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I am submitting herewith a thesis written by Duane E. White entitled "A Radiological Assessment of the SLAPS and Ball Field FUSRAP Sites near the St. Louis Airport, St. Louis, Missouri." I have examined the final copy of this thesis for form and content and recommend that it be accepted in partial fulfillment of the requirements for the degree of Master Science, with a major in Nuclear Engineering.

Laurence F. Miller, Major Professor

We have read this thesis
and recommend its acceptance:

Accepted for the Council:

Associate Vice Chancellor and
Dean of The Graduate School

A Radiological Assessment of the SLAPS and Ball Field FUSRAP Sites near the St. Louis Airport, St. Louis, Missouri

A Thesis
Presented for the
Master of Science Degree
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Duane E. White
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DEDICATION

This thesis is dedicated to my parents, Mr. Darold E. White and Mrs. Catherine P. White, and my sister, Avetta Marie White who have always supported me in my educational endeavors.

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ABSTRACT

During the 1940's and 1950's a site in St. Louis, Missouri was used to store residue from uranium processing which was processed in the downtown St. Louis site (SLDS). This site was near the Lambert-St. Louis Airport and was called the St. Louis Airport Site (SLAPS). This site is presently under the United States Department of Energy's Formerly Utilized Sites Remedial Action Program (FUSRAP). Objectives of this program is to evaluate FUSRAP sites relative to public use, to determine remediation options, and to clean up these sites as necessary. This thesis performs a radiological assessment of the SLAPS and near by ballfield sites. In this radiological assessment a parameter uncertainty analysis is used to estimate exposures from four radionuclides for several pathways.

To perform this radiological assessment, Argonne National Laboratory's RESRAD computer model (Version 5.6) was used to find the dose from the soil at SLAPS and the ballfield combined. RESRAD was also used to perform a sensitivity analysis. The sensitivity analysis identifies the most important parameters and pathways. The uncertainty analysis for this radiological assessment was performed by using Argonne National Laboratory's RESRAD-Probabilistic, which obtained cumulative probability distributions of dose for several pathways. A radiological assessment for off-site doses was performed by using the U. S. Environmental Protection Agency's (EPA) CAP88-PC computer model (Version 1.0).

The four main contaminants of concern at the SLAPS and ballfield sites are

Radium-226 (Ra-226), Uranium-238 (U-238), Thorium-232 (Th-232), and Thorium-230 (Th-230). For these sites to be considered clean, the Department of Energy (DOE) dose limit or the Environmental Protection Agency (EPA) risk limit must not be exceeded. One of the scenarios considered is whether the site could be used as a residential area. The concentration limits that satisfied the EPA limits for SLAPS and the ballfield, as residential areas, were 1 pCi/g for Ra-226, 125 pCi/g for U-238, 36 pCi/g for Th-230, and 2 pCi/g for Th-232. About 106,000 yd^3 of contamination at SLAPS and about 176,000 yd^3 of contamination at the ballfield must be removed to satisfy the EPA risk limit. Much of the concentration data provided by FUSRAP documentation had "less than" values for concentration rather than values with amount of uncertainty. If these "less than" values are omitted from the data, there would be about 71,000 yd^3 of contamination at SLAPS and about 168,000 yd^3 of contamination at the ballfield that would need to be removed for these sites to be used as residential areas.

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LIST OF ABBREVIATIONS AND ACRONYMS

AEC	Atomic Energy Commission
BRA	Baseline Risk Assessment
BRDL	Basic Radiological Dose Limit
CAP88	Clean Air Act Assessment Package, 1988; a U.S. EPA developed code used to evaluate offsite doses for air dependent pathways
CEDE	Committed Effective Dose Equivalent
cm	Centimeters
cm/s	Centimeters per second
CR	Concentration Ratio
DCFs	Dose Conversion Factors
DOE	Department of Energy
D/E	Dose/Exposure-parameter
D/S	Dose/Source
DSR	Dose to Source Ratios
EPA	Environmental Protection Agency
E/S	Exposure-parameter/Source-concentration
ETFs	Environmental Transport Factors
ft.	Feet
ft/yr	Feet per year
FUSRAP	Formerly Utilized Sites Remedial Action Program
g/cm^3	Grams per cubic centimeter
ha	Hecta acre
IAEA	International Atomic Energy Agency
ICRP	Internal Commission of Radiological Protection
in	Inch
km	Kilometer
LHS	Latin Hypercube Sampling
LLW	Low Level Radioactive Waste
l/min.	Liter per minute
MED	Manhattan Engineering District
m	Meter
m^3	Cubic meter
mrem/pCi	Millirem per picocurie
mrem/yr	Millirem per year
MUSLE	Modified Universal Soil Loss Equation
NESHAPS	National Emission Standards for Hazardous Air Pollutants
pCi/cm^3	Picocurie per cubic centimeter
pCi/g	Picocurie per gram
pdf	Probability Density Function

Ra-226	Radium-226
RESRAD	Residual Radioactivity software package; a DOE developed code
SAIC	Science Applications International Corporation
SFs	Source Factors
SFMP	Surplus Facilities Management Program
SLAPS	St. Louis Airport Site
SLDS	St. Louis Downtown Site
Th-230	Thorium-230
Th-232	Thorium-232
uR/h	microRoentgen per hour
U-238	Uranium-238
WL	Working Level

1. INTRODUCTION

1.1 HISTORY OF THE ST. LOUIS AIRPORT SITE

In August 1942, during World War II, a massive United States enterprise was brought into existence. This enterprise was called the Manhattan Project or Manhattan Engineering District (MED). The purpose of the Manhattan project was to develop, construct, and test the atomic bomb. After the war, the Atomic Energy Commission (AEC) became responsible for the oversight of all nuclear matters, including weapons research.

The Manhattan Engineer District/Atomic Energy Commission contracted with Malinckrodt Chemical Works, which was a commercial firm operating in downtown St. Louis, to perform several operations including processing and producing various forms of uranium compounds and pure uranium metal. As a result of these activities, materials, equipment, buildings, and parts of the property became contaminated with naturally occurring radioactive materials. This site was called the St. Louis Downtown Site (SLDS).

In 1946, the MED acquired a 22-acre site for storage of residues from Uranium processing conducted at the SLDS. This site lies just north of the Lambert-St. Louis Airport and is now called the St. Louis Airport Site (SLAPS). In 1966, the residues at SLAPS were purchased and removed by Continental Mining and Milling Company of Chicago. After the residuals were removed, buildings were demolished and buried on the property along with about 60 truckloads of scrap metal and a contaminated vehicle (EPA

1989a). Clean fill material was spread over the disposal area to achieve surface radioactivity limits that were acceptable at that time. The United States Government and the city of St. Louis agreed to transfer ownership of SLAPS by quitclaim deed from AEC to the St. Louis Airport Authority (DOE 1993).

The Department of Energy (DOE), which has replaced the AEC, has taken control of the cleanup of contamination at SLAPS. This cleanup is under the Department of Energy's Formerly Utilized Sites Remedial Action Program (FUSRAP).

1.2 CONTAMINATED AREAS ASSESSED IN STUDY

The main contaminated area of concern in this study is the entire SLAPS site which is about 22 acres (8.8 ha) and is surrounded by security fencing. SLAPS is bounded on the north by McDonnell Boulevard and the ballfield. The Norfolk and Western Railroad is on the southern boundary and Coldwater Creek is on the western boundary. In this study, the ballfield area is included as part of SLAPS. The ballfield is approximately 80 acres (32.4 ha). So, in this study SLAPS is considered to be 102 acres (22 acres + 80 acres). A map of the location of SLAPS and the ballfield is provided in Figure 1.1.

1.3 CONTAMINANTS OF CONCERN

Most of the surface soils at SLAPS and the ballfield are contaminated by radionuclides which exceed DOE guidelines. The principal radionuclides of concern are Uranium-238, Radium-226, Thorium-230, and Thorium-232. FUSRAP documentation states, depths of contamination range from the ground surface up to 5.4 meters (18 ft.), but usually average between 1.2 to 2.4 meters (4 to 8 ft.). SLAPS has an estimated

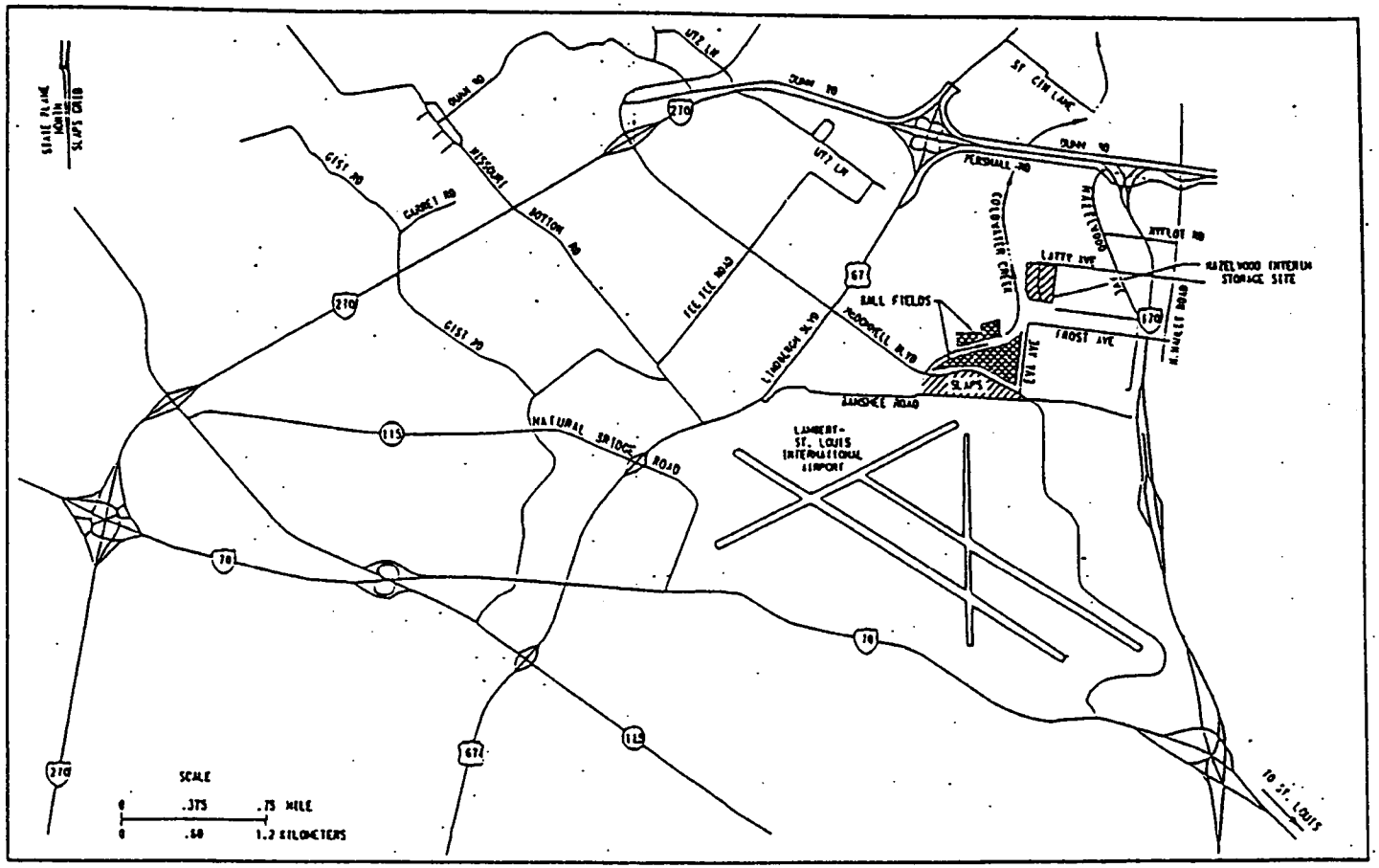


Figure 1.1 Location of SLAPS and the Ballfields

Source: U.S. Department of Energy. *Site Suitability Study for the St. Louis Airport Site, St. Louis,Missouri*. Prepared by Bechtel National, Inc. for the U.S. Department of Energy, Oak Ridge Operations, Oak Ridge,Tennessee, February 1994.

