeV, and the total gamma energy emitted per disintegration of the $^{232}$Th parent by members of the series in equilibrium is 2.49 MeV,($\sum f_i E_i$) a value which has been extracted from ICRP-38. (ICRP 38, 1983.)

Since the rate of gamma energy emission equals the rate of absorption in an infinite medium, the formula above gives the gamma dose rate in an infinite medium obtained from the expression above which is 5.304 $\mu rad \cdot h^{-1}/pCi \cdot g^{-1}$ $^{232}$Th. By well established theory, the dose rate in air in a cavity within any medium is given by the ratio of the linear absorption coefficients in that medium to that in air. Using mineral bone as a surrogate for soil, the conversion factor for 0.9 MeV gamma rays is 0.928 rad/R. (Spiers 1968.) The expression derived above then gives 5.304/.928 = 5.72 $\mu R \cdot h^{-1}/ pCi \cdot g^{-1}$. This compares very favorably with the 4 π calibration factor (5.64 $\mu R \cdot h^{-1}/ pCi \cdot g^{-1}$) derived from Beck.

In short this calibration factor is valid with a high degree of accuracy to derive average $^{232}Th$ concentration in soil, since the NaI probe was calibrated to measure μR/hr in air, the quantity determined during the downhole logging.

**Underground Background Gamma Exposure Rates**

An important question is, 'What is the appropriate background to subtract both underground and above ground from the increased gamma measured in each environment?' Borehole 27 was in background soil and the 13 measurements taken from the bottom of the hole to a foot and one half below the surface averaged 1726 counts per minute, equivalent to 21.7 μR/hr using the calibration establishing the relationship between count rate in the sodium iodide probe and exposure rate. This is an underground background and in a 2 $\pi$ geometry the equivalent background would be one half this or 10.9 μR/hr. The background gamma exposure rate underground in 4 inch diameter holes as well as the increased exposure rate which would be due to 5 pCi/g of $^{232}Th$ in soil are shown in Figure 5. In virgin soil the background gamma exposure rate is 22 μR/hr, in FeMo slag, 28 μR/hr, and the exposure rate in each media if it contained an average of 5 pCi/g $^{232}Th$ above normal gamma background would be 50 and 56 μR/hr respectively. The gamma exposure rate would be 163 μR/hr for 25 pCi/g of $^{232}Th$ above background in virgin soil..

**Estimation of $^{232}Th$ Concentration from Underground Exposure Rate Measurements**

Therefore the calculation of average $^{232}Th$ pCi/g in underground soil is obtained with the formulas shown in Appendix B relating concentration to the measured gamma exposure rate. The formula is summarized in simplified form below.

$$C = (Pk_1-21.7)/(5.64)*0.95*R = 0.187(Pk_1-21.7)/R$$

C = the concentration in pCi/g

R = the geometric correction factor, = 1 well below the surface

$Pk_1$ = exposure rate (μR/hr) measured underground

Because the intent of the 1990 report was to identify the horizontal and vertical distribution of underground radioactivity and not to provide information to comply with a subsequent agreement on decontamination of the site, the underground

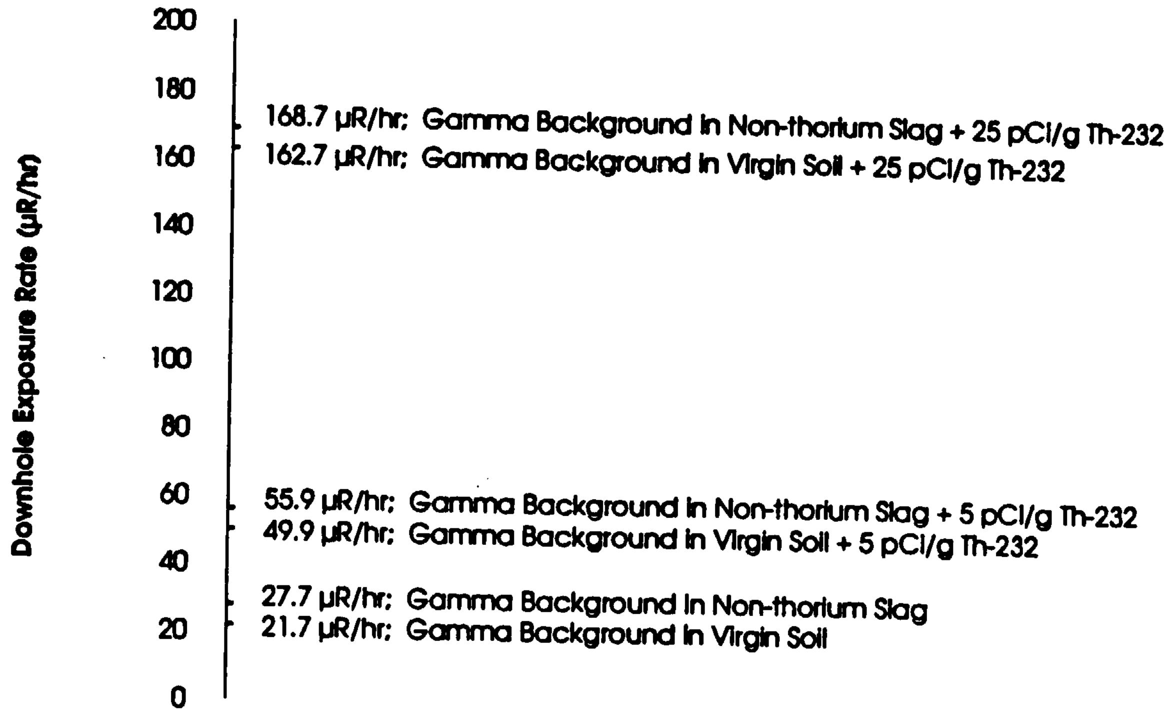



**Figure 5: Underground Background Gamma Radiation**

RSA, 12/30/92

background was rounded to the first significant figure in that report (i.e., 2000 vs. 1726 cpm in virgin soil). However in this and subsequent reports we will not round off background measurements to less than three significant figures. In this report all logging results will be presented in exposure rate in µR/hr which is the primary calibrated measurement.

## REVISED INFORMATION ON EXPOSURE RATE AND AVERAGE $^{232}$TH CONTENT IN BOREHOLES:

The exposure rates measured underground in borehole 28 (background in non-Th bearing FeMo slag) and borehole 27 (virgin soil) are shown in Figure 6. The mean exposure rate in borehole 27 from 1.5 feet and below to bedrock was 21.7 µR/hr. The mean exposure rate in FeMo slag was 27.7 µR/hr, from 1.5 to 6 feet. The exposure rate depth profiles are shown in Figures 7 and 8 for BH's 29 and 32 from which samples were taken every 1.5 feet (See RSA 1990 Report for the sampling protocol) for subsequent radiochemical analysis. BH 32 was chosen because it was at a location just inside the north boundary of the site where the external exposure rate was among the highest found (although still localized). BH 29 was chosen from a location in the pond area which exhibited the highest local surface exposure rate .

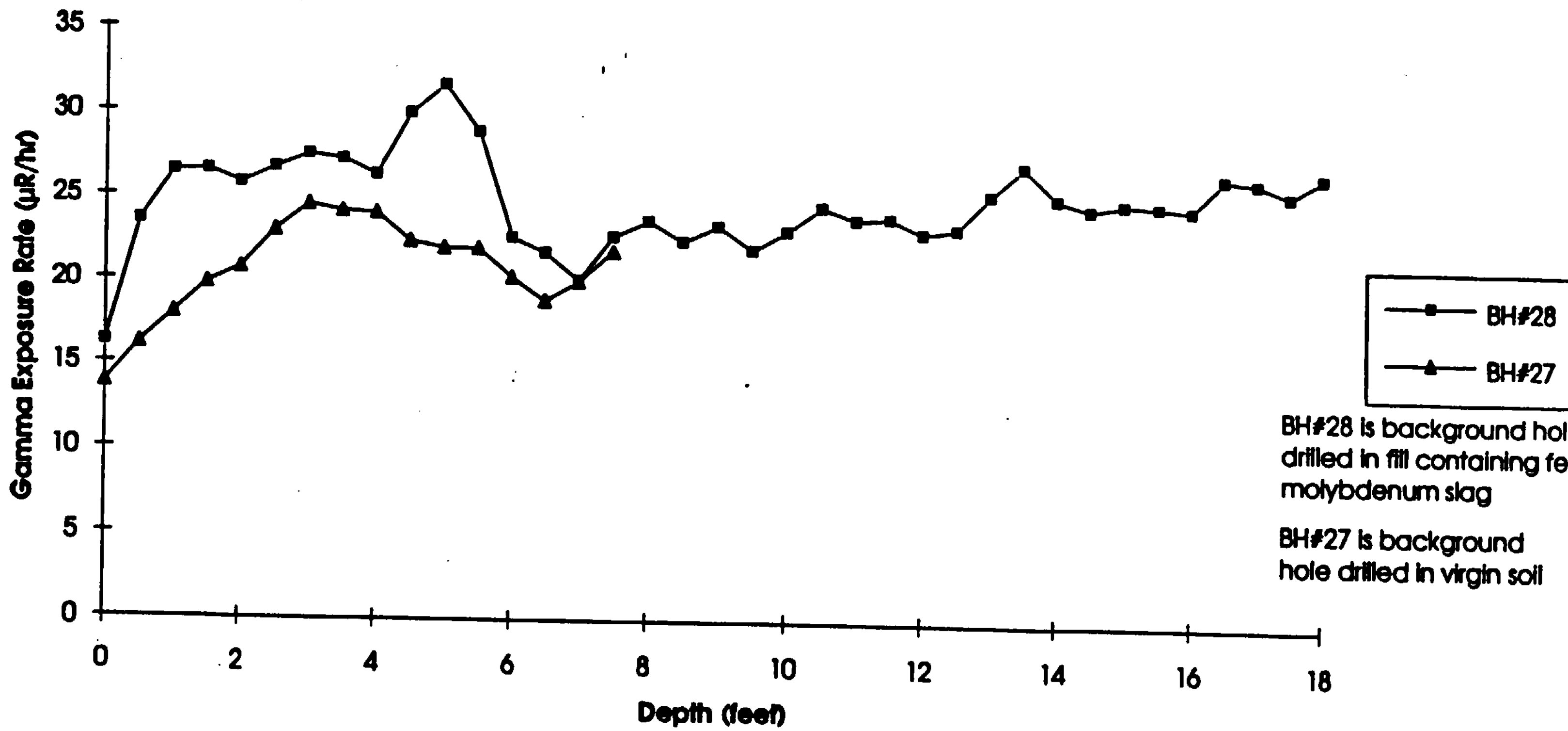
Revised tables and graphs of exposure rate (µR/hr) and. the average $^{232}$Th concentration underground in all the boreholes as a function of depth will be supplied later.

### Effective Volume of Soil Sampled for $^{232}$Th by Gamma Logging

The volume of soil sampled by the gamma probe downhole can also be approximated as follows: The maximum energy gamma ray emitted by $^{232}$Th in equilibrium with its daughters is 2.62 MeV, and the attenuation of these gamma rays in soil can be adequately represented by the attenuation in aluminum. Using the mass attenuation coefficient in aluminum of 0.0384 cm$^2$/g, and a soil density of 1.6 g/cm$^3$ gives a mean free path of 16.3 cm.