213,000 m^3 (279,000 yd^3) of radiologically contaminated soil in excess of the DOE guidelines (DOE 1993).

1.4 OBJECTIVES AND GOALS

The main purpose of this thesis is to perform a radiological dose assessment of SLAPS and the ballfield. This is accomplished by analyzing the data provided by FUSRAP with dose assessment computer packages which determine the on-site and off-site doses. An uncertainty analysis is also performed to determine the quality of the results.

The data about the St. Louis Airport Site were provided by the Department of Energy's Formerly Utilized Sites Remedial Action Program. The author did not attempt to validate the data or take samples of his own.

2. SITE CHARACTERIZATION

2.1 DESCRIPTION OF CONTAMINATED AREA

SLAPS is located in St. Louis County, Missouri, approximately 24 km (15 miles) west of downtown St. Louis. SLAPS is a 21.7 acre property and, for the purposes of this study, includes the ball field area, which is an adjacent tract of land that is approximately 80 acres. SLAPS is located immediately north of Lambert-St. Louis International Airport (BNI 1987). The north and south property boundaries are adjoined by ditches. Beyond these ditches, SLAPS is joined on the south by the Norfolk & Western Railroad, Banshee Road, and the airport. Coldwater Creek lies on the western boundary and on the north and east boundaries lies the ballfield area and McDonnell Boulevard. The SLAPS area is zoned for industrial use, and the nearest residential areas are located approximately 0.8 km (0.5 miles) west, 1.6 km (1 mile) northwest, and 2.4 km (1.5 miles) north of the site (BNI 1990). This property is currently owned by the city of St. Louis and is controlled by the St. Louis Airport Authority.

2.2 SITE PHYSICAL CHARACTERISTICS

2.2.1 Geology

In northern St. Louis County their is an upland area of rolling hills which surrounds a topographic depression known as the Florissant Basin. SLAPS lies on the southeastern edge of this basin. This basin is in a north-draining valley which is occupied by Coldwater Creek. Glaciolacustrine and alluvial sediments fills this basin. The Mississippian-age limestone that was exposed before the basin fill sediments were

deposited underlies the deepest part of the Florissant Basin. Pennsylvanian-age bedrock surrounds the basin (DOE 1994).

The site stratigraphy is based on data received from wells and boreholes. Figure 2.2 shows the locations of the monitoring wells and boreholes at SLAPS. The site stratigraphy is characterized as a buried preglacial valley in which sediments lap onto bedrock highs. The SLAPS stratigraphy has been divided into six units. Figure 2.3 gives a description of the six units.

Disturbed topsoil, fill, and undisturbed topsoil may be found in Unit 1. For this study, fill material is combined with the undisturbed topsoil. This fill is made up of many different materials. It is made up of construction rubble, rebar, scrap metal, asphalt, reinforced concrete, glass, wood, ceramic material, sand gravel, and slag distributed within loose and compacted silt. Both disturbed and undisturbed organic silts and clays are in the topsoil at the base of the fill. Some roots are also in the topsoil. Unit 1 sediments typically have low moisture content and are nonplastic to slightly plastic. The topsoil usually has a fairly low moisture content and is slightly plastic (DOE 1994).

Windblown silts and clays which consist of small amounts of fine-grained sand may be found in Unit 2. Unit 2 also contains scattered pods of organic material and iron concentrations. Iron oxide and manganese staining is common but decrease with depth. Root burrows filled with iron-oxide stained silt and scattered layers of shell fragments may also be found in Unit 2. Nine percent of Unit 2 contains different types of sands and the other 91 percent contain different types of fines. The geometric mean vertical laboratory permeability for Unit 2 is 2.5×10^{-6} cm/s (2.6 ft/yr) and the average porosity is 41.6

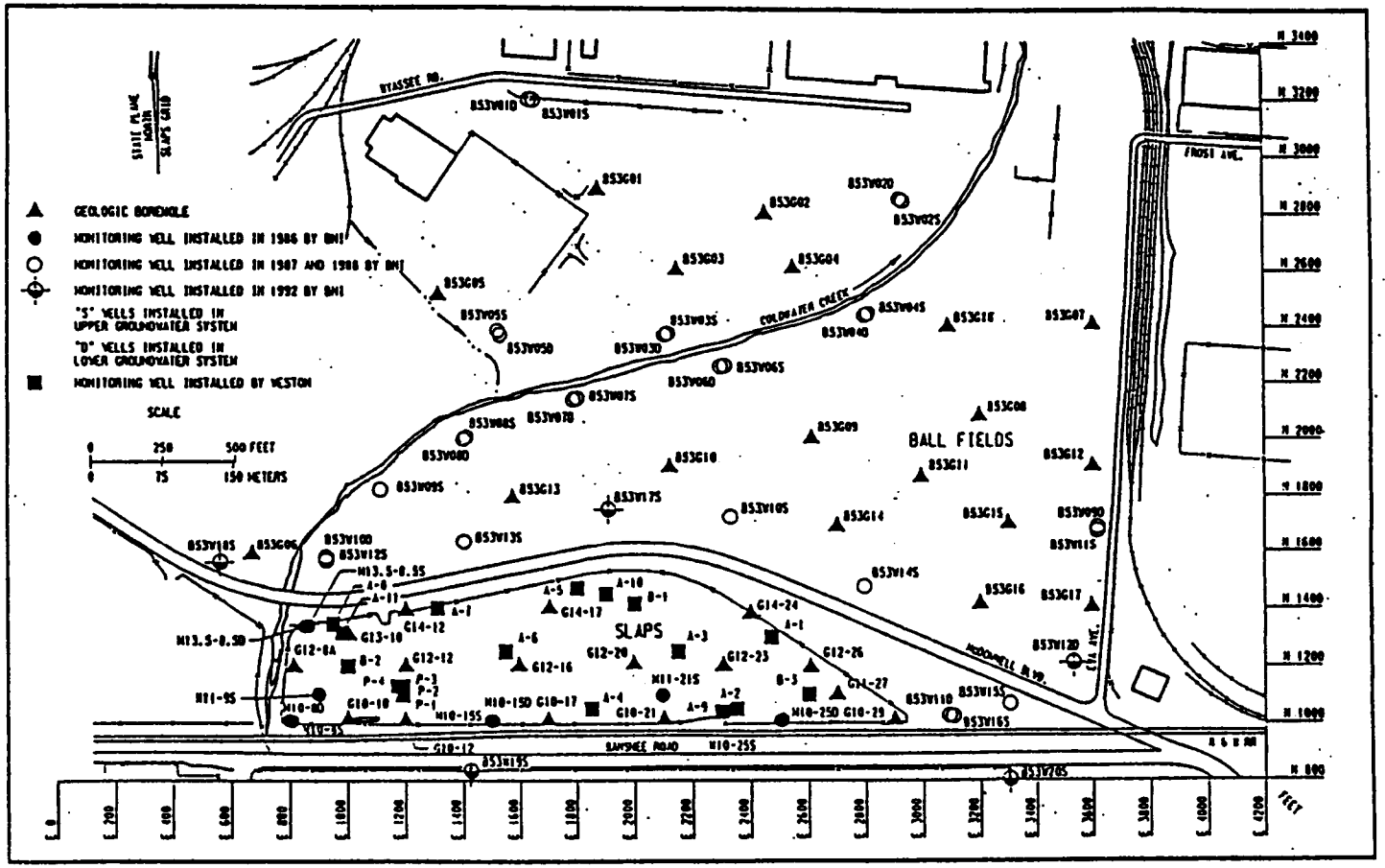


Figure 2.1 Borehole and Monitoring Well Locations

Source: U.S. Department of Energy. Site Suitability Study for the St. Louis Airport Site, St. Louis, Missouri. Prepared by Bechtel National, Inc. for the U. S. Department of Energy, Oak Ridge Operations, Oak Ridge, Tennessee, February 1994.