$$1/(0.0384 \text{ cm}^2/\text{g} \times 1.6 \text{ g/cm}^3) = 16.3 \text{ cm}$$

**Figure 6:**
**Depth Profile of Gamma Exposure Rate in BH#27 and BH#28**
**(Molycorp, Washington Pa plant site)**



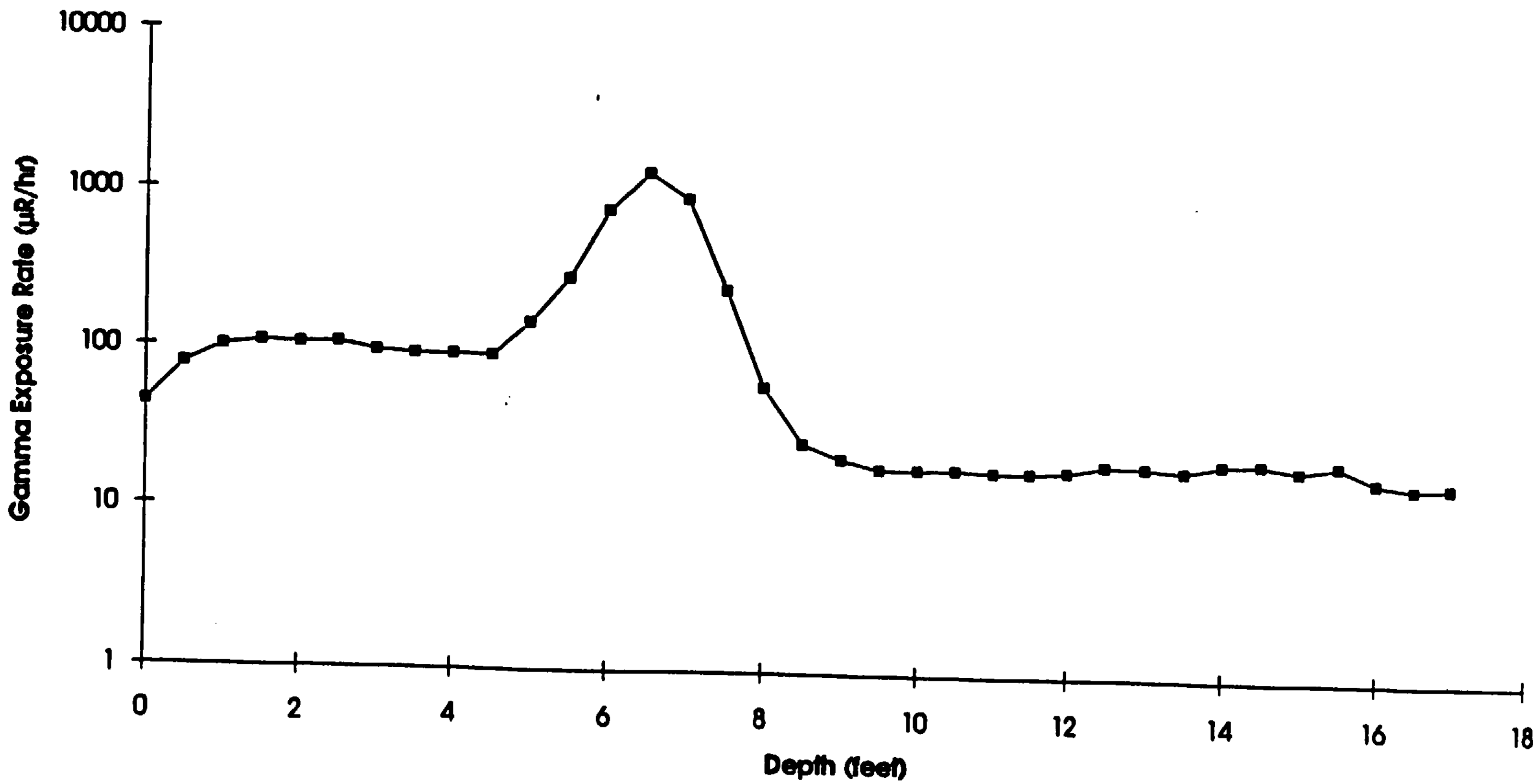

BH#28 is background hole drilled in fill containing ferro molybdenum slag

BH#27 is background hole drilled in virgin soil



RSA, 12/29/92

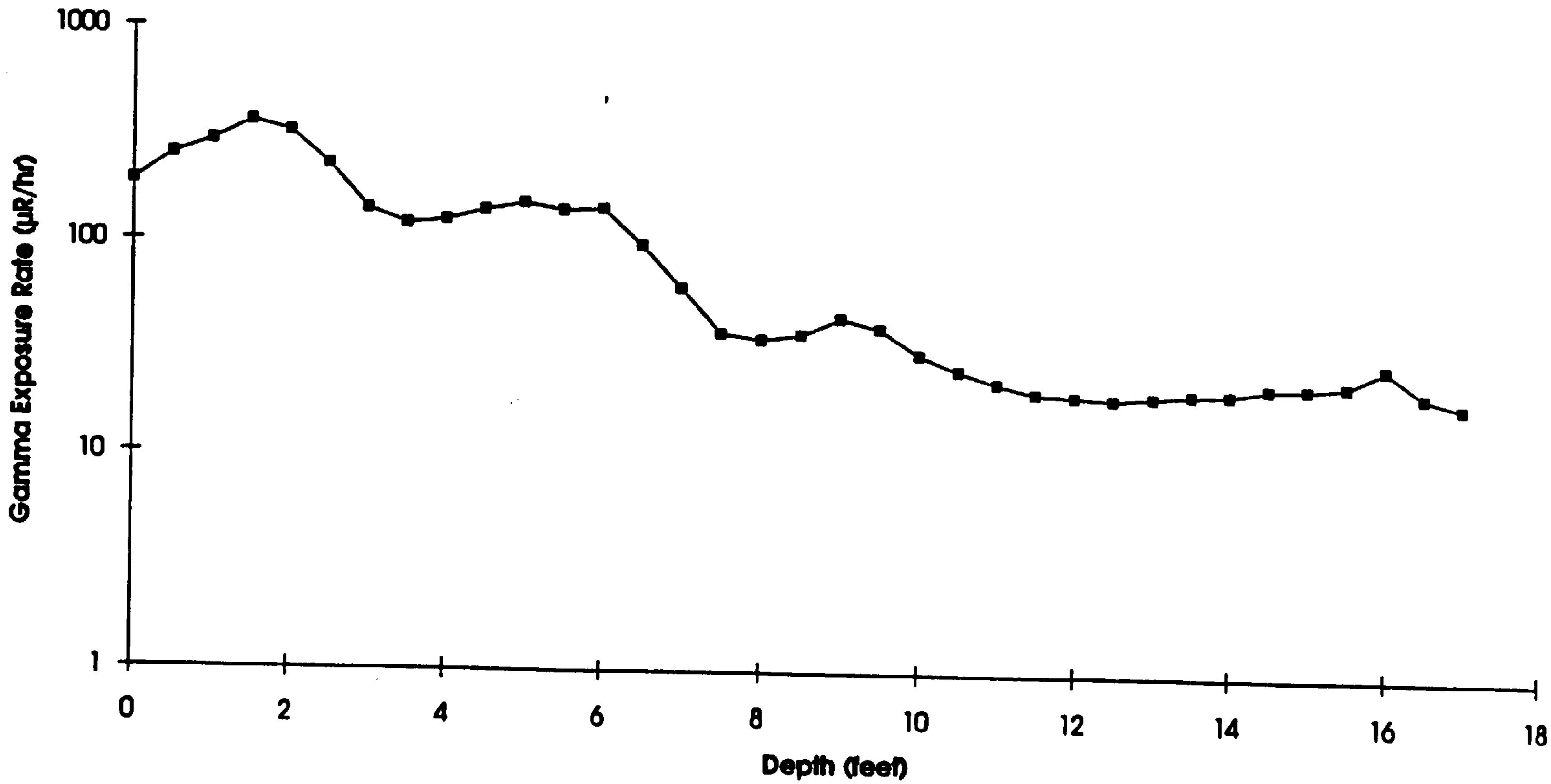
**Figure 7**
**Depth Profile of Gamma Exposure Rate in BH#29**
**(Molycorp, Washington Pa plant site)**






RSA, 12/23/92

**Figure 8**
**Depth Profile of Gamma Exposure Rate in BH#32**
**(Molycorp, Washington Pa plant site)**




RSA, 12/23/92

After 2 mean free paths in soil 13.5% of the primary flux is uncollided and after 3 mean free paths 5%. Therefore a significant part of the exposure comes from a sphere with a radius between 2 and 3 mean free paths. To illustrate we take 2.5 mean free paths or 41 cm as the radius within which much of the exposure at any point at the center of a sphere of material originates. The spherical mass of soil effectively sampled by the gamma probe is about (0.45)1/2 metric ton.

**Radiochemical Analysis of Slag and Core Samples**

This section presents results of radiochemical and alpha spectrometric measurements of the thorium isotopes in one sample of slag and in borehole samples. In addition the uranium concentration was also measured by alpha spectrometry in one aliquot of the same sample of slag. We believe but have not yet been able to confirm that the sample of slag which RSA has analyzed and was furnished by Molycorp came from the slag pile, which according to the report of Applied Health Physics, May 22, 1975 has an average specific activity of 1250 pCi/g of $^{232}$Th. (See Table 1.)

The radiochemical methods used are those reported by Singh and Wrenn (1988) using $^{229}$Th as a tracer (Wrenn, et al 1978). We had a great deal of difficulty in obtaining complete dissolution of this slag. This was finally made possible by heating finely ground samples in a mixture of concentrated nitric and hydrofluoric acid. Thus the analysis of soil samples in which small particles of slag may have been admixed is particularly difficult and time consuming, more so than we had originally anticipated. This also suggests that the material is not readily leachable into the environment.

The thorium was extracted from the samples, electrodeposited on platinum disks, and counted in EG&G alpha spectrometers with solid state surface barrier detectors. All spectra were stored in a 386 computer memory and will be kept on file until the termination of this program of site evaluation and decontamination. Hard copies of the spectral data have also been made and filed.

RSA also maintains a careful program to evaluate the analytical results of any given sample. In alpha spectrometry there are many potential problems to which attention must be carefully paid. For example: If mass on the planchette exceeds 100 μg a broadening of the spectrum occurs and it is difficult to completely resolve alpha peaks from each other. In the case of the samples here, we have used $^{229}Th$ as a tracer (Wrenn, 1978). $^{229}Th$ interferes slightly in the $^{230}Th$ region and therefore the non-Poisson error in the results for $^{230}Th$ are potentially larger than for $^{228}Th$ and $^{232}Th$.

The radiochemical results from 11 of the samples collected underground in boreholes 29 and 32 from the sample of slag are shown in Tables 2 and 3. Figure 9 shows the alpha spectrum of the slag to which no tracer was added, and the results for this sample are shown in Table 3 as slag aliquot 4. Taking $^{232}Th$ as 100%, based strictly on the count rates in the regions of interest, the relative $^{228}Th$ content was 95.8 ± 2.5% and the relative $^{230}Th$ content of slag was 6.5 ± 0.5%. The absolute activity can only be established using tracer. Two measurements of aliquots of the same sample in which the results differed by approximately 20% are shown as thorium slag aliquot 1 (1018 pCi/g) and aliquot 2 (1224 pCi/g). The difference reflects variations in sample homogeneity, analytical variability, and non-Poisson error. Two analyses were made of aliquots of the same sample of slag for uranium isotopes using alpha spectrometry, once using a $^{232}U$ tracer and once with a $^{233}U$ tracer. The two results showing about 54 and 68 pCi/g of $^{238}U$ are reasonably consistent. This suggests that the $^{238}U$ is in equilibrium with the $^{230}Th$. The ratio of $^{230}Th/^{232}Th$ determined by alpha spectrometry of the slag sample with tracer added is higher than that obtained when the tracer was not added. This is probably due to the inability to obtain an exact correction for the $^{229}Th$ tracer contribution to the $^{230}Th$ energy region, which varies with the mass deposited on the planchette.

The radiochemical results measured in thorium slag, around 1000-1200 pCi/g, are consistent with the Applied Health Physics Report evaluation of the average concentration of $^{232}Th$ in the slag pile, 1250 pCi/g $^{232}Th$. (See Table 1.)

Table 2 also shows the results from alpha analyses of the core samples collected from boreholes 29 and 32. Complete results from eleven samples are presented, two are partially complete results from two samples, showing $^{232}Th$ only. Three samples are being processed and are not yet complete. The results for $^{230}Th$ are subject to revision.

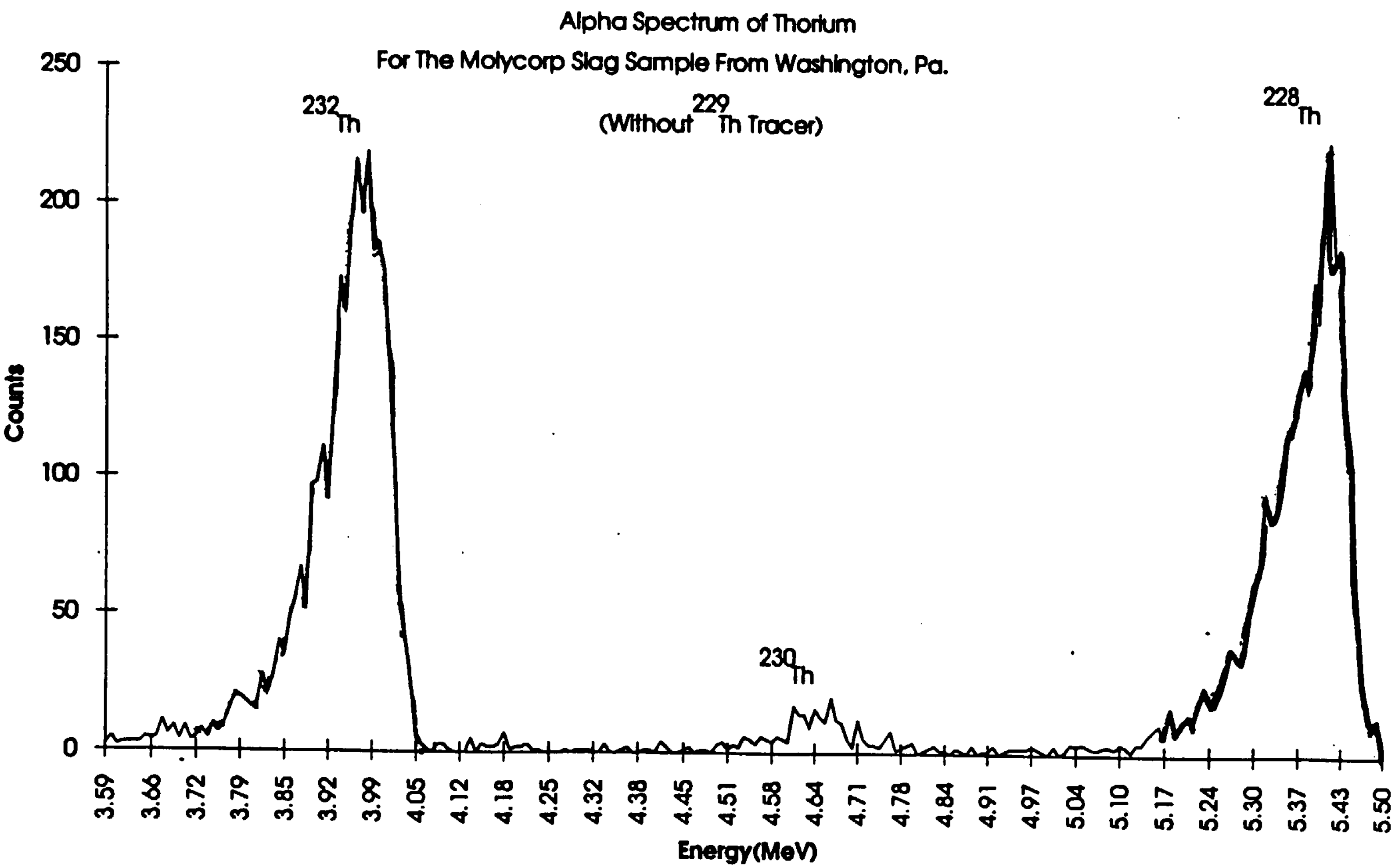



Figure 9. Alpha Spectrum of Thorium Slag Sample

Figure 9

RSA 12/21/1992

**Table 2: Alpha Spectrometric Analysis of Core ples Taken from BH#29 and BH#32 with Corresponding Gamma Probe Measurements**

Summary December 18, 1990

| | | | NaI Probe | | Activity pCi/g | | | | |
|---|---|---|---|---|---|---|---|---|---|
| Sample # | Borehole | Depth (ft.) | cpm | µR/hr | TH-228 | TH-230 | TH-232 | Yield | Accepted/Rejected |
| B29S3 | B29 | 3 | 7600 | 95.8 | 5.95 ± 0.183 | 2.1 ± 0.078 | 6.16 ± 0.18 | 45% | Accepted 10/29/92 |
| B29S4 | B29 | 4.5 | 7202 | 90.7 | 44.02 ± 1.001 | 10.97 ± 0.419 | 45.08 ± 0.998 | 47% | Accepted 10/29/92 |
| B29S9 | B29 | 12 | 1501 | 18.9 | 1.32 ± 0.088 | 1.19 ± 0.086 | 1.13 ± 0.095 | 37% | Accepted 10/29/92 |
| B29S10 | B29 | 13.5 | 1562 | 19.7 | 3.1 ± 0.17 | 1.78 ± 0.214 | 3.05 ± 0.172 | 46% | Accepted 11/16/92 |
| B29S11 | B29 | 15 | 1617 | 20.4 | 0.98 ± 0.059 | 0.96 ± 0.068 | 0.86 ± 0.064 | 57% | Accepted 11/16/92 |
| B29S12 | B29 | 16.5 | 1293 | 16.3 | 1.89 ± 0.14 | 0.93 ± 0.258 | 1.26 ± 0.171 | 20% | Accepted 11/24/92 |
| B32S3 | B32 | 3 | 11233 | 141.5 | 5.89 ± 0.233 | 17.4 ± 0.28 | 5.3 ± 0.246 | 70% | Accepted 10/29/92 |
| B32S4 | B32 | 4.5 | 11268 | 142.0 | 30.12 ± 0.647 | 15.16 ± 0.363 | 28.27 ± 0.668 | 40% | Accepted 10/29/92 |
| B32S5 | B32 | 6 | 11458 | 144.4 | N/A N/A | N/A N/A | 1.36 ± 0.195 | 14% | Accepted 12/18/92 |
| B32S8 | B32 | 10.5 | 2047 | 25.8 | N/A N/A | N/A N/A | 1.97 ± 0.24 | 25% | Accepted 12/18/92 |
| B32S9 | B32 | 12 | 1574 | 19.8 | 2.56 ± 0.197 | 1.95 ± 0.478 | 2.17 ± 0.214 | 19% | Accepted 10/29/92 |
| B32S10 | B32 | 13.5 | 1631 | 20.6 | 6 ± 0.268 | 4.41 ± 0.276 | 5.33 ± 0.284 | 41% | Accepted 10/29/92 |
| B32S11 | B32 | 15 | 1773 | 22.3 | 2.18 ± 0.124 | 1.71 ± 0.209 | 2.18 ± 0.124 | 92% | Accepted 10/29/92 |

± represents one standard deviation, Poisson error, counting statistics only.

N/A: unacceptable spectral resolution to analyze for Th-228 and Th-230.

RSA, 12/29/92

## Table 3: Alpha Spectrometric Analysis of Aliquots of Th Bearing Slag

Summary December 18, 1990

| | Activity pCi/g | | | | |
|---|---|---|---|---|---|
| Sample # | TH-228 | TH-230 | TH-232 | Yield | Accepted/Rejected |
| Thorium Slag, aliquot 1 | 1018.19 ± 6.505 | 96.34 ± 2.117 | 1019.26 ± 6.501 | 45% | Accepted 10/29/92 |
| Thorium Slag, aliquot 2 | 1223.65 ± 18.757 | 96.11 ± 6.377 | 1234.77 ± 18.672 | 5% | Accepted 12/18/92 |
| Thorium Slag, aliquot 4 | 95.8 ± 2.50% | 6.5 ± 0.50% | 100% | NA | Accepted 12/8/92 |

| | U-238 Activity | U-234 Activity | Recovery |
|---|---|---|---|
| Thorium Slag, aliquot 5 | 55.3 ± 0.031 | 53.8 ± 0.948 | 19% |
| Thorium Slag, aliquot 6 | 68.3 | 68.3 | 12% |

1 Data acquired on 30 September 1992; analyzed with tracer.

2 Data acquired on 23 November 1992; analyzed with tracer.

4 Data acquired on 03 December 1992; analyzed without tracer.
The numbers given are ratios of the counts with respect to Th-232

5 Analyzed using U-232 as a tracer.

6 Analyzed for U-238 using U-233 as a tracer, U-234 assumed to be in equilibrium.

RSA, 1/4/93

These samples all show equilibrium between $^{228}$Th and $^{232}$Th. The lowest result obtained shows approximately 1 pCi/g of all three thorium isotopes, and this most likely represents a background level, being consistent with typical background concentrations in soil found elsewhere (NCRP-50, 1976).

Sample B32S3 is unusual in that it shows more $^{230}$Th than $^{232}$Th and possibly derives from a material other than the FeCb slag based on all analyses of FeCb slag we have seen to date (RSA 1992, AHP 1975, ORAU, 1985). Based upon results from gamma spectrometric analysis from 55 samples of surface soil taken from the site (reported by ORAU 1985) which showed elevated concentrations of $^{232}$Th above background (range 10 to 1380 pCi/g) the ratio of $^{226}$Ra/$^{232}$Th was 0.22, somewhat higher than our observed ratio of $^{230}$Th/$^{232}$Th in one sample of slag. BH 32 was also taken from the area exhibiting the highest background in the north plant area. Further underground core samples may be required to establish the extent of this material and its origin.

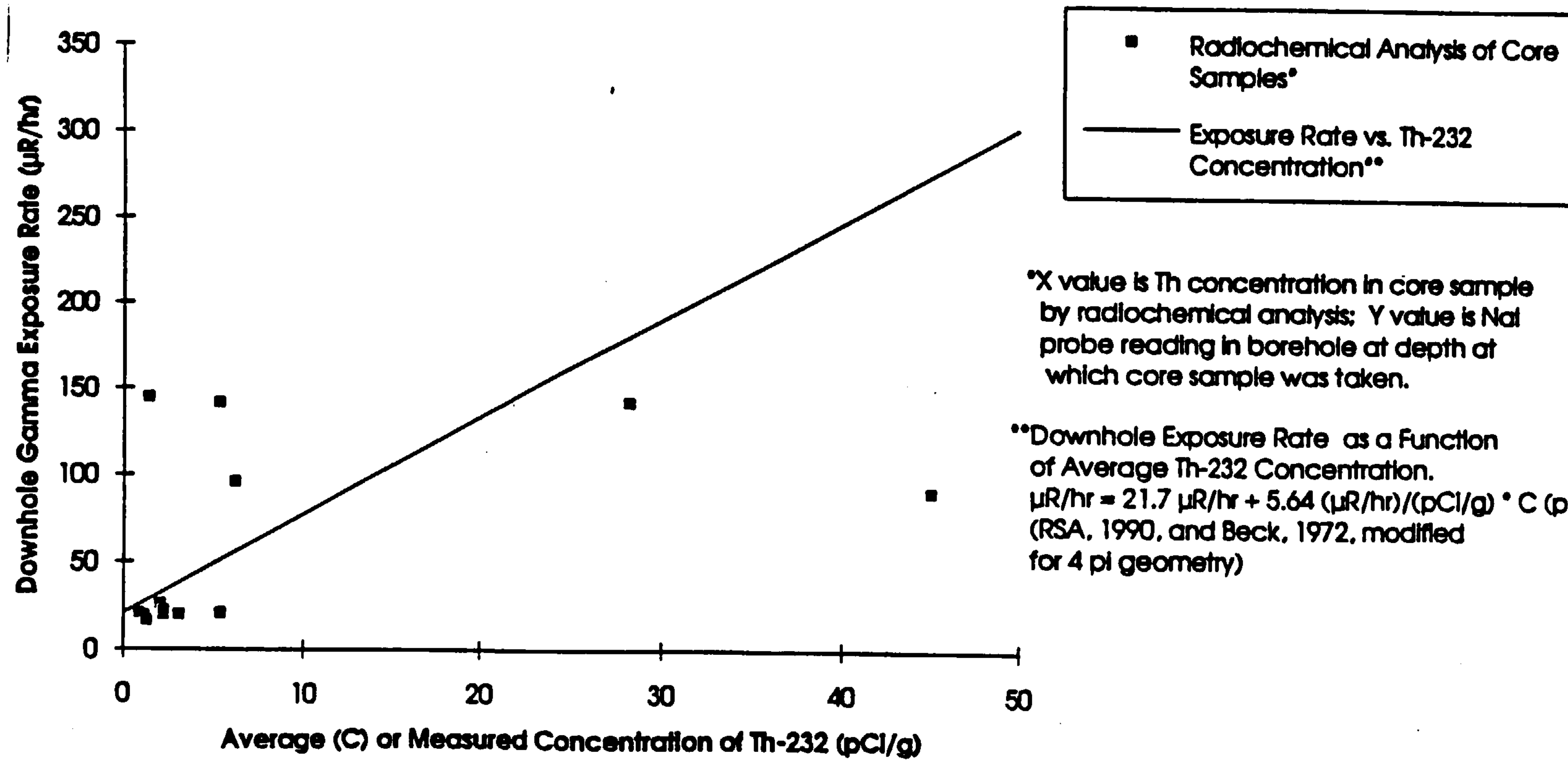
Figure 10 is a scatter plot of exposure rate (μR/hr) measured downhole (at the depth where the soil sample was taken) as a function of $^{232}$Th concentration (pCi/g, measured by alpha spectrometry) of the soil sample. The line on the graph in Figure 10 is the calibration curve for the NaI probe (expressed in $\mu R \cdot hr^{-1}/pCi \cdot g^{-1}$) derived from the work by Beck and reported in the RSA 1990 report. Several of the points show less thorium than the response curve would predict and several show more. The variation is, in fact, quite large, but not surprising given the fact that the soil volume sampled was very small compared to the volume of the region sampled by the NaI gamma probe.

For example if material with a specific activity of 1250 pCi/g were mixed with background material at 1 pCi/g a very small piece or portion of the higher specific activity material could influence the average concentration measured in the alpha spectrometric analysis quite dramatically, depending on whether or not it was included in the core sample and aliquot analyzed.

The advantage of the **down hole gamma measurements** is that they **integrate the results over a larger volume of soil than a single soil sample; the results are also directly interpretable in terms of ability to produce external exposure.** Therefore RSA sees no reason to believe that the calibration factors

## Figure 10

**Radiochemical Analysis of Th-232 Concentration in Core Samples from BH#29 and BH#32 vs Downhole Measurements of Gamma Exposure Rate; and, Average Th-232 Concentration in Soil Calibrated against Downhole Exposure Rate.**




*X value is Th concentration in core sample by radiochemical analysis; Y value is NaI probe reading in borehole at depth at which core sample was taken.

**Downhole Exposure Rate as a Function of Average Th-232 Concentration.
µR/hr = 21.7 µR/hr + 5.64 (µR/hr)/(pCi/g) * C (pCi/g)
(RSA, 1990, and Beck, 1972, modified for 4 pi geometry)

RSA, 12/23/92

developed in the RSA 1990 Report are not valid. However one needs to understand that they represent averages over much larger volumes of soil than would be taken in any reasonable size single soil or sediment sample. Even the volumes over which the downhole external gamma measurements integrate, are small compared to the volumes of material which would contribute significantly to any future exposures.

## RELATIONSHIP OF ABOVE GROUND GAMMA EXPOSURE RATE TO CONCENTRATION OF $^{232}$TH IN SURFACE SOILS:

The radius of material distributed in surface soil which contributes to external exposure in air is much larger than that underground, primarily because the mean free paths of gamma rays are much longer in air than in soil. Beck (personal communication citing Artuso 1981, 1992)) indicates that 95% of the exposure rate coming from a distributed natural source is due to radioactivity within a radius of 10 meters. To a depth of 20 cm a right circular cylinder of soil with a density of 1.6 g/cc would weigh about 100 metric tons. Thus gamma ray measurements in air at 1 meter above the surface effectively sample large volumes of soil and average the resulting potential for exposure. In the Site Characterization Plan and the RSA survey in 1990, a gamma grid of 20 feet spacing (about 6.5 meters) was proposed or used. The exposure rate at each measurement point, due to a disc source with a radius of 6.5 meters results from the integrated average activity of $^{232}$Th in soil to a depth of 20 cm which has a mass of about 40 metric tons. To properly assay the mean activity of $^{232}$Th in this volume of material by soil sampling followed by laboratory analyses would require a prohibitive number of samples and analyses. Therefore external gamma survey measurements are an accurate and effective means of assessing average soil concentration of $^{232}$Th, with an exposure rate at 1 meter above a uniformly contaminated half-space of 2.82 $\mu R \cdot h^{-1} / pCi \cdot g^{-1}$.

## REPLY TO THE NRC'S GENERAL COMMENTS, DATED OCT. 29, 1992 :

Based on the comments in this NRC communication we believe the NRC has not properly characterized the calibration procedure used by RSA in the 1990 report on underground radiation levels at the Molycorp Washington, Pennsylvania site. The preceding report, has the intent of making those procedures more understandable and clearer to the Staff. The preceding sections should be read before reading these replies to the NRC comments.

The measurements made down boreholes were calibrated to measure exposure rate, using a sodium iodide probe which was cross calibrated against a pressurized ionization chamber, for which the calibration is traceable to NIST. Thus the exposure rate (μR/hr) in each borehole is known as a function of depth. The results in several boreholes are plotted in the accompanying report.

Since the borehole geometry is 4 $\pi$, the exposure rate in 2 $\pi$ geometry (i.e. if the overburden were removed down to the depth where the measurement was made) is very close to one half that in the 4 $\pi$ geometry. In short the exposure rate measurements underground are relatable to the exposure rate which would be established if the material were exposed.

The gamma measurements produce an average over a much larger volume of soil than the volume of soil samples which were removed from the borehole; about 90% of the exposure rate in planar geometry originates above a depth of about 20 cm (derived from Beck, 1972) and the mean free path in soil of gamma rays from the $^{232}$Th series is about 21 cm. Thus the exposure rate measured in a borehole at a given depth can be thought of as averages from a spherical source which has a mass about 1/2 to 1 metric ton with a diameter of 2.5 to 3 feet (see page 12).