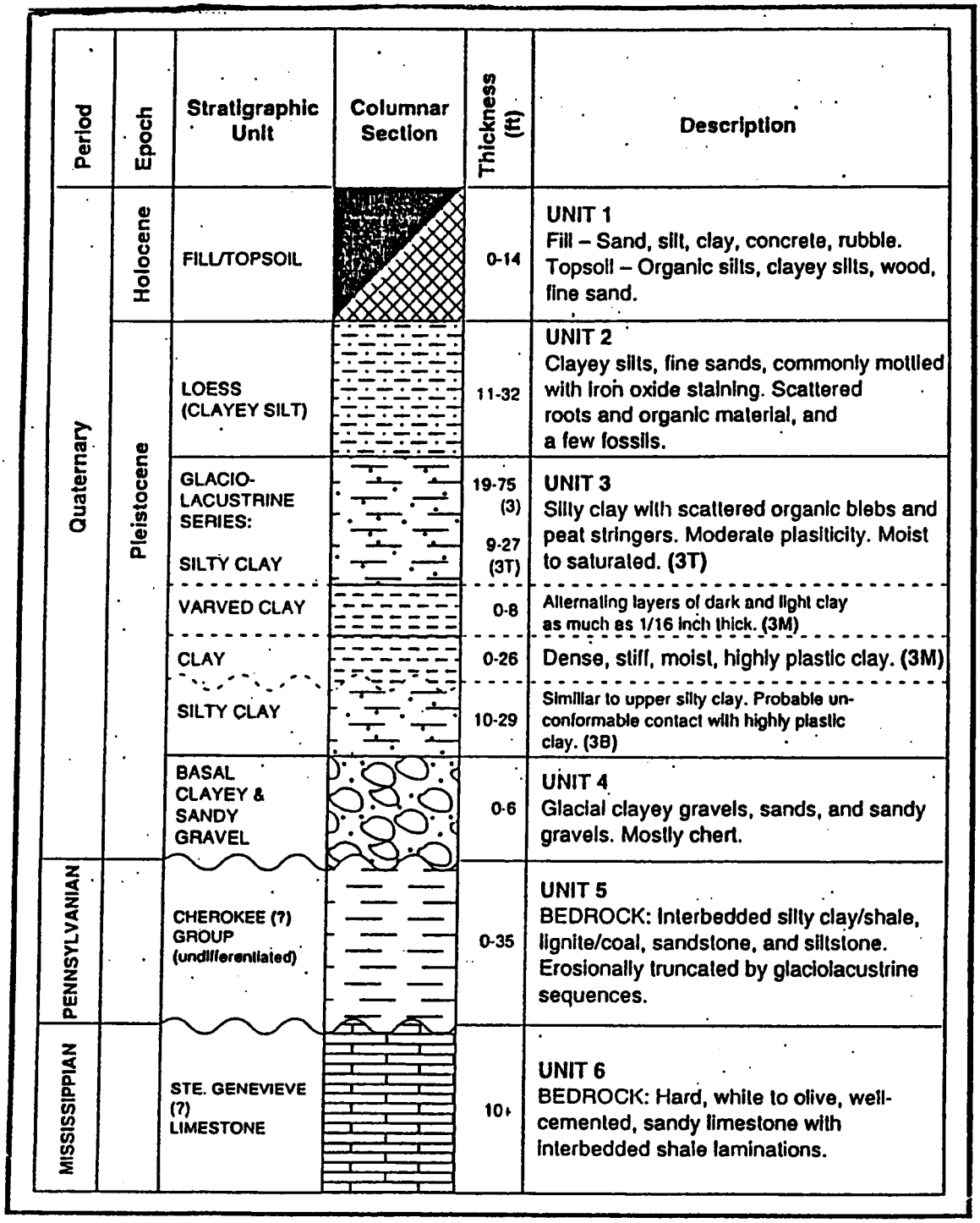


Figure 2.2 Generalized Stratigraphic Column for the SLAPS/Ballfield Area

Source: U.S. Department of Energy. *Site Suitability Study for the St. Louis Airport Site,St. Louis, Missouri*, Prepared by Bechtel National, Inc. for the U. S. Department of Energy, Oak Ridge Operations, Oak Ridge,Tennessee, February 1994.

percent (DOE 1994).

Unit 3 has been divided into three subunits based on stratigraphic position, differing lithologies, and geotechnical properties. The subunits are subunit 3B, subunit 3M, and subunit 3T. Unit 3 is basically a thick arrangement of glaciolacustrine silty clays and other types of clays. Subunit 3B is the basal unit and it contains silty clay. Subunit 3M consist of a highly plastic clay and subunit 3T contains silty clay. At some locations, Unit 3 overlies Unit 4, but at other locations Unit 4 is missing, and Unit 3 lies directly on bedrock (DOE 1994).

Silty clays with small amounts of very fine- to fine-grained sand may be found in subunit 3B and 3T. Usually both subunits are moderately plastic and moist to saturated, but subunit 3B is sometimes dry. Organic blebs, peat stringers, varve-like laminations, and mottling are found in some locations at subunit 3T. But, they are not present in subunit 3B. On the average, both subunits contains 86 to 93 percent of different types of fines and 14 percent of less sand. The vertical permeabilities measured in the laboratory range from 3×10^{-8} to 7×10^{-5} cm/s (0.031 to 72 ft/yr). The average porosity is about 40.5 percent (DOE 1994).

On the average, subunit 3M contains 92 percent of different types of fines and 8 percent sand. Subunit 3M contains a stiff, moist, and highly plastic clay. The average porosity and the geometric mean vertical laboratory permeability is 45.3 percent and 5.5×10^{-8} cm/s (0.056 ft/yr) respectively. Subunit 3M uncorrespondingly overlays subunit 3B and the contact between subunits 3M and 3T is usually gradational. The samples from subunit 3M showed higher values for liquid limits and plasticity indexes than for subunits

3T and 3B. Subunit 3M is also one to two orders of magnitude less permeable than samples from subunits 3T and 3B (DOE 1994).

Clayey and sandy gravels and clayey sands may be found in Unit 4. The gravel is fine to medium- grained sand and clay matrix. The sands are very coarse-grained and commonly contain clay and silt. Unit 4 sediments indicate an average composition that is 34 percent sand and 53 percent fines. The average porosity of Unit 4 is about 44 percent and the vertical geometric mean permeability measured in the laboratory is 1.3×10^{-6} cm/s (1.3 ft/yr). Unit 4 unconformably overlies Unit 5 (DOE 1994).

It is unclear whether Unit 5 is bedrock or not. Some characteristics of the unit suggest that bedrock is present, but these characteristics are underlain by unconsolidated sediments. For the purpose of this study Unit 5 is considered to be bedrock. Interbedded layers of silty clay and shale, lignite and coal, sandstone, and siltstone may be found in Unit 5 (DOE 1994).

There were two onsite wells where Unit 6 was discovered. The borings from these wells indicated that Unit 6 is a dense hard, sandy limestone with interbedded shale laminations and a few shell fragments. There was no barren space in the well cemented limestone. And, shale layers were brittle and fissile. Because there is such little data on Unit 6, the data may not fully depict the unit characteristics (DOE 1994).

Porosity and permeability data for sediments in Units 2, 3, 4, 5, and 6 at SLAPS are summarized in Table 2.1. The geometric mean permeability data, which are believed to reflect a more accurate measure of the central tendency of the data than arithmetic means do, is also presented in Table 2.1.

There are three different types of soils that the U.S. Conservation Service identified at SLAPS. They are the Nevin-Urban land complex, the Nevin silt loam, and the Menfro silt loam (USDA 1982). Nearly level, poorly drained, black silt loams intermixed with areas of urban growth may be found in the Nevin-Urban land complex. The Nevin silt loam is made up of nearly level, poorly drained, dark gray, brittle silt loam. The Menfro silt loam is moderately sloping, well drained, and brown (DOE 1994). Figure 2.1 shows a soil map of SLAPS

Table 2.1. Porosity and Permeability of Sediments at SLAPS

Unit	Mean Porosity[a] (%)	Geometric Mean Vertical Laboratory Permeability (cm/s)	Geometric Mean Field Permeability (cm/s)
2	41.6 (10)[b]	2.5×10^{-6} (9)	1.2×10^{-4} (5)
3T	41.0 (11)	2.7×10^{-6} (13)	1.1×10^{-5} (8)
3M	45.3 (4)	5.5×10^{-8} (4)	3.1×10^{-5} (1)
3B	37.8 (2)	3.1×10^{-7} (2)	1.5×10^{-5} (7)
4	44.3 (2)	1.3×10^{-6} (4)	3.7×10^{-5} (3)
5	[c]	[c]	1.1×10^{-7} (2)
6	[c]	[c]	2.9×10^{-6} (2)

[a]Porosity is calculated from dry unit weight and specific gravity.
[b]The numbers in parentheses represent the number of analyses.
[c]Test not performed on unit.

Source: U.S. Department of Energy. *Site Suitability Study for the St. Louis Airport Site, St. Louis, Missouri*. Prepared by Bechtel National, Inc. for the U.S. Department of Energy, Oak Ridge Operations, Oak Ridge, Tennessee, February 1994.

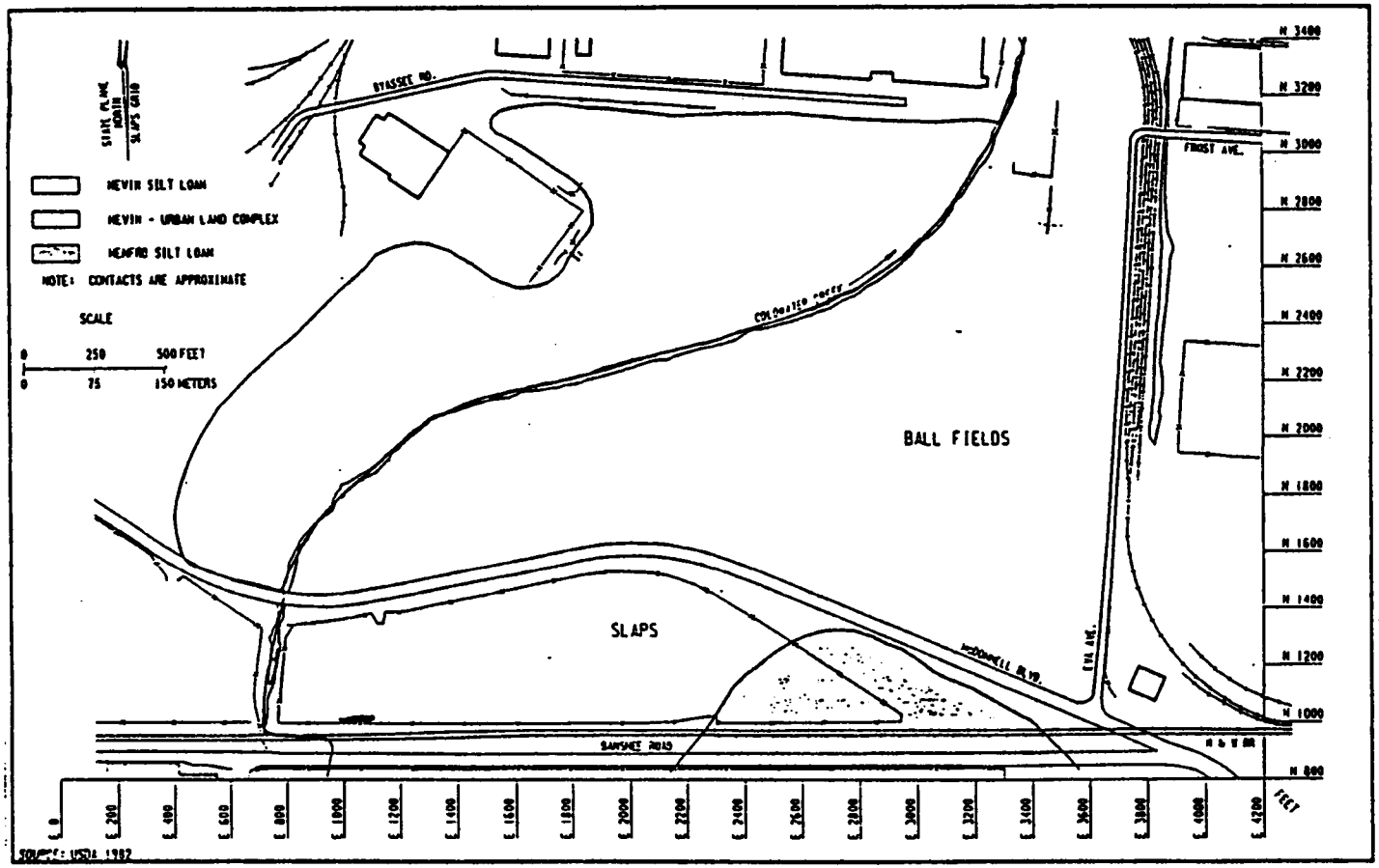


Figure 2.3 Soil Map of SLAPS and Vicinity

Source: U.S. Department of Energy. Site Suitability Study for the St. Louis Airport Site, St. Louis, Missouri. Prepared by Bechtel National, Inc. for the U. S. Department of Energy, Oak Ridge Operations, Oak Ridge, Tennessee, February 1994.