Soil samples, on the other hand, are usually much smaller samples. In the laboratory, for alpha spectrometric analyses, between 0.1 and 1 gram are analyzed, usually about 0.1 gram. The largest core taken in the field was 2 inches in diameter. Even if all the material in a core sample six inches long were analyzed, the volume would represent less than 1% of the volume "sampled" by the gamma measurement. The in situ gamma measurement gives a much more representative measure of the average $^{232}Th$ concentration than could any reasonably sized core sample. Moreover 0.1 gram of sample analyzed represents only 0.02% of the mass of the core sample taken. Since most samples analyzed were about 0.1 gram, the soil aliquot analyzed represents less than 1/1,000,000 the mass of soil effectively sampled by the gamma measurements.

It is therefore not reasonable to expect that analyses of the core samples should confirm the external gamma calibration. Also the statement by the NRC staff that "The resulting high degree of uncertainty in the derived $^{232}Th$ would propagate into the resulting doses to individuals calculated for times during decontamination and decommissioning and following unrestricted release" is the opposite of what is expected. Averages inferred from gamma measurements would have much less uncertainty and variability than would results from soil samples. Thus, gamma measurements are preferable over soil samples in order to minimize the uncertainties to asses the doses expected from radioactivity which is not uniformly distributed in soil.

The NRC also states that, "Precise determination of the extent and quantity of residual activity is a prerequisite to assessing doses to be used as basis for NRC decommissioning decisions". Although RSA agrees that the extent and quantity of contamination should be established, we do not believe it would be reasonable to require that the scale of variation to be investigated be on the order of inches or feet, since both external and internal exposures which might be delivered would be determined by radioactivity concentrations averaged over much greater distances.

Since the slag pile is composed of material which has a mean specific activity of 1250 pCi/g $^{232}Th$, and since some of this material is still distributed in small pieces on site, we believe that averages which are more closely related to expected radiation doses rather than maximum specific activities which can be found in small samples, should be used for both dose estimation and compliance determinations.

We believe that it is appropriate that Molycorp use the quantitative determination of average $^{232}Th$ concentration underground determined with in situ gamma measurements as a basis to establish cleanup criteria, as a basis for the dose assessment, and to demonstrate compliance.

Also referring to the downhole measurements, the NRC stated that, "additional information would be required to demonstrate the accuracy of the calculated concentrations. This demonstration should be based on direct measurement of soil concentrations via sample analysis, portable survey meter, or some combination of the methods." We point our that the measurement of count rate underground in a NaI crystal with a scaler to record counts over preset time intervals is equivalent to a survey meter. Therefore the calibration RSA performed is consistent with this recommendation of the NRC.

Molycorp did not agree to a cleanup level of 5 pCi/g in the July 8, 1992 meeting with the NRC. In fact it was specifically emphasized in the technical briefing that Molycorp intends to consider a modified Option 2 (25 pCi/g $^{232}Th$) for subsurface levels. It was stated that surface radiation levels above background would not exceed the equivalent of that produced by an average of 5 pCi/g $^{232}Th$ in equilibrium, or a total of 14.1 µR/hr above background measured 1 meter above the surface averaged over a 10 meter grid spacing. The Molycorp proposals were identified in the table entitled "Proposed Actions" which was given to the NRC on July 8th during the briefing by Molycorp, and this table was retransmitted by the NRC to Molycorp as an enclosure to their memorandum dated July 31, 1992.

**REPLY TO THE NRC'S SPECIFIC COMMENTS, DATED OCT. 29, 1922:**

**1.** The results of 11 of the 16 core soil samples taken underground are given in the preceding report (RSA 12/30/92). The delay in its availability was occasioned by the need to develop a new technique to completely dissolve the refractory particles of slag. This was accomplished by heating pulverized samples in combined, heated concentrated nitric and hydrofluoric acid.

**2.** The background count rate underground established in virgin soil was 1726 cpm and is discussed in detail in the preceding report. The 2000 cpm figure plotted in the RSA 1990 Report was a rounded number used for the purposes of the RSA 1990 Report. We agree that the results in borehole #28 do not represent natural soil background nor were they intended to. They do, however, over the first six feet of depth, represent background in slag which was produced from other processes than the ones involving FeCb ore or concentrate which was licensed by the NRC. A plot of exposure rate vs. depth in FeMo slag is given in Figure 6. Thus it may well be an appropriate background above which to measure compliance.

3. The NRC staff asks, "Why would cosmic rays not produce a response in a NaI scintillation detector as they would in an ion chamber?" Cosmic rays are known to produce less of a response in NaI count rate instruments than do gamma rays. The reason can be illustrated as follows. A fast meson (mesons comprise most of the cosmic ray flux at sea level) passing through an inch of NaI would deposit about 20 MeV of energy, but would be recorded by the PM tube and electronic scaler as one event. A 0.2 MeV gamma ray would likewise be recorded as one event. Thus MeV for MeV deposited in the crystal, the associated count rate meter would respond 100 times more strongly to the gamma rays than the cosmic rays. A pressurized ion chamber on the other hand integrates charge, and hence ion pairs produced in the sensitive volume, and therefore responds to cosmic rays almost equally with gamma rays per unit of deposited energy and therefore also with respect to exposure and dose. A useful reference for this subject area is NCRP-50.

4. The response to the request for identification of the water wells and their relationship to the ORAU report will be provided by Molycorp staff as RSA was not involved in the location or construction of these wells. RSA has not yet made any study of radioactivity in well water samples. However some information is available from Molycorp. This information will be furnished in the report of the results of the Site Characterization Study and possibly also during pond closure.

5. The contention of the NRC that the value 0.01% thorium would be used as a criteria for excavation of radioactive contaminated material is the NRC's own conclusion. It was not our intent in the RSA 1990 Report to suggest that 0.01% be used as a level for decontamination. The NRC and Molycorp have subsequently agreed on a process which involves extensive site characterization, a dosimetric analysis and development of a site decommissioning plan. It would accordingly be premature now to select levels of activity to which the

decommissioning will be accomplished. The underground radiation exposure rate measurements will be used to evaluate the average concentration of $^{232}Th$ and also in the dosimetric evaluations, including those involving assumed future scenarios of exposure.

6. In this comment, the reviewer uses the number 9.33 μR/hr, taken from page 33, as the natural background for the site. The text on page 33 does not claim that 9.33 μR/hr, taken at location PIC18, is an adequate measure of natural background for the site. This single PIC reading, taken on Molycorp property immediately adjacent to the site, should not be interpreted as establishing background. RSA did not include a program to measure the natural gamma background in the vicinity of the site as part of the 1990 study. The text on page 33 simply points out that the 9.33 μR/hr reading does not result from a gamma spectrum representative of thorium because it is due to naturally occurring emitters, and is only partly due to thorium.

The statement that 31 μR/hr is roughly twice background is based on a natural background exposure rate of 11 μR/hr reported in the ORAU 1985 report on the site. RSA assumed that ORAU was reporting gamma background (since the readings were taken with NaI instruments, which don't respond appreciably to cosmic) so for the executive summary we added 4 μR/hr cosmic radiation to the natural gamma to obtain 15 μR/hr. Twice 15 is 30 μR/hr. Therefore, the conclusion as we stated it in the report, based on our understanding of the natural radiation background at the time, was correct. More recent work by RSA at the Washington Pennsylvania site indicates that the natural background for the area may be less than that reported by ORAU. Appendix A gives the results of 12 off-site PIC measurements made in the summer of 1992, which averaged 10.5 μR/hr gamma's plus cosmic. Molycorp will include a rigorous study of the natural radiation background for the plant site as part of the Site Characterization Report.

As a matter of definition, RSA and Molycorp request the NRC to make a distinction between natural external background and natural gamma background, since the two are not the same. Natural background, as measured by the PIC, includes both gamma and cosmic radiation. Twice external natural background, therefore, is twice the measured exposure rate with a pressurized ionization chamber. For external radiation when we use the term "twice natural background," we mean double gamma plus cosmic.

The reviewer also pointed out that in examining Site Map III in the RSA 1990 Report, it appeared to him or her that readings exceeded the natural background by a factor of two or more over much of the site. The two reasons why these conclusions are incorrect follow:

(a) The numbers reported on the map are based on a calibration factor that was derived by measurements made over a distributed thorium source. The calibration is accurate when used over soil contaminated with sufficient amounts of thorium that the radiation being measured comes predominately from thorium and its daughters. When the measurements are made over soil that is not contaminated above normal background with thorium, the spectrum is only partly due to thorium, and the gamma ray spectrum emitted from the soil is softer (i.e., has a lower energy frequency distribution) than that for Th. Using the calibration factor established for thorium contaminated areas for measurements taken over uncontaminated soil has the effect of overestimating the gamma background. The calibration factor used for the NaI survey meter in the 1990 report (0.73 true/indicated) is valid for exposure rates that exceed 20 μR/hr, but at the lower exposure rates and softer gamma spectra, characteristic of natural background, the calibration factor is closer to 0.6. Offsite, in clearly natural background areas, the true indicated gamma exposure ratio is approximately 0.55. (See Appendix A.) For the purposes of the 1990 report, RSA considered this overestimation to be a second order effect, and therefore we did not include a correction for it. In the Site Characterization Report, we will make a correction for this factor.

(b) Much of the Molycorp site is covered with fill. The fill includes ferro-molybdenum slag and other material from decades of industrial activity at the site. Except for the FeCb slag buried in portions of the site, none of the fill is licensed radioactive material. However, because the Washington Pennsylvania area has an unusually low natural external gamma radiation background (generally under 8 μR/hr), this non-licensed, non-radioactive fill will tend to raise the background just by dint of the fact that it was brought into the area from somewhere else. Since the natural gamma background in

Washington Pennsylvania is naturally low, material brought in from outside will probably tend to raise the natural background, rather than lower it.

Based on the newly available data given in Appendix A, it would be correct to say that the natural gamma background is about 8 µR/hr, and that 16 µR/hr is twice gamma background. 22.8 µR/hr [= 2*(8 µR/hr gamma + 3.4 µR/hr cosmic)] is double the external natural background. The NRC staff suggestion that "residual contamination levels appear to contribute <u>significantly</u> to the surface exposure rates over a large portion of the study area," is incorrect. There are 422 readings reported on Site Map III in the 1990 report. Of those readings, only 92, or 22%, are above 22.8 µR/hr. Of those 92 elevated readings, 34 are located in a limited area adjacent to the north fence line. For the readings taken outside of this limited area along the north fence line, only 14% are elevated above twice natural background.

7. We agree with the comments of the NRC in the first paragraph and will attempt to construct cross sectional maps of underground contamination when a greater density of borehole information becomes available.

8. The 25 µR/hr level alluded to on the July 8, 1992 meeting is not inconsistent with the 30 µR/hr cited in the RSA 1990 report for total external exposure. In fact with 30 µR/hr total external exposure rate the gamma contribution would be approximately 26 µR/hr.

Based on measurements of background off site made since the July 8th meeting our calculations suggest that 22 or 23 µR/hr of gamma might be a more appropriate level as being equivalent to the exposure rate from gamma background plus an average 5 pCi/g $^{232}$Th in surface soil. We will however await the results of a more extensive background survey during the site characterization study, before deriving this gamma exposure rate equivalent to 5 pCi/g $^{232}$Th above background.

9. A reply to these comments will be made by Molycorp staff. However we believe that a number of pilot studies such as those suggested by the NRC will be both useful and essential to effectively plan for decontaminating the site. In its review of the report the NRC staff indicated that it was not convinced that the

downhole calibration was a valid one. RSA points out that use of external gamma to assess average concentration of thorium in soil is a technique recognized in both the scientific literature and the NCRP publications. Moreover gamma measurements of this type average over reasonably large variations, and are directly related to the potential for human exposure, being direct radiation measurements. Use of gamma measurement to infer average $^{232}Th$ concentrations should produce less variability in estimation of doses than should soil sampling. In this report we have laid out the rationale and additional information for accepting the calibration factors derived in the RSA 1990 Report and present additional information on the isotopic composition of thorium in the slag pile and additional information on thorium isotopes found underground in boreholes 29 and 32.

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# Appendix A: Off-site PIC Readings, Molycorp, Washington Pa Plant

| Pressurized Ionization Chamber | | | | | | | | Scintillometer |
|---|---|---|---|---|---|---|---|---|
| PIC Location Number | date | time | µR | minutes | seconds | Total (µR/hr) | Gamma (PIC - cosmic) | Ludlum Model 19 (RSA) |
| #10 | 8/24/92 | 4:15 PM | 2 | 11 | 54 | 10.08 | 6.68 | 12.60 |
| #11 | 8/25/92 | 12:09 PM | 2 | 11 | 46 | 10.20 | 6.80 | 12.62 |
| #12 | 8/25/92 | 1:00 PM | 2 | 12 | 10 | 9.86 | 6.46 | 11.75 |
| #13 | 8/25/92 | 2:15 PM | 2 | 11 | 11 | 10.73 | 7.33 | 13.00 |
| #14 | 8/25/92 | 3:15 PM | 2 | 10 | 17 | 11.67 | 8.27 | 14.55 |
| #15 | 8/25/92 | 4:15 PM | 2 | 10 | 53 | 11.03 | 7.63 | 12.80 |
| #16 | 8/25/92 | 4:45 PM | 3 | 17 | 29 | 10.30 | 6.90 | 12.18 |
| #17 | 8/25/92 | 5:45 PM | 2 | 11 | 57 | 10.04 | 6.64 | 12.25 |
| #18 | 8/25/92 | 6:30 PM | 2 | 11 | 32 | 10.40 | 7.00 | 13.20 |
| #19 | 8/26/92 | 10:00 AM | 2 | 11 | 6 | 10.81 | 7.41 | 13.13 |
| #20 | 8/26/92 | 11:30 AM | 2 | 12 | 13 | 9.82 | 6.42 | 11.83 |
| #21 | 8/26/92 | 12:00 PM | 2 | 10 | 45 | 11.16 | 7.76 | 14.28 |
| | | | | | Average | 10.51 | 7.11 | 12.85 |
| | | | | | Standard Deviation | 0.574 | 0.574 | 0.870 |

# Appendix B

## Calibration of NaI Probe for Exposure Rate and Calculation of Average $^{232}Th$ Content

$$E = (P - B)k_1$$

$$C = \frac{E}{A \cdot k_2 \cdot R}$$

$E =$ exposure rate measured downhole in excess of background $(\mu R / hr)$

$C =$ average concentration of $^{232}Th$ in soil $(pCi / g)$

$P =$ NaI probe measured count rate (cpm)