2.2.2 Groundwater Hydrology

The sediments underlying SLAPS have been subdivided into three hydrostratigraphic units. The first unit consists of stratigraphic units 1,2 and subunit 3T This unit is considered the upper groundwater system. The second hydrostratigraphic unit is made up of subunit 3M and is a fine-grained zone which acts as an aquitard. The third hydrostratigraphic unit is known as the lower groundwater system. It is made up of subunit 3B, Unit 4, and bedrock (DOE 1994).

Low permeable clay layer separates the upper and lower ground systems. This clay layer is an aquitard that contains subunit 3M with parts of subunits 3B and 3T also contributing to it. Some areas of subunit 3B are dry due to the sediments in subunit 3M which isolate the groundwater in the upper groundwater system from the lower groundwater system. Precipitation influence water levels in the wells installed in the upper ground water system, but water levels in the wells installed in the lower groundwater system are not influenced. Comparison of groundwater level measurements and water quality in two monitoring wells screened in shale with those in wells screened in subunit 3B and Unit 4 suggests that groundwater in the shale bedrock has the same source as groundwater in subunit 3B and Unit 4. The recharge source for groundwater is to the southeast both onsite and offsite (DOE 1994).

2.2.3 Surface Water Hydrology

The SLAPS area is covered with grass, and has no buildings. Most of the land surface across SLAPS is flat, except for areas on the banks of the drainage ditches, Coldwater Creek, the main waste storage pile, and small mounds of waste. The site

generally slopes to the northwest, toward Coldwater Creek. The average slope of the land surface is 3.1 percent with a mean elevation of 161 m (528 ft) above mean sea level. The site is elevated 4.6 m (15 ft) above the Coldwater Creek bed. There is a sharp rise with a slope of about 25 to 30 percent on the creeks bank. The elevation varies from a minimum of 153 m (503 ft) next to the edge of Coldwater Creek to a maximum of 166m (543 ft) in the southeastern corner of SLAPS (DOE 1994).

The average annual precipitation in the vicinity of SLAPS is estimated to be 95.5 cm (37.6 in.), which is based on a 27 year rainfall record (1964 to 1990) at the airport. The maximum annual precipitation between 1964 to 1990 was 139.7 cm (55 in.), and the minimum was 55.59 cm (21.89 in.). Generally, the winter months have the least amount of precipitation, and the spring and early summer months have the greatest (DOE 1994).

The surface water flow at SLAPS is collected in one of four drainage ditches which drains directly into Coldwater Creek. The ditches are wide, shallow channels with top widths of approximately 20 ft at bankful capacity and depths ranging from 4 to 6 ft. All of the drainage ditches flow into Coldwater Creek (DOE 1994).

2.2.3.1 Coldwater Creek

Coldwater Creek drains an area of 122 km^2 in the northern section of St. Louis County. The creek flows toward the northeast for approximately 20 miles before joining the Missouri River. The Coldwater Creek basin is enormously developed with residential, commercial, and industrial areas. Seventy-six percent of Coldwater Creek is used for urban areas; thirteen percent of Coldwater Creek is used for agricultural; six percent is used in open space; and four percent is forested (SAIC 1992).

Coldwater Creek flows under the Lambert-St. Louis International Airport through a double 3 by 4.5 meter box culvert. The double culvert discharges at Banshee Road at the northern boundary of the airport, which is on the western side of SLAPS. The creek then flows about 1 km along the boundary of SLAPS. The channel of Coldwater Creek is about 6 meters wide. And it flows beside SLAPS (DOE 1994).

2.2.3.2 Soil Erosion

The soils at SLAPS erode easily, but the property has well-established grass cover and, therefore, is not subject to excessive erosion. The main area of erosion at SLAPS is along the bank of Coldwater Creek. A gabion wall was constructed along the western boundary of SLAPS to control erosion on the creek bank. The Modified Universal Soil Loss Equation (MUSLE) (EPA 1988) was used to estimate the average annual sediment yield from SLAPS based in the volume of runoff, peak runoff, ability of the soil to erode, length and gradient of the ground surface, and ground cover. The erodibility of the soil is 0.32 (USDA 1982). The erosion control practice factor was estimated to be 0.003 for a well established area of grass (DOE 1994).

3. METHODOLOGY

The methodology used to do this dose assessment/uncertainty analysis is based on the requirements and procedures outlined in the DOE Order 5400.5, "Radiation Protection of the Public and the Environment" and the International Atomic Energy Agency's (IAEA) Safety Series No. 100, "Evaluating the Reliability of Predictions Made Using Environmental Transfer Models." Chapter 4 of DOE Order 5400.5 presents radiological protection requirements and guidelines for cleanup of residual radioactive material; management of the resulting wastes and residues; and release of property. The IAEA Safety Series No. 100 provides a step by step method on how to do a proper uncertainty analysis.

Information on the application of the guidelines presented in DOE Order 5400.5 are presented in DOE/CH 8901, "A Manual for Implementing Residual Radioactive Material Guidelines, A Supplement to the U.S. Department of Energy Guidelines for Residual Radioactive Material at Formerly Utilized Sites Remedial Action Program and Surplus Facilities Management Program Sites," June 1989. A computer model, RESRAD Version 5.6, written by Argonne National Laboratory under contract by DOE and based entirely on the procedure and methodology in DOE/CH 8901, is used for the dose assessment.

3.1 RADIOLOGICAL ASSESSMENT FOR ON-SITE EXPOSURE

A radiological assessment for an on-site exposure is usually done for a site or facility that contains or contained radioactive materials. The main purpose of the

assessment is to determine if there are radiation doses that exceed government limits and may endanger the worker and the public at some time. There are many types of assessments done for an on-site exposure. For this study, only a soil assessment was done for on-site exposure.

3.1.1 Description of RESRAD

A radiological assessment for on-site exposure was done by using computer software developed by Argonne National Laboratory. This software implemented methods for determining guidelines for residual radioactive material in soils, and therefore was called RESRAD. The idea for RESRAD came from a project funded by the U. S. Department of Energy (DOE) for sites identified by the Formerly Utilized Sites Remedial Action Program (FUSRAP) and by the Surplus Facilities Management Program (SFMP). The main purpose of RESRAD was to provide a straightforward computational methodology for determining acceptable concentrations of many radionuclides in the soil. The methodology used in RESRAD can provide "guidelines" for cleanup criteria and for site remediation alternatives.

" A guideline is defined as a radionuclide concentration or a level of radiation or radioactivity that is acceptable if a site is to be used without radiological restrictions. Guidelines are expressed as (1) concentrations of residual radionuclide in soil, (2) concentrations of airborne radon decay products, (3) levels of external gamma radiation, (4) levels of radioactivity from surface contamination, and (5) concentrations of residual radionuclides in air and water. Generic guidelines for thorium and radium in soil, airborne radon decay products, external gamma radiation, surface contamination, and residual

radionuclides in air and water are specified in the DOE guidelines" (Yu 1993).

By applying a basic radiation dose limit of 100 mrem/yr (as specified in the DOE guidelines) to a member of a critical population group using an environmental pathway analysis site-specific soil guidelines may be found. The radiation dose is defined as the effective dose equivalent from external radiation plus the committed effective dose equivalent from internal radiation .

All significant exposure pathways for the critical population group should be considered in deriving soil guidelines (DOE/CH-8901). These significant pathways are:

1.) direct exposure to external radiation from the contaminated soil material,

2.) internal radiation exposure from inhalation of airborne radionuclides,

3.) ingestion of plant foods,

4.) ingestion of meat,

5.) ingestion of milk,

6.) ingestion of fish and other aquatic foods,

7.) ingestion of groundwater,

8.) ingestion of surface water, and

9.) ingestion of soil.

The methodology used in RESRAD may also determine the dose obtained from a specified exposure scenario. Therefore, RESRAD provides the user with clean up criteria for the site under investigation for a given exposure scenario. The exposure of individuals to radiation from contaminated sites may occur through a variety of scenarios. Some of these scenarios are:

1.) resident farmer,

2.) recreational user,

3.) industrial worker, and

4.) intruder.

There is a considerable amount of variability for potential exposure within each of these scenarios. The amount of time obtained on the site may vary significantly, the mechanisms for exposure for a given pathway may be very different, and exposure from a certain pathway may or may not be possible.

3.1.1.1 Guidelines for Residual Radioactive Material

Since radon is a part of both the Radium-226 and Uranium-238 decay chain, it is a important pathway that is looked at in this study. The guidelines state that for concentrations of airborne radon decay products, for existing occupied or habitable structures, shall not exceed an annual average concentration of 0.02 working levels (WL) (DOE 1990).

The guidelines for external gamma radiation require that the average level inside a building or habitable structure on a site to be released without restrictions shall not exceed the background level by more than 20 μR/h and shall comply with the basic dose limit (100 mrem/yr). Since there are not any structures at the SLAPS site at this time, this guideline is not applicable to this study. The guideline for surface contamination on existing structures is also not applicable (DOE 1990).

The last guideline states that any exposure to the public from residual radionuclides in air and water should not exceed 100 mrem/yr or any other applicable

federal and/or state laws (DOE 1990). The applicable laws provided by the federal and state governments are beyond the scope of this thesis and are not considered.

3.1.1.2 Pathway Analysis

There are four parts needed to perform a pathway analysis for deriving soil concentration guidelines. They are: (1) source analysis, (2) environmental transport analysis, (3) dose/exposure analysis, and (4) scenario analysis (Yu 1993).

"Source analysis addresses the problem of deriving the source terms that determine the rate at which residual radioactivity is released into the environment. This rate is determined by the geometry of the contaminated zone, the concentrations of radionuclides present, the rates of ingrowth and decay of the radionuclides, and the rate of removal by erosion and leaching" (Yu 1993). The source is a contaminated zone of cylindrical shape within which radionuclides are present in above-background concentrations. It is assumed that this source is uniformly distributed.

"Environmental transport analysis addresses the problems of (1) identifying environmental pathways by which radionuclides can migrate from the source to a human exposure location and (2) determining the rate of migration along these pathways" (Yu 1993). The three main pathways through which radionuclides can enter the body are external radiation, inhalation, and ingestion. The scenario determines the pathway. The environmental transport factor (ETF) is used to calculate the rate of migration along these environmental pathways.

"Dose/exposure analysis addresses the problem of deriving dose conversion factors for the radiation dose that will be incurred by exposure to ionizing radiation" (Yu 1993).

The dose conversion factors (DCFs) used in this study may be found in Appendix A.