$B =$ background count rate (cpm)

$A = 0.95 =$ compensation factor included to compensate for attenuation of gamma rays due to the presence of water in the soil

$R =$ Fractional reduction in NaI probe response due to geometry

$k_1 = 12.6\ \mu R \cdot hr^{-1} / 1000$ cpm $=$ Calibration factor established in field with $^{232}Th$ distributed source (probe inside 2" and 1" Schedule 40 PVC pipe)

$k_2 = 5.64\ \mu R \cdot hr^{-1} / pCi \cdot g^{-1} =$ Beck's conversion factor adjusted for $4\pi$ geometry

# Appendix B

## Calibration of NaI Probe for Exposure Rate and Calculation of Average $^{232}Th$ Content

$$E=(P-B)k_1$$

$$C=\frac{E}{A \cdot k_2 \cdot R}$$

$E =$ exposure rate measured downhole in excess of background ($\mu R / hr$)

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$P =$ NaI probe measured count rate (cpm)

$B =$ background count rate (cpm)

$A = 0.95 =$ compensation factor included to compensate for attenuation of gamma rays due to the presence of water in the soil

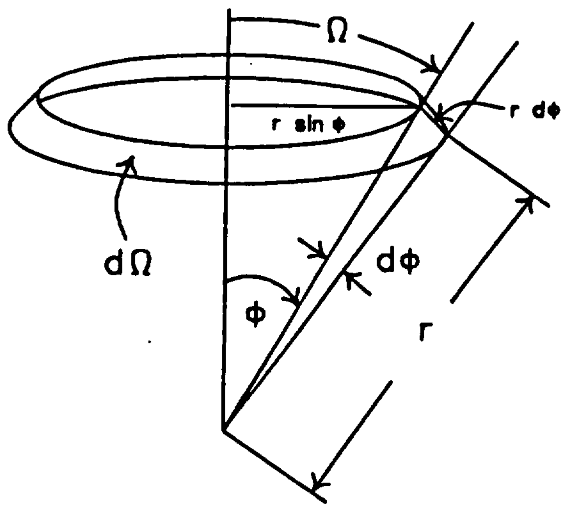
$R =$ Fractional reduction in NaI probe response due to geometry

$k_1 = 12.6\ \mu R \cdot hr^{-1} / 1000$ cpm $=$ Calibration factor established in field with $^{232}Th$ distributed source (probe inside 2" and 1" Schedule 40 PVC pipe)

$k_2 = 5.72\ \mu R \cdot hr^{-1} / pCi \cdot g^{-1} =$ Infinite source term for $^{232}Th$, approximately Beck's conversion factor adjusted for $4\pi$ geometry

# Appendix C

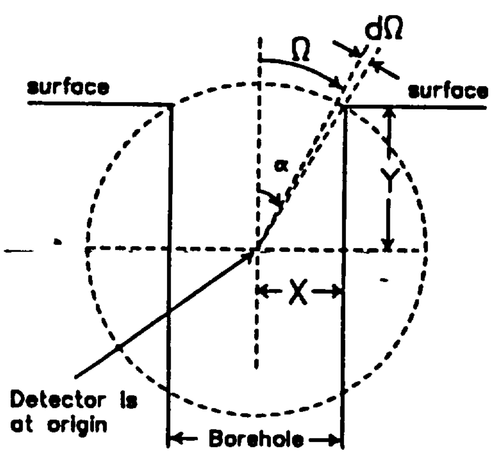
**Correction for Deviation from 4π Geometry Due to Opening at Top of Borehole**




ϕ = azmuthal angle from spherical coordinates

Ω = solid angle

$d\Omega = area / r^2 = (2\pi r \sin\phi)(r d\phi)/r^2$
$= 2\pi \sin\phi\, d\phi$




α = the angle formed by the y axis and the line from the detector to the rim of the borehole

X = radius of borehole

Y = depth of detector in borehole

$$\Omega = \int_0^\alpha 2\pi \sin(\phi) d\phi = -2\pi\left[\cos(\phi)\right]_0^\alpha = 2\pi[1-\cos(\alpha)] = 2\pi\left[1 - Y/\sqrt{X^2+Y^2}\right]$$

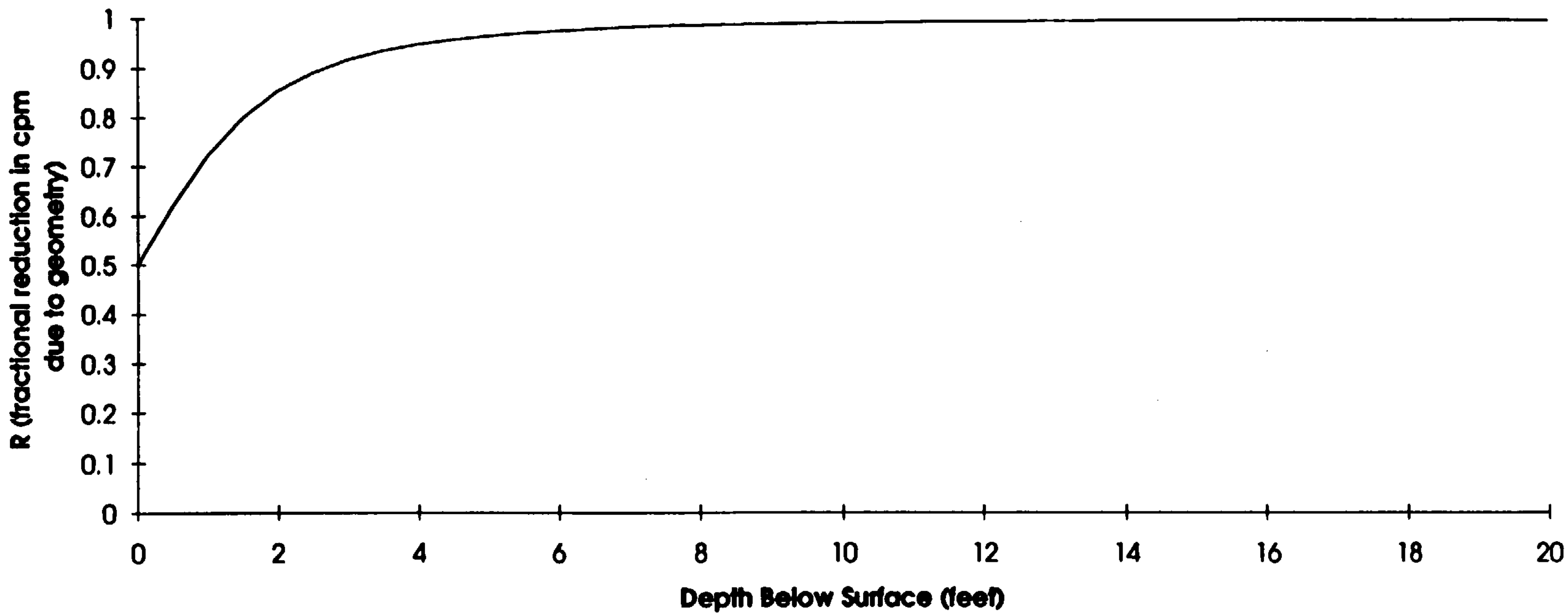
4π = solid angle encompassing entire sphere

*R* = fractional reduction in cpm due to absence of radiation source from solid angle Ω

$$R = \frac{4\pi - \Omega}{4\pi} = \frac{4\pi - 2\pi\left[1 - Y/\sqrt{X^2+Y^2}\right]}{4\pi} = \frac{1}{2}\left[1 + Y/\sqrt{X^2+Y^2}\right]$$

## Appendix C (Continued)

**Plot of Fractional Reduction in NaI Count Rate Due to Geometry at Top of Hole, as a Function of Depth, for a 4 Inch Diameter Borehole**




RSA, 8/3/93

UNITED STATES
NUCLEAR REGULATORY COMMISSION
WASHINGTON, D. C. 20555

OCT 2 9 1992

Docket No. 40-8778
License No. SMB-1393

Molycorp, Inc.
ATTN: Ms. Barbara K. Dankmyer
Resident Manager
300 Caldwell Avenue
Washington, Pennsylvania 15301

Dear Ms. Dankmyer:

SUBJECT: COMMENTS ON SUB-SURFACE SURVEY FOR THORIUM CONTENT AT MOLYCORP'S SITE IN WASHINGTON, PENNSYLVANIA

We have completed our review of the report entitled, "A Sub-surface Survey for Thorium Content at the Molycorp Plant Site in Washington, PA" and have enclosed our comments for your consideration. We expect that you will address these comments in any revision of this report, or in the Site Characterization Report for the Washington site.

It is clear from this report that Molycorp has taken a significant first step in characterizing the Washington, PA site. The report indicates that down-hole gamma logging is an effective tool in identifying the general zone of sub-surface contamination in close proximity to each borehole. This sub-face characterization method would appear equally effective in roughly imating what areas of the site are free of significant sub-surface contamination. The Nuclear Regulatory Commission's major concern with the report is in the procedure used to convert down-hole gamma measurements to sub-surface soil concentrations. NRC is not prepared to accept the derived sub-surface concentrations for the reasons outlined in the enclosed comments.

If you have any questions or wish to discuss these comments further, please do not hesitate to contact me on 301-504-2546.

Sincerely,

Chad Glenn

Chad Glenn, Project Manager
Decommissioning and Regulatory
Issues Branch
Division of Low-Level Waste Management
and Decommissioning
Office of Nuclear Material Safety
and Safeguards

Enclosure: As stated

cc:
G. Dawes
J. Yusko, PA DER-RP

NRC COMMENTS ON REPORT ENTITLED "A SUB-SURFACE SURVEY FOR THORIUM CONTENT AT THE MOLYCORP PLANT SITE IN WASHINGTON, PENNSYLVANIA"

General Comment

Molycorp's procedure for converting direct gamma measurements to sub-surface soil concentration of $^{232}$Th remains unproven. The staff's difficulties with Molycorp's procedure concern: 1) the calibration factor selected for converting direct gamma measurements to sub-surface soil concentration; 2) the effect of shielding on down-hole gamma measurements by less contaminated soil; and 3) the lack of radiochemical analysis from core data to substantiate the subsurface soil concentrations.

First, the 2.82 (μR/hr)/(pCi/g) calibration factor is based on direct radiation emanating from an infinite (area > 100 m$^2$ and thickness > 1 meter) slab (volume) source containing uniformly distributed radionuclides of the $^{232}$Th chain in secular equilibrium. At Molycorp's site in Washington, PA, although the radionuclides of the $^{232}$Th chain are in equilibrium, they exist as discrete and finite volumes of sub-surface soil and slag. The discrete nature of contamination at this site does not support the use of this calibration factor.

In addition, shielding provided by relatively less contaminated or clean soil between a source of radiation and the detector in the borehole could result in gross underestimates of the $^{232}$Th concentration. Similarly, a finite volume of relatively high concentration of $^{232}$Th, located immediately adjacent to the borehole could result in overestimates of the derived average $^{232}$Th concentration. The resulting high degree of uncertainty in the derived average $^{232}$Th concentration would propagate into the resulting doses to individuals calculated for times during decontamination and decommissioning following unrestricted release. Precise determination of the extent and ...ntity of residual activity is a prerequisite to assessing doses to be used as bases for NRC decommissioning decisions.

Another difficulty in the procedure for converting direct gamma measurements to subsurface concentration is the lack of analytical results of core data. On page 44, the report states that two of the boreholes drilled for the study were cored, and soil samples from the cores were taken at 18 inch intervals for radiochemical analysis to verify the calibration of gamma radiation in boreholes. Page 46 indicates that core samples were also taken for radiochemical analysis from 2 other boreholes (BH29 and BH32). However, the subject report does not present any results from the analysis of core samples. As a result, the validity of the analytically derived concentrations have not been demonstrated and remains unproven.

It is also unclear how Molycorp intends to use the sub-surface concentrations derived from gamma measurements (Appendices B and C). Is the intent to use these analytically derived concentrations as a relative indicator of concentration, or will these concentrations be used to demonstrate compliance with some established cleanup criterion? If the intent is to use these calculated values to show compliance with an established cleanup standard, then additional information would be required to demonstrate the accuracy of the calculated concentrations. This demonstration should be based on direct measurement of soil concentration via sample analysis, portable survey meter, or some combination of these methods. If, on the other hand, the calculated values are intended to be used only as a relative indicator of concentration, then no further confirmation of concentration may be necessary.

It should be noted that a critical part of the decommissioning process is the termination or final survey. The licensee is expected to conduct this survey once the cleanup activities have been completed. The recommended survey procedure, generally acceptable to NRC, is contained in draft NUREG-5849. To avoid the difficulties discussed above, it may be reasonable to combine sub-surface soil characterization with excavation as proposed on page 12 of the subject report. Under this approach, material expected to contain $^{232}$Th levels above 5 pCi/g (excluding background) could be excavated and consolidated onsite until a decision is reached on the final disposition of this waste. This cleanup level corresponds to Option 1 of NRC Branch Technical Position "Disposal or Onsite Storage of Thorium or Uranium from Past Operations" referenced in NRC's Action Plan (Federal Register, Vol. 57, No.74, April 16, 1992, pp. 13389-13392). Molycorp also referred to a cleanup level of 5 pCi/g in a meeting with representatives of NRC and Pennsylvania-DER earlier in the year. Existing sub-surface gamma logging data would be useful in estimating the depth and thickness of the contaminated zone. Following cleanup, a detailed final survey should provide assurance, at the 95% confidence level, that the residual $^{232}$Th activity is below the decommissioning criteria.

Specific Comments

1. Page 5, second paragraph; page 44, fourth paragraph:
From which two boreholes were soil samples obtained at 18 inch intervals, and have the samples been analyzed for radioactivity? When will the results be made available to NRC? In the July 8, 1992 meeting between representatives of Molycorp, the Commonwealth of Pennsylvania, and NRC, NRC staff inquired about the availability of the analytical results of core samples and Molycorp's consultant indicated that this information would be provided to NRC in the near future.