"The parameters that control the rate of radionuclide release into the environment and the severity and duration of human exposure at a given location are determined by patterns of human activity referred to as exposure scenarios" (Yu 1993).

3.1.1.3 Derivation of Guidelines for Residual Radioactive Material in Soil

"The basic criterion for releasing a site for use without radiological restrictions is the dose limit. The dose limit is converted to soil guidelines-specified as radionuclide concentrations-by means of dose/source ratios (DSRs) that are expressed in terms of three primary factors: DCFs, ETFs, and source factors (SFs)" (Yu 1993). These factors are discussed in Appendix A.

3.1.1.3.1 Radiological Release Criteria

The basic dose limit that must be satisfied before a site can be released for use without radiological restrictions, according to RESRAD methodology, is given in the following inequality,

$$H_E(t) \le H_{EL,} \qquad t_r \le t \le t_h \qquad \textbf{3.1}$$

where,

$H_E(t)$ = average annual committed effective dose equivalent received by a member of the critical population group at time (t) following the radiological survey of the site (mrem/yr),

H_{EL} = basic dose limit (100 mrem/yr default),

t_r = time at which the site is released for use without radiological restrictions following the radiological survey (1 year), and

t_h = time horizon (1,000 years default) (Yu 1993).

3.1.1.3.2 Effective Dose Equivalent to the Receptor

The average annual effective dose equivalent received by the human receptor in the family-farm scenario from the ith principal radionuclide transported through the pth environmental pathway together with its associated decay products (mrem/yr), $H_{E,ip}(t)$, is given by the following equation,

$$H_{E,ip}(t) = DSR_{ip}(t) \times S_i(t) \qquad 3.2$$

where,

DSRip(t) = dose/source-concentration ratio for the ith principal radionuclide and environmental pathway [(mrem/yr)/(pCi/g)], and

Si(0) = initial concentration of the ith principal radionuclide in a uniformly contaminated zone (pCi/g) (Yu 1993).

Thus, the total annual effective dose equivalent to the target receptor is,

$$H_E(t) = \sum_i \sum_p H_{E,ip}(t) \qquad 3.3$$

3.1.1.4 Description of Exposure Scenarios

The resident farmer scenario assumes that the site may be used at sometime to plant a garden, to raise livestock and to live off of its surroundings. This scenario also assumes that the site will be occupied most of the time (at least 15 hours/day). So for this scenario, it is important that the amount of dose provided by all of the important pathways are known.

The recreational user scenario assumes that the site may be used for recreational

purposes only. Therefore the time a person occupies the site may be relatively small. However, dust generation could be high. Therefore, the inhalation dose is important to know. The SLAPS site has a high potential for being a recreational site.

The industrial worker scenario can take into account a number of scenarios. Some of these scenarios may include: remediation workers, office personnel, building service staff, grounds maintenance groups, and utility crews. It is assumed that most of these scenarios have an occupancy time of at least 8 hours per day.

The intruder scenario assumes that there is someone or something on the site that is not supposed to be there. The occupancy time for this scenario is relatively small. However, the occupancy time would vary if institutional controls were in effect compared to not being in effect. It is assumed that if intrusion occurs while institutional controls are in effect, the intruder is aware of the risk, and the opposite is assumed if there are no institutional controls in effect.

3.2 RADIOLOGICAL ASSESSMENT FOR OFF-SITE EXPOSURE

A radiological assessment for off-site exposure is generally done to determine if there is any radiation that exceeds the government limits and if any type of danger is or will be done to the environment surrounding a contaminated facility or site. Radionuclide emissions to the air are usually the main concern to the surrounding environment. There are several methods used to determine if there are any radionuclide emissions in the air. For this study, the computer program CAP88-PC will be used.

3.2.1 Description of CAP88-PC

CAP88-PC is a computer model that was developed by DOE to provide a

computational methodology for determining compliance with the Environmental Protection Agency (EPA) rules for radionuclide emissions to air under 40 CFR Part 61.93 (a), National Emission Standards for Hazardous Air Pollutants (NESHAPS). This model includes a set of computer programs, databases and associated utility programs for estimation of dose and risk from radionuclide emissions to air (Parks 1992).

A modified Gaussian plume equation is used to estimate the average dispersion of radionuclides released from up to six sources. These sources may be elevated stacks or uniform area sources (such as mill tailing piles). Plume rise may be calculated assuming either a momentum or buoyancy-driven plume. Assessments may be done for up to fifty miles around the site. CAP88 provides meteorological data for many major cities and DOE facilities, and population files are provided for some DOE facilities (Parks 1992).

The CAP88-PC software is used in this study to evaluate off-site doses from suspended particulate. The SLAPS site is modeled as an area source, and doses are calculated for an individual at specified distances.

3.3 METHODS USED FOR SENSITIVITY ANALYSIS

The purpose of a sensitivity analysis is to identify the components of a model that are potentially important contributors to a predictive uncertainty (IAEA 1989). The most sensitive parameters of the model are determined by perturbing each parameter in the model separately by a certain amount and determining the influence of the perturbation on the predictive quantity. The influence of the perturbation is determined by taking the fractional change of the calculated value divided by the fractional change of the parameter. The results from these calculations are called sensitivity coefficients and they have no

units. The results from a sensitivity analysis are site specific. For this study, RESRAD is used to determine which parameter is most sensitive. It should also be noted that the sensitive parameters found in the model vary by pathway.

3.4 METHODS USED FOR UNCERTAINTY ANALYSIS

When doing an uncertainty analysis for environmental assessments it is assumed that much of the information needed about the environment is typically lacking. Therefore, the main purpose of the uncertainty analysis is to attempt to account for the various unknowns by estimating the entire set of possible outcomes.

To perform the proper uncertainty analysis, the following tasks are usually required (paraphrased from IAEA 1989):

1.) determine all of the parameters in the model that are potentially important contributors to uncertainty (this is accomplished by doing a sensitivity analysis),

2.) specify the maximum range of each sensitive parameter,

3.) establish the degree of belief (in percentage) that the parameter value is not larger than the values selected from the range specified in step 2 and select a probability density function (pdf),

4.) determine correlations among parameters,

5.) propagate probability density functions through the model to generate a subjective probability distribution of predicted values,

6.) establish confidence intervals for model predictions,

7.) rank parameters with respect to their contributions to the uncertainty in the

model predictions, and

8.) present and interpret results.

3.4.1 Latin Hypercube Sampling

Latin hypercube sampling (LHS) is used to generate multivariate samples at random. For this study, the computer code RESRAD-Probabilistic will use LHS to propagate the probability density function through the model and generate a subjective probability distribution of the predicted values.

To generate a subjective probability distribution, LHS selects a specified number (n) of different values within the specified range set for the sensitive parameters. This is done by (Paraphrased from Iman 1984):

1.) dividing the range of each sensitive parameters into n nonoverlapping intervals,

2.) selecting one value at random from each interval with respect to the probability density in the interval,

3.) pairing the n values obtained from the first sensitive parameter in a random manner with the n values of the second sensitive parameter, and

4.) combining these n pairs in a random manner with the n values of the third sensitive parameter to form n triplets, and so on, until n k-tuplets are formed.

For this study, it is assumed that all sensitive parameters are lognormally distributed. The ranges of the sensitive parameters, minimum and maximum values respectively, are used to determine the .1% and 99.9% limits of a lognormal distribution.

4. RESULTS

4.1 ON-SITE CONTAMINATION

By looking at the contamination at SLAPS and the ballfield separately, one can get a better understanding of how the contamination is distributed throughout the whole site. Analyzing the data, provided by the St. Louis Baseline Risk Assessment (BRA), for each location was one of the first things that was done to get a better understanding of how the contamination was distributed throughout the whole site. A Fortran program was written to analyze the data for each location. These programs determined the average maximum depth of contamination, average concentration, total area, and the volume of contaminated soil. The data was read and sorted to correspond to a predetermined grid position. Also PSI software was used to graphically illustrate the concentration and the depth of contamination throughout each location. The data provided by the BRA are listed by horizontal position and axial depth (east and north coordinates) and may be found in Appendix D.

4.1.1 Contaminant Concentration Distribution

By looking at Figures 4.1 through 4.8, the peak concentration and the distribution of the contamination of Ra-226, Th-232, Th-230, and U-238 vary greatly between SLAPS and the ballfield. Figures 4.1 and 4.5 shows that Ra-226 is more widely dispersed and has a greater peak concentration at SLAPS than the ballfield (about 700 pCi/g vs. about 25 pCi/g). Also, Figures 4.2 and 4.6 show that the U-238 peak concentration (about 350 pCi/g) is much greater than the ballfield U-238 concentration (about 11pCi/g). By looking