2. Page 8, second paragraph:
A count rate of 2000 cpm cannot be assumed to be representative of background. Exposure rate measurements from borehole 28 do not represent natural background. The drillers log in Appendix D indicates slag, brick, and glass fragments to a depth of seven feet. Also, page 44 of the report, indicates that this borehole was drilled in a pile of ferromolybdenum slag. The borehole logging data in Appendix C indicates a count rate of roughly 2000 cpm through this contaminated interval. Background levels should be determined from boreholes in virgin soil.

3. Page 15, second paragraph; page 21, first paragraph:
The report states that the NaI scintillometer was calibrated by taking simultaneous pressurized ionization chamber (PIC) and scintillometer reading at several locations within the Molycorp plant site. The report goes on to state that the cosmic ray contribution to the PIC readings was subtracted. Why would cosmic rays not produce a response in a NaI scintillation detector as they would in an ion chamber?

4. Page 48, last paragraph:
The 1985 Oak Ridge Associated Universities (ORAU) report described four water wells at this facility. The location of three of the water wells in ORAU's report appear to correspond to water wells WW2, WW3, and WW4 in this study. However, the location of WW1 in this study does not correspond with WW1 in the ORAU report. Also, WW5 is not mentioned in ORAU's 1985 survey. Additional information would be helpful in clarifying the relationship of water wells described in ORAU's 1985 survey report with the wells described in this report. In addition, it would be useful to know if the recent study analyzed any well water samples for radioactivity content.

Page 6, second paragraph:
In a number of places in the report, 0.01% thorium appears to be used as the threshold for the excavation of radioactively contaminated material. For example, in a discussion of the use of a NaI survey meter to guide excavation, the report states that the use of this detector will make it possible to assess the local content of thorium and "guide the depth of excavation as well as to sort out materials exceeding 0.01% from those below 0.01% thorium." The report should discuss how the licensee proposes to use this radiation level in future decontamination and decommissioning work along with a justification for the selection of this level.

6. Page 3, third paragraph, Executive Summary:
The report states that the radiation exposure rates at 1 meter above the ground are predominantly the result of naturally occurring radioactive materials. Page 33 of the report states that natural background in the study area is 9.33 μR/hr, and the gamma surface survey (Site Map III) indicates that the entire study area exceeds background levels. Exposure rates over portions of the south, southwest, and northern part of the study area, exceed background by a factor of 2 or more. Therefore, residual contamination levels appear to contribute significantly to the surface exposure rates over a large portion of the study area. Also, the statement on page 11 indicating that 31 μR/hr is roughly twice natural background is inconsistent with the natural background level of 9.33 μR/hr noted in the report.

7. Page 12, second paragraph:
This section states that the lack of correlation between radiation profiles in 2 pairs of boreholes (BH#16-BH#29, and BH#16-BH#32 drilled 5 feet apart) demonstrates that it is not feasible to accurately model the subsurface activity by extrapolating between boreholes. However, an examination of the gamma profiles between these 2 sets of bore holes suggests that it may be possible to correlate the depth and zone of contamination over short distances between boreholes. Therefore, it may be useful to attempt to construct cross-sections across the study area in an effort to establish the extent to which the study area can be characterized and modeled by extrapolating between boreholes.

Based on the July 8, 1992 meeting between NRC, Molycorp, and the Pennsylvania-DER, NRC understands that Molycorp plans to expand the surface and sub-surface characterization of the site. Surface and sub-surface surveys similar to those conducted in the study area may be effective in determining those areas of the site without significant levels of contamination. The use of these characterization tools may assist in confining cleanup efforts to areas where there is significant contamination. However, it should be noted that the final survey of the affected areas must demonstrate that cleanup of soil volumes, containing $^{232}$Th concentrations above the guideline level, has been achieved.

8. Page 12, first paragraph, Conclusions and Recommendations:
The discussion of a proposed approach for excavating contaminated material in the study area generally appears reasonable with the following changes. In step 1, areas to be excavated should be defined using both surface and sub-surface survey data. Limiting excavation to those areas where the surface exposure rate at 1 meter exceeds 30 μR/hr would leave substantial sub-surface contamination in place as evidenced by the gamma logs of the boreholes throughout the study area. Also, the 30 μR/hr threshold for excavation and consolidation of contaminated material is inconsistent with the 25 μR/hr level (including background) proposed by Molycorp in the July 8, 1992 meeting.

9. In certain cases, the physical separation of discrete volumes of contaminated material, via a sifting process, is sometimes effective in isolating the radioactive component in large volumes of material. This method is effective where the contaminated material is consolidated in fragments large enough to be separated. However, based on a description of the ferrocolumbium process in a 1971 Health Physics Report to Molycorp, entitled "Results of Radiological Evaluation of Columbium Slag Waste Disposal Problem", the contaminated slag at Molycorp's Washington facility was crushed in a ball mill and pumped to large settling basins where it dried to a hard grey mass and was subsequently used as fill. This crushing process may make it impractical to effectively separate thorium slag from soil. Also, the tables in Appendices B and D suggest that a significant amount of radioactivity is present in soil. These observations suggest that the physical separation of slag, via sifting, may not be an effective decontamination approach at Molycorp's Washington, PA site. Notwithstanding these observations, if Molycorp believes that sifting of contaminated soil may be effective is isolating the source of contamination, Molycorp may wish to consider a pilot study to test the feasibility of this idea.

**Appendix K: 1975 Report by Applied Health Physics, Inc., Entitled "Summary of Actions Taken During 1972-1974 to Comply with Requirements of the Nuclear Regulatory Commission"**

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HEALTH PHYSICS REPORT

for

MOLYCORP, Inc.

# SUMMARY OF ACTIONS TAKEN DURING 1972-1974 TO COMPLY WITH REQUIREMENTS of the NUCLEAR REGULATORY COMMISSION

MOLYCORP, Inc.
Washington, Pa.

Prepared by

Robert G. Gallaghar, CHP, CSP
President

Revision - May 22, 1975

Applied HEALTH PHYSICS inc.

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## ABSTRACT

This report summarizes the actions taken by Molycorp, Inc. during the years 1972 through 1974 to comply with regulatory requirements of the Nuclear Regulatory Commission (formerly United States Atomic Energy Commission) relative to the disposal of radioactive materials ~~wastes~~ at Molycorp's plant in Washington, Pennsylvania. It briefly describes the company's efforts which began in 1966 to obtain Federal and state authorization to bury on site ~~waste~~ slag containing less than 1.0% natural thorium (Th). No official action was taken during 1967-1970 to Molycorp's requests for a burial permit. During this period about 10 million pounds of ~~waste~~ slags were retained on site containing 89,500 pounds of thorium resulting from the production of ferrocolumbium (FeCb) alloys.

In June of 1971 an NRC compliance inspection revealed that thorium-bearing slags had been inadvertently buried on site in violation of NRC regulations. The NRC issued a citation and requested remedial action be taken by Molycorp to excavate these NRC licensed materials and to dispose of them in accordance with Title 10-CFR 20. Molycorp contracted with Applied Health Physics, Inc. to perform a thorough radiological survey of the site and to provide health physics and waste disposal services necessary to comply with NRC's requests.

This report describes the findings of radiation surveys of the site. It also summarizes action taken to excavate and dispose of the radioactive slag material ~~wastes~~ at NRC licensed ~~waste~~ disposal grounds. After 21 truckloads of ~~wastes~~ had been shipped to Nuclear Fuel Services (NFS) in West Valley, New York, state officials refused to permit NFS to continue to provide burial service for these materials. New York, as well as regulatory officials in other states, considered the burial of such low level radioactive materials ~~wastes~~ as poor utilization of valuable licensed waste disposal grounds intended for far greater radioactive wastes. All attempts to resolve this impasse with NRC and state officials failed to produce any agreement as to where these materials ~~wastes~~ could be buried legally and at reasonable costs. Attempts were made to acquire suitable land in Ohio, New York, and West Virginia for use in disposing of these materials, but again, these efforts were unsuccessful.

As a last resort, all radioactive slags ~~wastes~~ have been excavated and consolidated into a pile containing 27,700 cubic yards of slag. This pile is located at the southern end of the plant site. An 8 foot steel security fence surrounds the pile and appropriate warning signs are posted. The storage of these licensed materials are in compliance with NRC and Pennsylvania requirements and with the terms and conditions of Molycorp's Source Material License SMB-744. Molycorp's production of FeCb at this site has ceased and, in view of the inherent problems, probably will not be resumed.

## INTRODUCTION AND BACKGROUND INFORMATION

Molycorp, formerly the Molybdenum Corporation of America, has owned and operated a plant on the outskirts of Washington, Pennsylvania for over 50 years. Although primarily manufacturing molybdenum, the plant also produced ferrocolumbium (FeCb) during 1964-70, as well as other metal alloys. Naturally-occurring radioactive materials are unwanted contaminants in some ores, and, if they occur in excess of 0.05% by weight, are classified as "source materials." As such, they are subject to license and controls of the Nuclear Regulatory Commission (NRC) (formerly U. S. Atomic Energy Commission) as specified in Federal regulations (Title 10-CFR-40)[1] and 10-CFR-20, "Standards for Protection Against Radiation."[2] Pennsylvania also exercises regulatory controls over these and other sources of radiation.[3]

In 1964 Applied Health Physics was retained to assist Molycorp in obtaining an NRC Source Materials License in order to receive and process ore concentrations containing up to 2% natural thorium. Most of this material was a phrochlore produced at Molycorp's Araxa mine in Brazil. It contained 1.6-1.7% Th which concentrated in the ~~waste~~ slag resulting from the aluminothermic production of ferrocolumbium alloys. These ~~waste~~ slags can contain 0.1-0.7% Th and were retained on the plant site. These low specific radioactive ~~wastes~~ slags do not constitute a public health or safety hazard since they contain less than 1% thorium in an insoluble ceramic or glass-like form. The plant produced far more nonradioactive molybdenum slags which were normally used as landfill on the plant property.

## Requests to NRC and Pennsylvania for ~~Waste~~ Slag Burial Permit, 1967

Recognizing the need to dispose of the mildly radioactive slags in accordance with regulations, Applied Health Physics, Inc. recommended that Molycorp file requests with the Nuclear Regulatory Commission (formerly AEC) and Pennsylvania officials for appropriate authorization to bury these ~~waste~~ slags on site. During 1966 several meetings were held with state and NRC personnel in pursuit of a ~~waste~~ burial permit and formal applications were submitted in 1967.[4,5]

Applied Health Physics, Inc. had conducted leaching studies on the FeCb slags which indicated these ~~wastes~~ slags would not release radioactive materials to ground water in excess of prescribed limits. In May of 1970, copies of a report on this study were sent to NRC and Pennsylvania officials.[6] No action has been taken during seven years by NRC or Pennsylvania Department of Health to approve or deny Molycorp's requests for permission to bury FeCb slags in the same manner as other ~~waste~~ slags are buried on their own property.

## NRC Compliance Inspection and Citation, June 1971

The NRC's Division of Compliance, Region I, inspected Molycorp's operations involving NRC licensed materials at the plant in Washington, Pennsylvania. The NRC inspector discovered that sometime during 1970 to mid-1971, thorium-bearing slags had been buried on site in violation of the terms and conditions of Molycorp's NRC license and NRC regulations. Apparently the burial occurred inadvertently during a large scale clean-out of settling basins and regrading of the plant site by a private contractor who was totally unaware of the restrictions on the use of FeCb slags for landfill.

The Director of Compliance, Region I, issued a letter setting forth violations found in this inspection[7]. Subsequent meetings were held with Molycorp and NRC officials in Nuclear Regulatory Commission's regional office in Newark and in Washington, D. C. in an effort to resolve the problem of how to dispose of the radioactive ~~waste~~ slags in an acceptable manner.

The task of retrieving and disposing of about 89,500 pounds of thorium which had become mixed with millions of pounds of other ~~waste~~ slags posed a formidable technical, as well as financial problem. Obviously, the first step was to locate the buried slags containing NRC licensed materials so that some estimate could be made on the volume ~~of wastes~~ that must be relocated in order to comply with NRC's orders. See Page 10 for weight of the storage pile.

## Results of Initial Radiological Surveys of the Plant Site

There was no information on the exact location and depth at which thorium-bearing slags had been buried nor to what extent these slags had become diluted in other slags or soil used in backfilling. Thus, a thorough radiation survey was started by Applied Health Physics, Inc. in August of 1971 and completed in October 1971. Alpha, beta and gamma radiation measurements were made using calibrated radiation survey meters to monitor radiation levels at exposed surfaces of the ground throughout the plant property. In addition to surface measurements, this survey also included collection and analyses of 21 core samples taken at various locations on the site. These core borings were 2 inch diameter and ranged in depth from 2 to 14 feet.

Analyses of the core samples indicated thorium concentrations ranged from below limits of detection ( 0.001% Th) to 0.8% thorium. Surface radiation measurements indicated the alpha activity ranged from 2 to 3,000 alpha disintegrations per minute (dpm) per 100 square centimeters while gamma levels ranged from normal background of 0.005 to 1.25 mR/hr. Results of this survey are shown in Figure 1. Further details on the types of instruments used and specific data on sample analyses are contained in a report entitled, "Results of Radiological Evaluation of Columbium Slag Waste Problem" prepared by Robert G. Gallaghar on December 15, 1971[8]. Copies of this report were submitted to NRC and to the Bureau of Radiological Health, Pennsylvania Department of Health.

## Evaluation of Possible Reuse of FeCb Slags

Since Molycorp was faced with the very costly problem of locating, excavating, and disposing of the FeCb slags, every possible aspect of reducing these costs was carefully examined. The possibility that these slags could be reworked to extract trace concentrations of rare earths was researched on December 22, 1971. Molycorp requested the Nuclear Regulatory Commission (NRC) to allow six months in which to conduct this study.[9] Approval was given, however, extraction of the 4 to 5% rare earths from the columbium slags was found to be economically unfeasible.

## Excavation and Disposal of Buried Radioactive Slags

On July 6, 1972, officers of Molycorp and Applied Health Physics, Inc. signed a contract authorizing the excavation and disposal of NRC licensed materials. These materials were to be dug, sampled, concentrated as much as possible, and shipped in bulk form to an NRC licensed ~~waste~~ facility operated by Nuclear Fuel Services, Inc. in West Valley, New York. Four large trailers were purchased and 2 tractors were leased plus certain earth-moving equipment.

On August 8, 1972, the NRC and Pennsylvania Dept. of Environmental Resources, Bureau of Radiological Health, were notified that excavation and disposal of the licensed materials was to begin. The U. S. and Pa. Dept. of Transportation were also notified and appropriate regulatory requirements were met. By the end of August Applied Health Physics, Inc. was shipping about two truckloads of slag per day to Nuclear Fuel Services (NFS). The concentration of source materials averaged a little over 0.1% thorium. Our objective was to complete the removal of the licensed material ~~waste slags~~ by the end of 1972 in order to comply with NRC requirements.

## New York State Refuses NFS Authorization to Accept Bulk Slag ~~Waste~~ Shipments

On September 8, 1972, Nuclear Fuel Services notified Applied Health Physics that New York State Department of Health officials had ordered them to cease accepting any low specific activity (LSA) materials in bulk form. Twenty-one truckloads of ~~waste~~ slags had been shipped to NFS by September 8, 1972. These shipments contained a total of 1,022 pounds of thorium in 887,480 pounds of soil. Average concentration ~~[illegible]~~ was 0.132%Th.

The position of the New York officials was firmly stated in a meeting on September 26, 1972 in Albany, New York. Nuclear Fuel Services summarized the official decision by New York authorities that these material ~~wastes~~ are "of insignificant contamination and of too large a volume to bury and waste valuable burial area."[10] Similar letters of refusal were received from officials operating or regulating other NRC licensed burial grounds.

As a result of this impasse, a meeting was called by the Nuclear Regulatory Commission in Bethesda, Maryland on October 3, 1972 to review the situation. This meeting was attended by representatives of New York State Dept. of Commerce, New York State Dept. of Health, New York State Dept. Environmental Conservation, New York Atomic & Space Development Authority, NRC Div. of Compliance (Region I Headquarters), NRC Div. of Regulations, NRC Licensing, Molycorp, and Applied Health Physics, Inc. The following conclusions resulted from this meeting:

1. Molycorp's ~~waste~~ radioactive slags do not pose a health problem.
2. Disposal of these ~~wastes~~ materials is a technical and administrative problem requiring policy decision by the Nuclear Regulatory Commission (formerly AEC).
3. New York and other states are unwilling to permit valuable waste burial areas to be used for such trivial concentrations of radioactivity from out of state.
4. NRC's General Council would have to rule on any requests for interpretation or modification of rules and regulations.

To summarize the situation resulting from this impasse, a report, "Problems in Disposing of Waste Slag Containing Traces of Thorium" was prepared by Applied Health Physics, Inc. on October 13, 1972.[11]

Attempts to Find Alternative Means of Disposal

Since the NRC's regulations (10 CFR 20) permit disposal of licensed radioactive ~~wastes~~ materials by dilution in water and air, Applied Health Physics, Inc. attempted to get NRC approval of dilution of these ~~wastes~~ slags in solids -- namely in soil. Dilution of the thorium to concentrations below licensed limits, 0.05% by weight in soil would constitute far less risk of any possible reconcentration by biological means than exists with air or water. On October 10, 1972, a formal request was made to the NRC's General Council to consider this technically feasible solution. This approach was found unacceptable by NRC's General Counsel.[12]

During 1973 and part of 1974, we attempted to locate suitable sites in West Virginia, Ohio, and New York that would meet the NRC and state criteria for burial. Pennsylvania had rejected any consideration of this approach. Possible West Virginia sites failed to satisfy the geological and hydrological criteria. Consultant geologists did locate suitable areas in Ohio, only to meet strong objections from county planning officials and local landowners.[13]

As a result of numerous meetings with various NRC officials, it was suggested that NRC might easily resolve the problem by accepting the ~~waste~~ slags at their plant in Fernald, Ohio. We learned from personnel at the plant that these slags would be useful as landfill over much higher level wastes and would actually save NRC from purchasing fill. Thus, on August 8, 1973, Molycorp outlined past efforts to resolve this problem and asked for relief, suggesting the practical use of these slags at the NRC's Fernald plant. Authoritative sources within NRC indicated there was considerable reluctance to take any action on this request for fear of being criticized by operators of licensed burial grounds who might consider this as unfair competition even though their state regulatory agencies forbid them to accept these ~~wastes~~ materials. Thus, no formal action was ever taken on this request.

Thus, on November 27, 1973, Molycorp requested NRC to authorize storage of the ~~waste~~ slags on site.[14] This request was approved on December 17, 1973[15] and work resumed to complete consolidation of the licensed ~~waste~~ slags into one pile for storage on site.

## Concentration and Storage of the FeCb ~~Waste~~ Slag on Site

After attempts at burial were thwarted and an alternate burial site could not be found, the only apparent solution was to concentrate all the FeCb slag into one pile. The rationale behind this is compatible with the theory of retrievable storage. It was planned that once the pile was formed, it would then be covered with a spray-on plastic coating that would serve as an impermeable barrier.

Work began on consolidating all ~~waste~~ slags into a pile on April 2, 1974. The ~~Waste~~ slag was hauled to a site specially prepared on the south end of the property. (Figure 2 shows a profile of the consolidated pile). The storage pile is located in an area bounded by Chartiers Creek, Caldwell Avenue, and a right-of-way as shown in Figure 1 which also shows settling basins and areas of activity of 0.25 mR/hr. or greater. These areas were cleaned out and the material moved to the above-ground burial site.

D. F. and D. R. Farabee, Inc. were contracted to do the excavation and earth-hauling work throughout this phase of the project under the supervision of Applied Health Physics, Inc.'s health physics personnel. The general procedure involved digging out the slag which contained radioactivity using a backhoe and transferring it to a dump truck, dumping it on a pile and then compacting it with a tractor-caterpillar. Figures 3 and 4 depict the excavation and pile consolidation on site.

Workers were required to wear respirators when certain phases of the operation might create airborne dusts. Examples of dusty operations were blasting to remove impacted earth and digging on dry days which could raise dust. Personal air samples were taken daily by an Applied Health Physics, Inc. technician or health physicist present on site. No airborne activity in excess of NRC limits was found during the entire phase of the operation. The excavation and earth-hauling routes and ~~waste~~ slag pile were monitored during work to see that only material that gave readings of 0.2 mR/hr. or greater went into the storage pile.

Special precautions were taken to conserve the total volume of the pile, since total storage capacity was limited by the presence of overhead electrical lines and buried water pipes around the base of the pile which could not be covered by radioactive ~~waste~~ slags.

After cleaning the northside of the site next to the plant, work continued in the southern portion of the property in an area bounded by Chartiers Creek, Caldwell Avenue and the Tylerdale Connecting Railroad (See Figure 1). The area designated as reading 0.5 - 1.25 mR/hr. was removed from the pile first, then the lower reading slag areas were removed next. The same health and safety procedures that were instituted at the beginning of the project were continued until completion on June 17, 1974. The objective of having the area cleared of columbium slag so that a survey meter registered 0.2 mR/hr or less, was obtained. A final survey performed in June of 1974 (Figure 5) shows radiation levels after completion of the work.

## Characterization of the ~~Waste~~ FeCb Slag Storage Pile

The radioactive slag storage pile was calculated to have a volume of 249,408 cubic feet. Appendix 1 contains specific details relative to these computations.

After the thorium containing slag was concentrated into the present storage pile, twenty samples were obtained and analyzed for thorium content. Gamma-ray spectroscopy was the method used with the thorium analyses based on the measurement of the thallium-208 daughter, using the 2.7 MeV gamma emission. Using this high energy gamma ray eliminates any significant interferences from other naturally-occurring radionuclides. The results of these analyses are shown on Table 1 . From these results, the average concentration is 11.4 $\pm$ 0.2 mgTh/g sample. The weight of the pile was calculated to be 22,446,720 pounds.

The total thorium activity in the pile that can be accounted for is:

$$11.4 \pm 0.2 \text{ mgTh/g sample} \times \frac{454\text{g}}{\text{pound}} \times 2.24 \times 10^{7} \text{ pounds}$$

$$= 11.65 \times 10^{10} \text{ mg Thorium}$$

$$11.65 \times 10^{10} \text{ mg Thorium} \times 1.09 \times 10^{-7} \text{ Curies/g}$$

$$= 12.7 \text{ Curies of Thorium.}$$

As of January 1975, all of the recoverable source materials have been unearthed and consolidated into an above-ground storage pile. The final step in this disposal will be the application of a polyvinyl copolymer protective coating. This film will serve as a type of containment for the slag, keeping it confined and protected against the weather. An 8 foot steel security fence has been erected to surround the entire pile and to act as a final barrier. With the posting of appropriate radiation warning signs on the pile, Molycorp completed its requirements for compliance with NRC regulation concerning storage of licensed materials.

TABLE 1

THORIUM ANALYSES OF THE FeCb [redacted] SLAGS STORAGE PILE SAMPLES

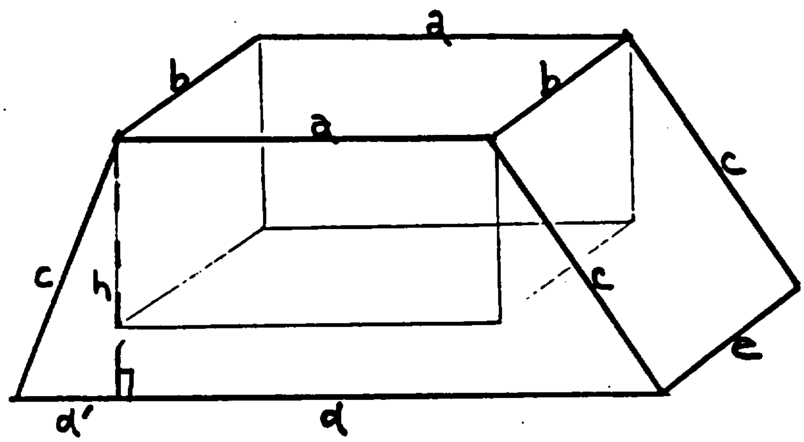
| Sample Number | Sample Weight (grams) | Thorium Content (mg) | Thorium Content (mgTh/g Sample) |
|---|---|---|---|
| L-462 | 49.80 | 696 ± 12 | 14.0 ± 0.2 |
| L-463 | 38.62 | 510 ± 10 | 13.2 ± 0.3 |
| L-464 | 49.61 | 386 ± 9 | 7.8 ± 0.2 |
| L-465 | 47.99 | 507 ± 10 | 10.6 ± 0.2 |
| L-466 | 19.10 | 61.2 ± 2.5 | 3.2 ± 0.1 |
| L-467 | 59.63 | 493 ± 10 | 8.3 ± 0.2 |
| L-468 | 71.49 | 865 ± 14 | 12.1 ± 0.2 |
| L-469 | 52.39 | 789 ± 13 | 15.1 ± 0.2 |
| L-470 | 27.75 | 441 ± 10 | 15.9 ± 0.4 |
| L-471 | 32.35 | 431 ± 10 | 13.3 ± 0.3 |
| L-472 | 60.97 | 926 ± 14 | 15.2 ± 0.2 |
| L-473 | 48.61 | 676 ± 12 | 13.9 ± 0.2 |
| L-474 | 54.49 | 580 ± 11 | 10.7 ± 0.2 |
| L-475 | 54.45 | 496 ± 10 | 9.1 ± 0.2 |
| L-476 | 45.59 | 635 ± 12 | 13.9 ± 0.3 |
| L-477 | 64.48 | 530 ± 11 | 8.2 ± 0.2 |
| L-478 | 45.35 | 638 ± 12 | 14.1 ± 0.3 |
| L-479 | 59.31 | 554 ± 11 | 9.3 ± 0.2 |
| L-480 | 48.18 | 443 ± 10 | 9.2 ± 0.2 |
| L-481 | 66.13 | 732 ± 12 | 11.1 ± 0.2 |

Average Thorium Content = 11.4 + 0.2 mgTh/g sample.

## APPENDIX 1

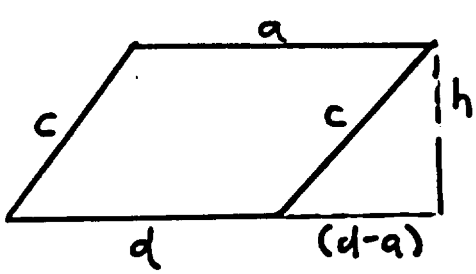
<u>Calculation of the FeCb [redacted] Slag Storage Pile Volume</u>

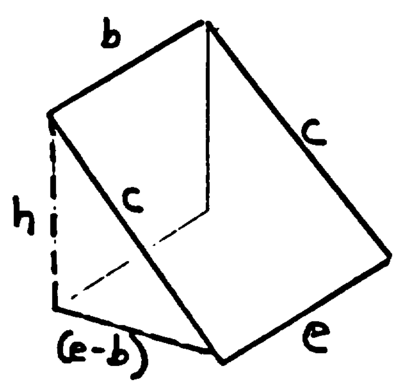
The approximate shape of the storage pile can be seen in Figures 6 and 7. Measurements were taken on June 11, 1974 to estimate the volume and ultimately, the mass of the material present. The shape of the pile approximates a truncated pyramid. Such a pyramid looks like the following with sides a, b, c, d, and e.




The height of the solid is found by the Pythagorean formula $C^2-(d^1)^2=h^2$. The solid can be dissected into a prism and four half-pyramids, the two opposite ones being equal.

The volume of the prism is found by taking $\overline{ab}$ and projecting this area perpendicular to their plane, which essentially is h, and then this $\overline{abh}$ is a partial volume of the solid. Further determination of the entire volume is done by clearing the half-pyramids away from the prism and looking at them separately. These respectively look like this:



The volume of one-half pyramid would be the area of a triangle times the length of $1/2\overline{(d-a)hd}$. Elaborating on this, the volume of the four half-prisms would be: [(d-a)ha) + [(e-b)hb].

Summing the individual volumes, the volume of the truncated pyramid would be $\overline{abh}$ + [$\overline{(d-a)ha}$] + [$\overline{(e-b)hh}$].