RA-226 Soil Concentration at SLAPS

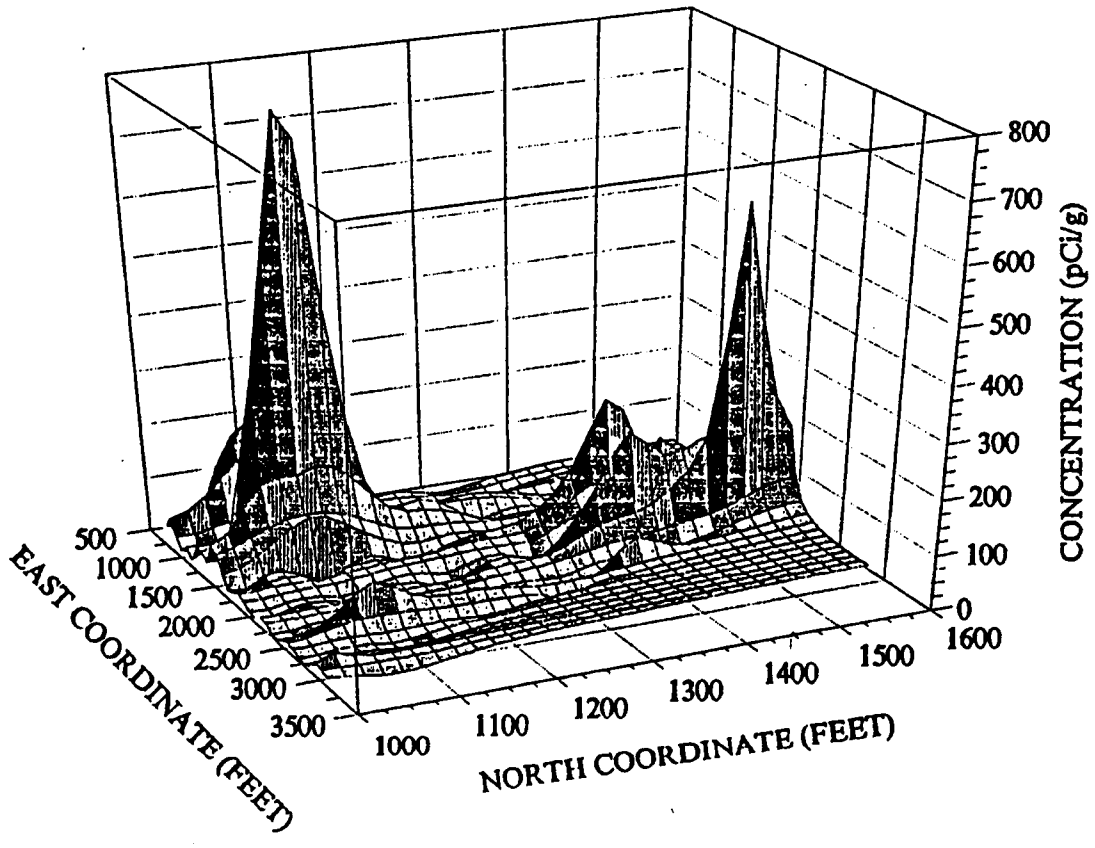


Figure 4.1 Concentration of Ra-226 at SLAPS

U-238 Soil Concentration at SLAPS

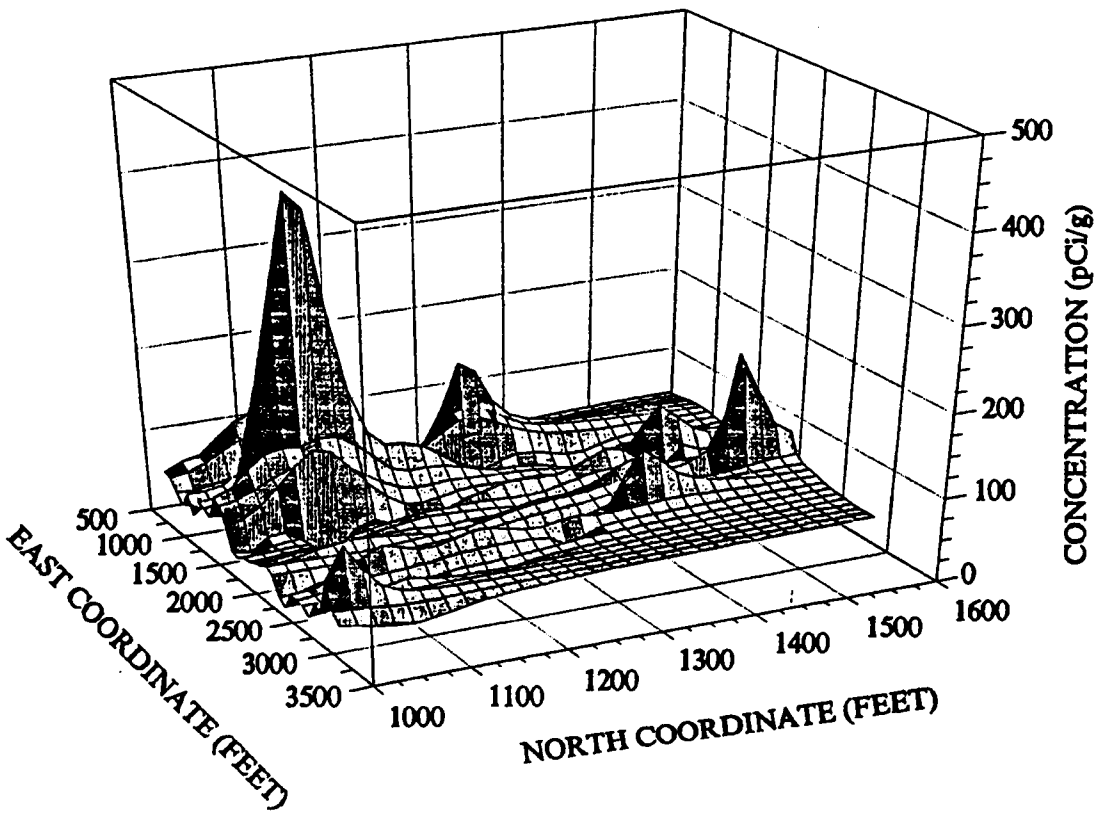


Figure 4.2 Concentration of U-238 at SLAPS

TH-230 Soil Concentraion at SLAPS

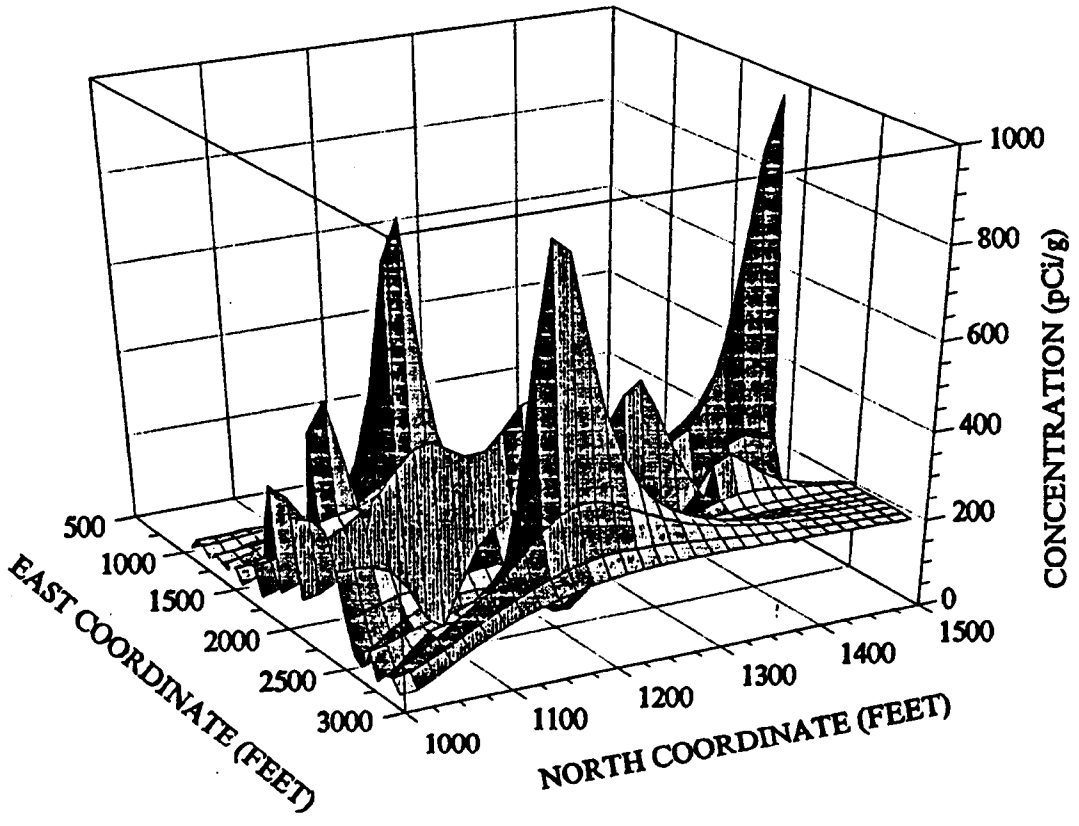


Figure 4.3 Concentration of Th-230 at SLAPS

TH-232 Soil Concentration at SLAPS

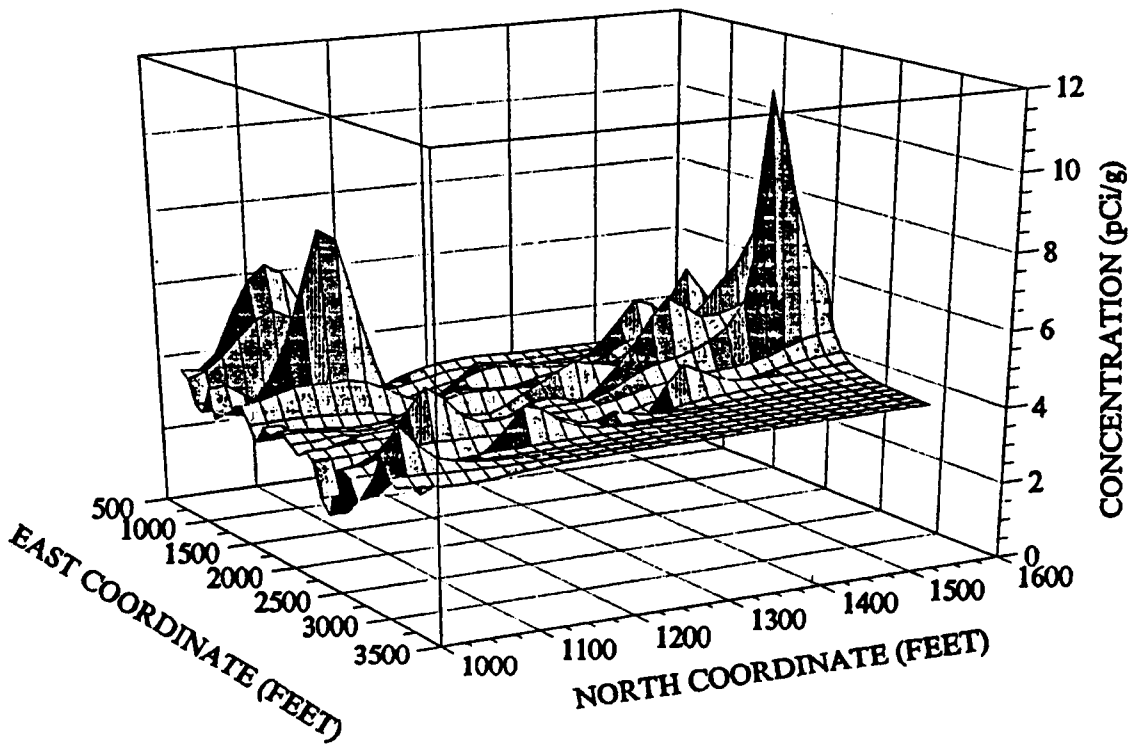


Figure 4.4 Concentration of Th-232 at SLAPS

RA-226 Soil Concentration at the Ballfield

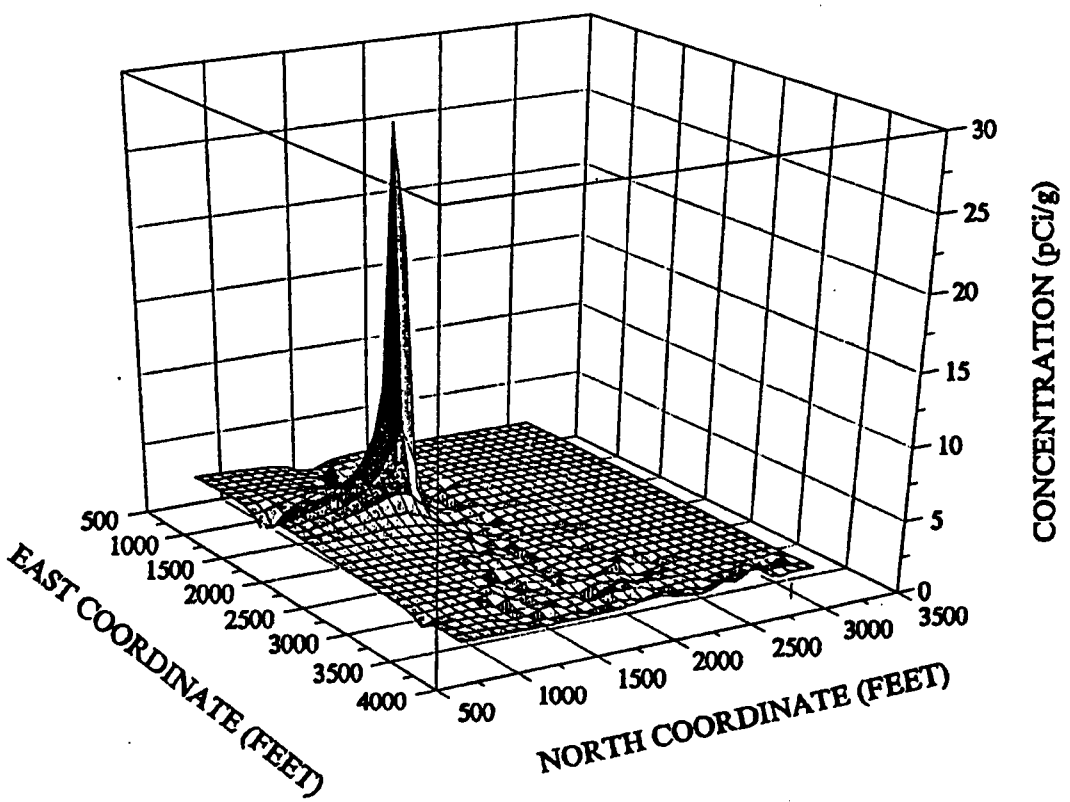


Figure 4.5 Concentration of Ra-226 at the Ballfield

U-238 Soil Concentration at the Ballfield

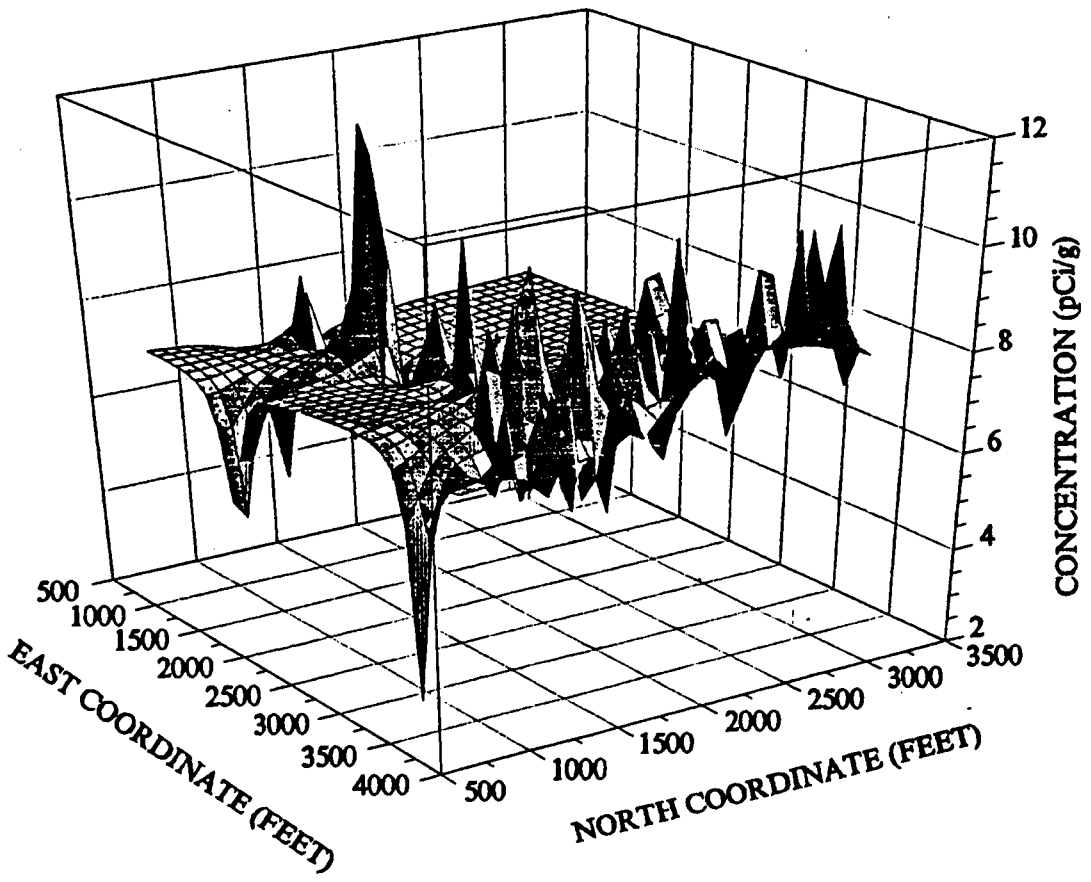


Figure 4.6 Concentration of U-238 at the Ballfield

TH-230 Soil Concentration at the Ballfield

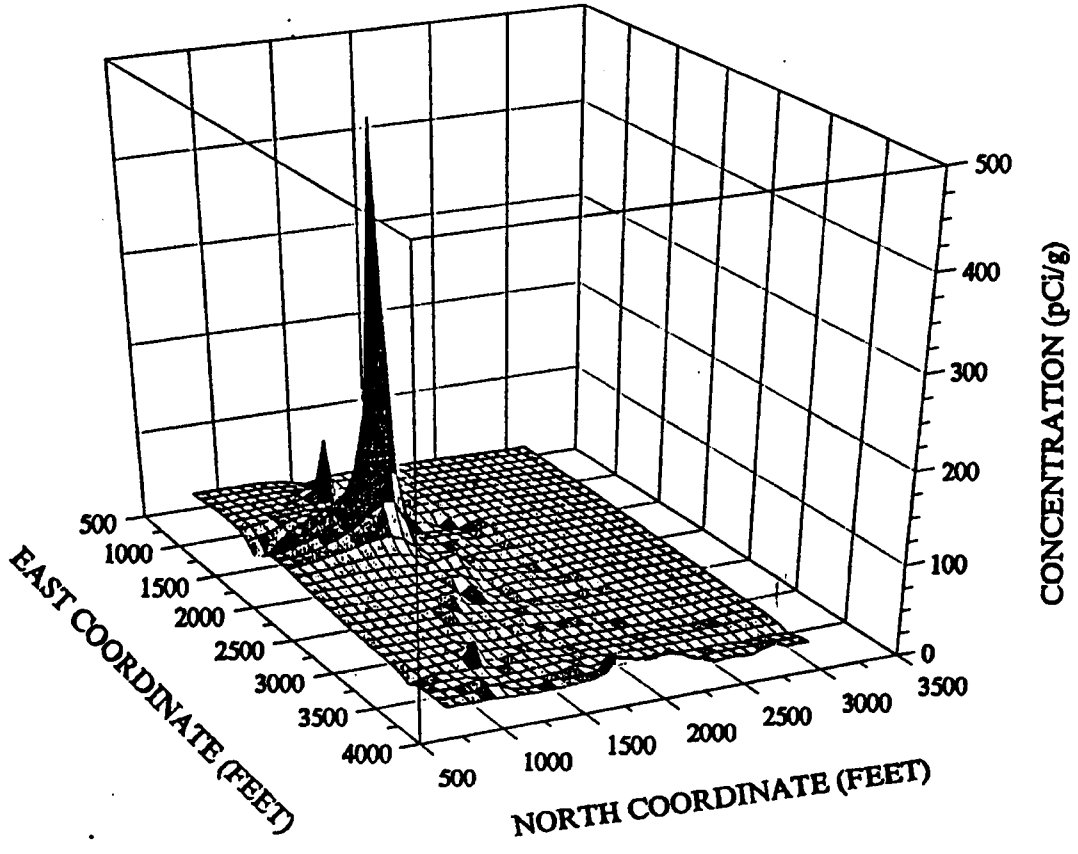