This situation was the one applied to the storage pile at Molycorp and the pile-volume of 249,408 $ft.^3$ was based on the above approximations and the measurements shown below.

The dimensions and the corresponding sides are:

a = 130 ft.
b = 57 ft.
h = 12 ft.
c = 30 ft.
d = 232 ft.
e = 59 ft.
d-a = 102 ft.
e-b = 2 ft.

Following the formula, the volume is:

[(130)(57)(12)] + [(102)(12)(130)] + [(2)(12)(57)] =

88,920 + 159,120 + 1,368 =
249,408 $ft.^3$

This figure is an approximation if the pile were a perfect solid, since d and e are not used in the determination. The pile is irregular and this number can be used for finding the mass.

The average density of the columbium slag is 90 $lbs/ft.^3$, based on a range of densities from 80 to 100 $lbs/ft^3$. Therefore, the weight of the storage pile is:

$$249{,}408\ ft^3 \times 90\ lbs/ft^3 = 22{,}446{,}720\ lbs.$$

## LIST OF FIGURES

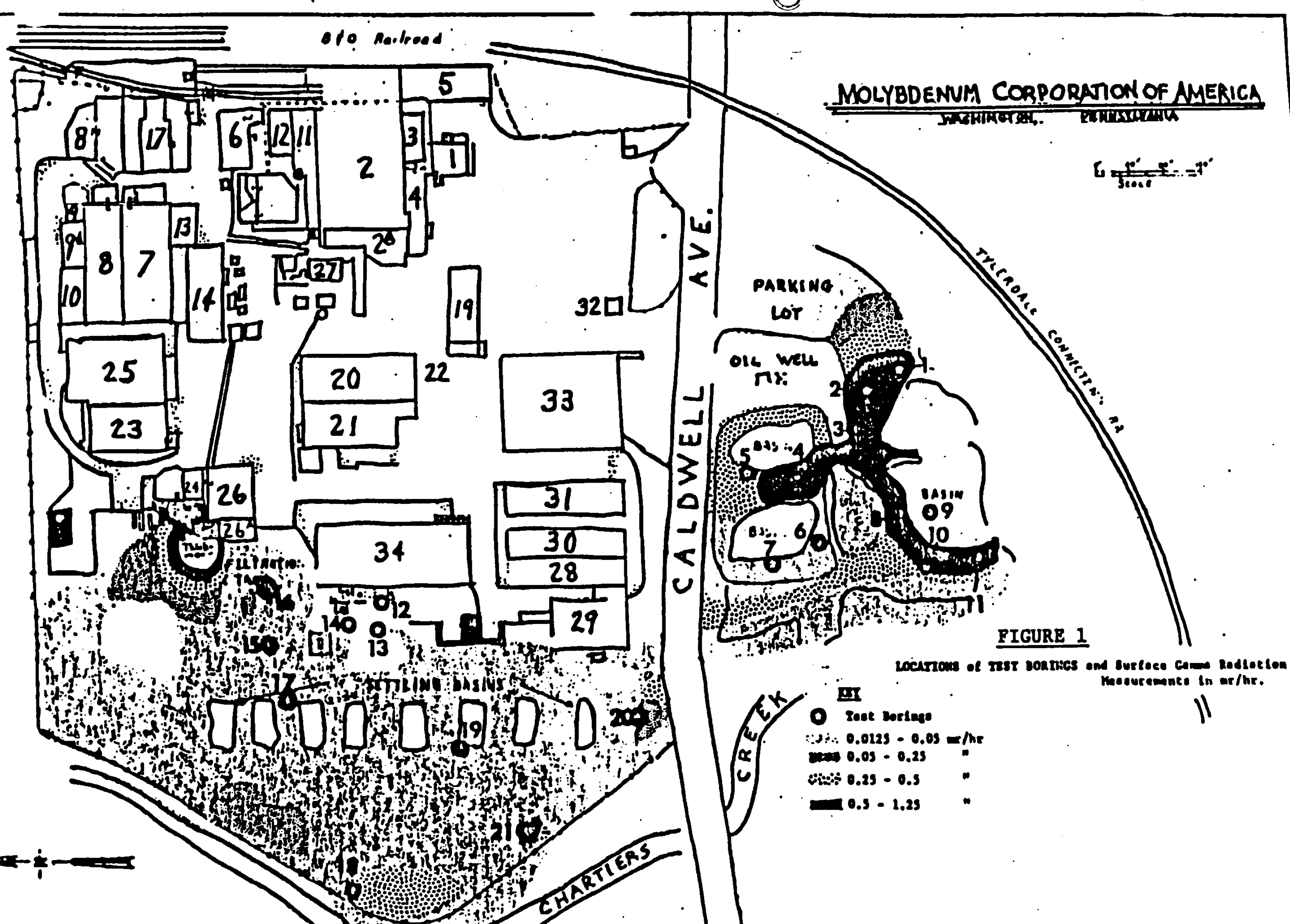



FIGURE 1

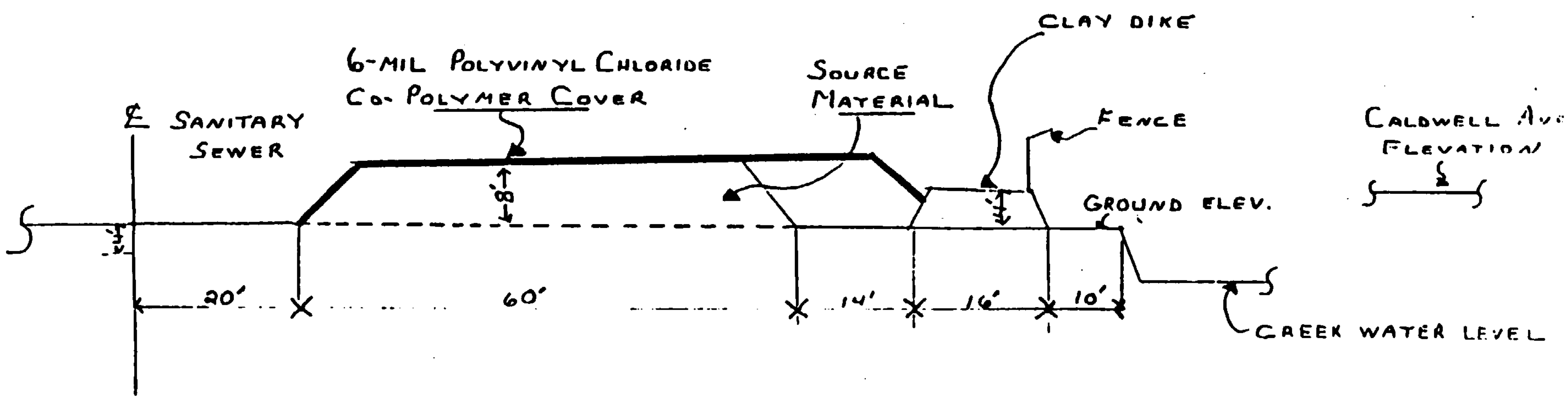
LOCATIONS of TEST BORINGS and Surface Gamma Radiation Measurements in mr/hr.

KEY

- Test Borings
- 0.0125 - 0.05 mr/hr
- 0.05 - 0.25 "
- 0.25 - 0.5 "
- 0.5 - 1.25 "

**FIGURE 2**

PROFILE OF SOURCE MATERIAL STORAGE PILE AND DIKE



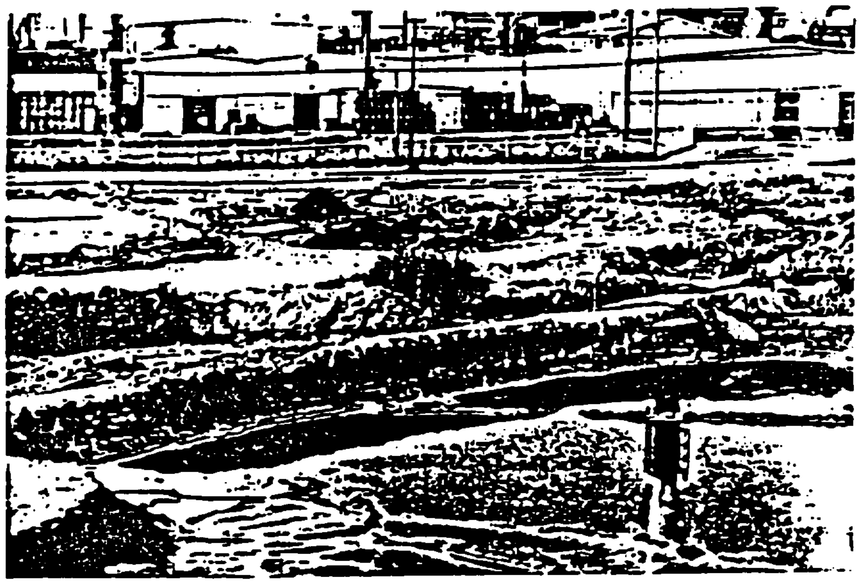


FIGURE 3. Partial View of the Excavation Site

FIGURE 4. Overall View of the Site during Excavation

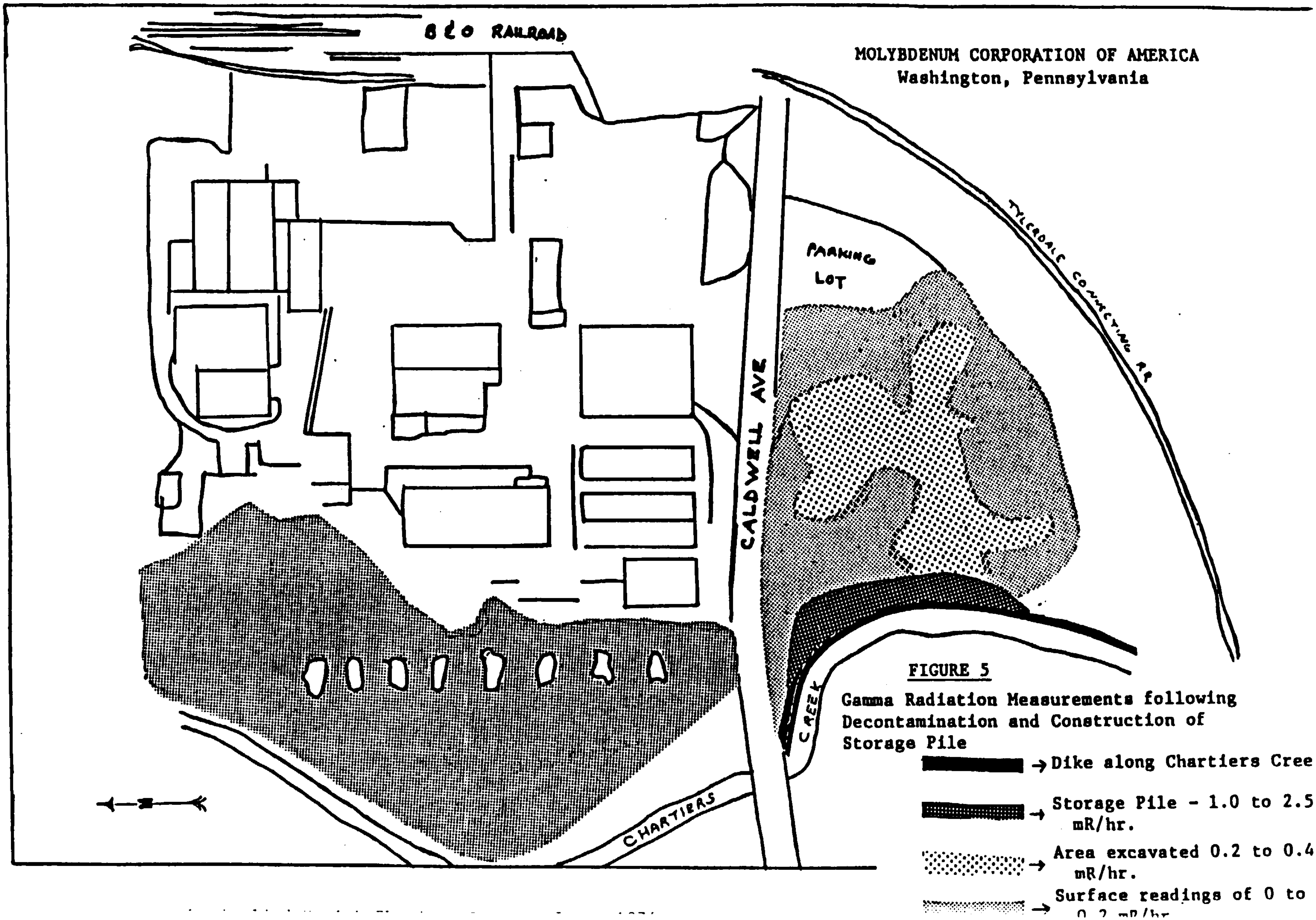



FIGURE 5

Gamma Radiation Measurements following Decontamination and Construction of Storage Pile

FIGURE 6. ~~Waste~~ Ferrocolumbium SLAG Storage Pile

FIGURE 7. ~~Waste~~ FeCb Slag Storage Pile and Some Equipment used in the Excavation and Pile Construction

REFERENCES


1. Title 10 Code of Federal Regulations Part 40 "Licensing of Source Materials" .

2. Title 10 Code of Federal Regulations Part 20, "Standards for Protection Against Radiation" .

3. Pennsylvania Atomic Energy Development and Radiation Control Act (73 P.S.: 100 (et seq.) .

4. Molybdenum Corporation of America Application to United States Atomic Energy Commission (now known as Nuclear Regulatory Commission) Form AEC-2 for Amendment of Source Materials License SMB-744, Item 13 Waste Disposal October 19, 1967.

5. Letter, R. A. Coulter, Washington, Pa. Plant Manager, to D.A. Lozarchick, Chief, Div. Sanitary Engineering, Pa. Dept. of Health, October 20, 1967.

6. "Leachability of FeCb Waste Slag", Applied Health Physics, Inc. May, 1970.

7. Letter, J. P. O'Reilly, Director, AEC Div. of Compliance Region I, to R. A. Coulter, Mgr. Molycorp, Washington, Pa., July 25, 1971.

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