Figure 4.7 Concentration of Th-230 at the Ballfield

TH-232 Soil Concentration at the Ballfield

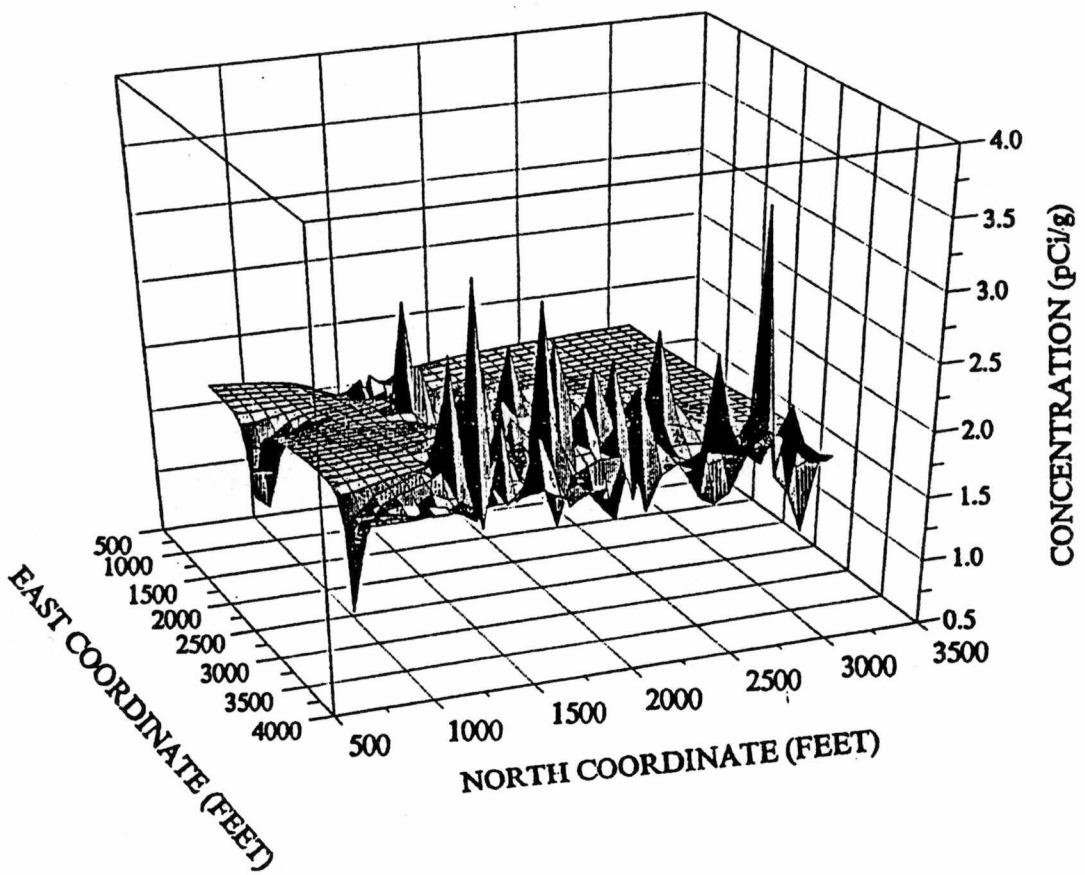


Figure 4.8 Concentration of Th-232 at the Ballfield

at Figures 4.3 and 4.7, Th-230 is more widely dispersed at SLAPS than at the ballfield but, both locations has a fairly high maximum peak (SLAPS has the higher peak, 950 pCi/g). Th-232 at both locations is widely dispersed and has a relatively low concentration peak compared to the other radionuclides, Figures 4.4 and 4.8. By looking at these figures, it can be seen that SLAPS has a much higher concentration and the contamination is more widely dispersed than the ballfield. It should be noted that the figures provided by the PSI software are not topographic maps of the sites but, rectangular areas inclusive of all the properties within the contaminated site.

4.1.2 Depth, Area and Volume of Contamination

The depth of the contamination has a significant impact on the volume of material that must be removed for remediation of the site. Figures 4.9 through 4.16 shows the depth of each radionuclide present at SLAPS and the ballfield. By looking at these figures, it can be seen that the contamination at SLAPS is deeper than the contamination at the ballfield.

Tables 4.1 and 4.2 provide general characteristics of SLAPS and the ballfield respectively. The information provided in these tables were obtained from the Fortran computer programs which were mentioned earlier. The volume of contamination provided in Tables 4.1 and 4.2 were determined by multiplying the maximum depth of contamination in a particular grid by the grid area. The average maximum depth was determined by averaging the maximum depths over all of the grid locations. By looking at Table 4.1 and Table 4.2, it can be seen that the volume of contaminated soil at SLAPS and the ballfield combined is about 318,700 yd^3. FUSRAP documentation stated that the

Ra-226 Depth of Concentration at SLAPS

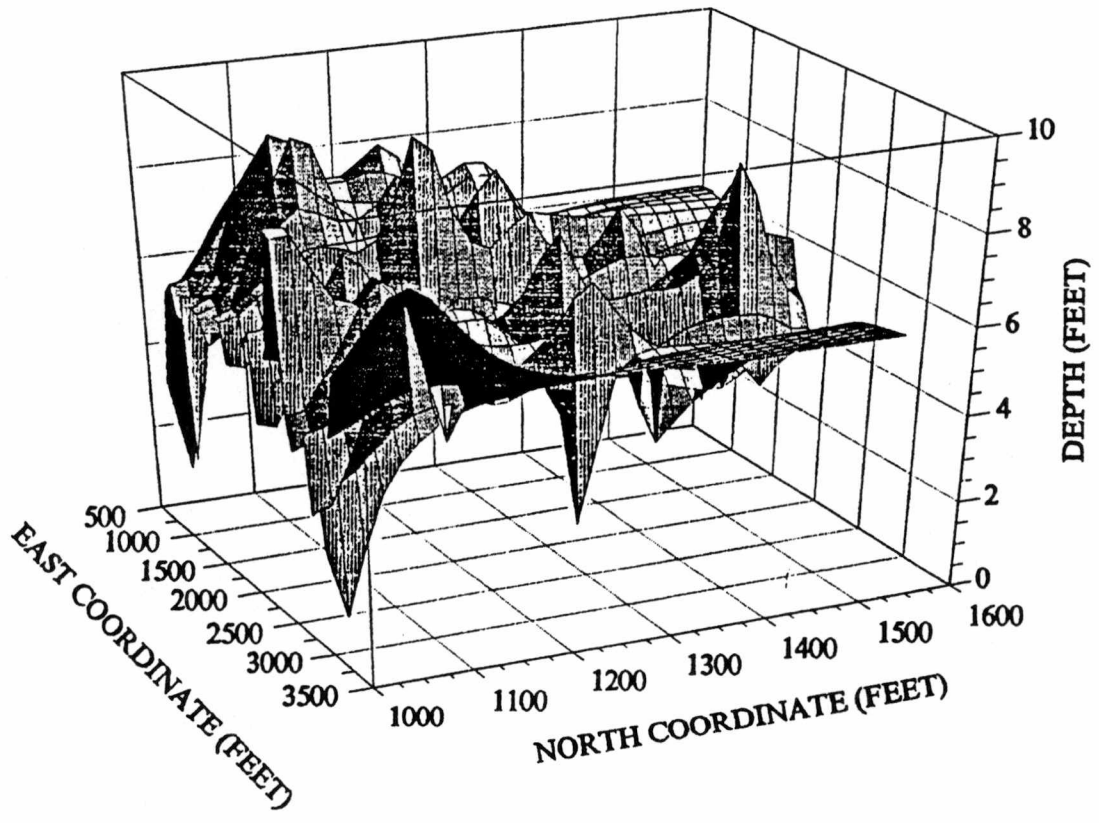


Figure 4.9 Depth of Ra-226 Concentration at SLAPS

U-238 Depth of Concentration at SLAPS

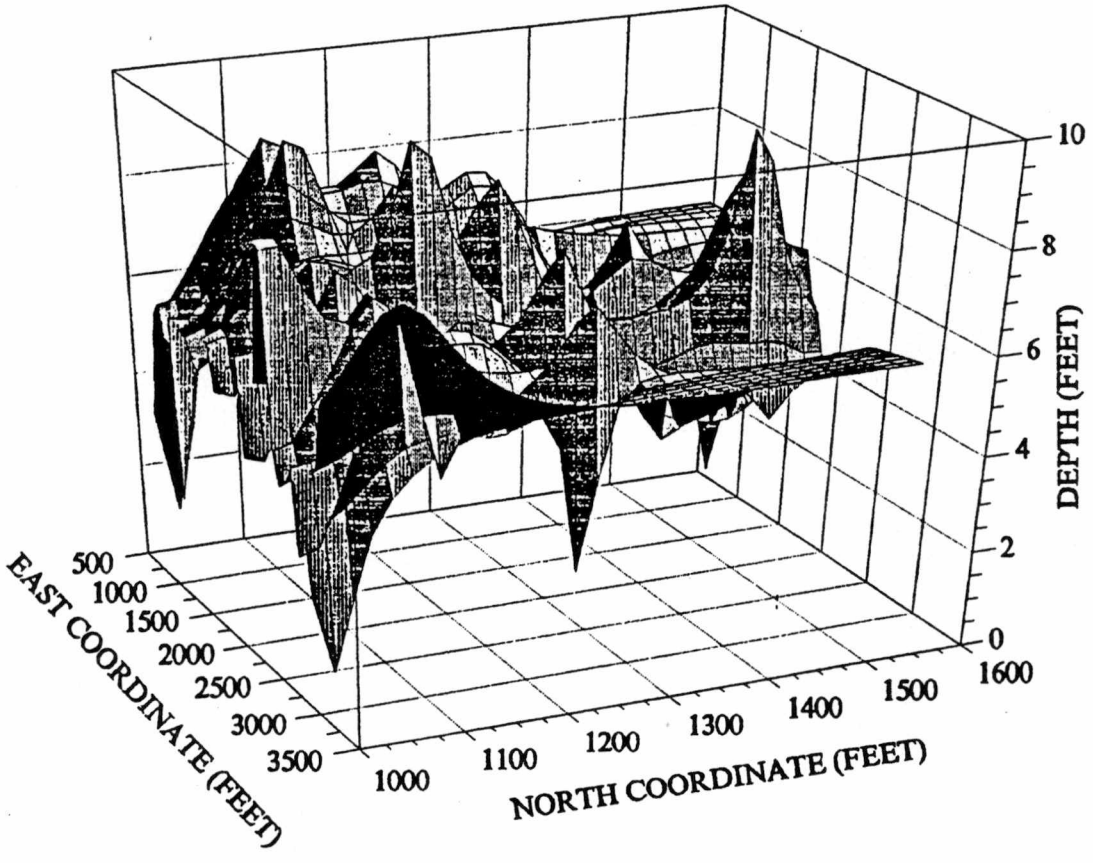


Figure 4.10 Depth of U-238 Concentration at SLAPS

Th-230 Depth of Concentration at SLAPS

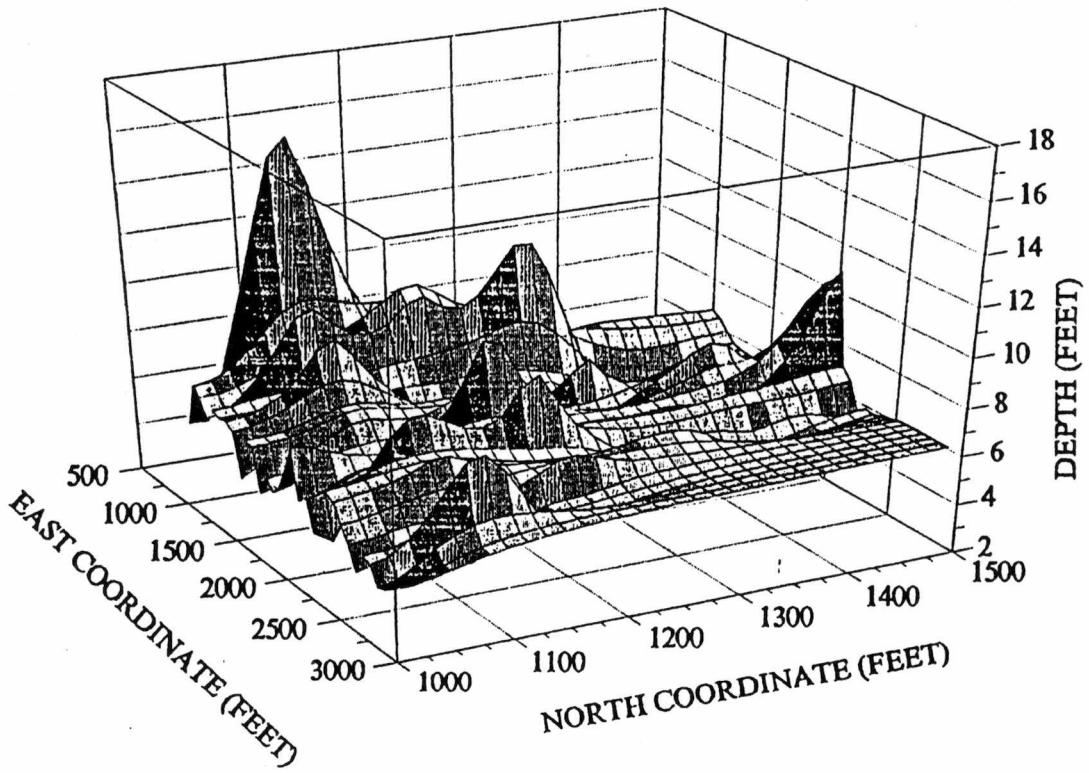


Figure 4.11 Depth of Th-230 Concentration at SLAPS

Th-232 Depth of Concentration at SLAPS

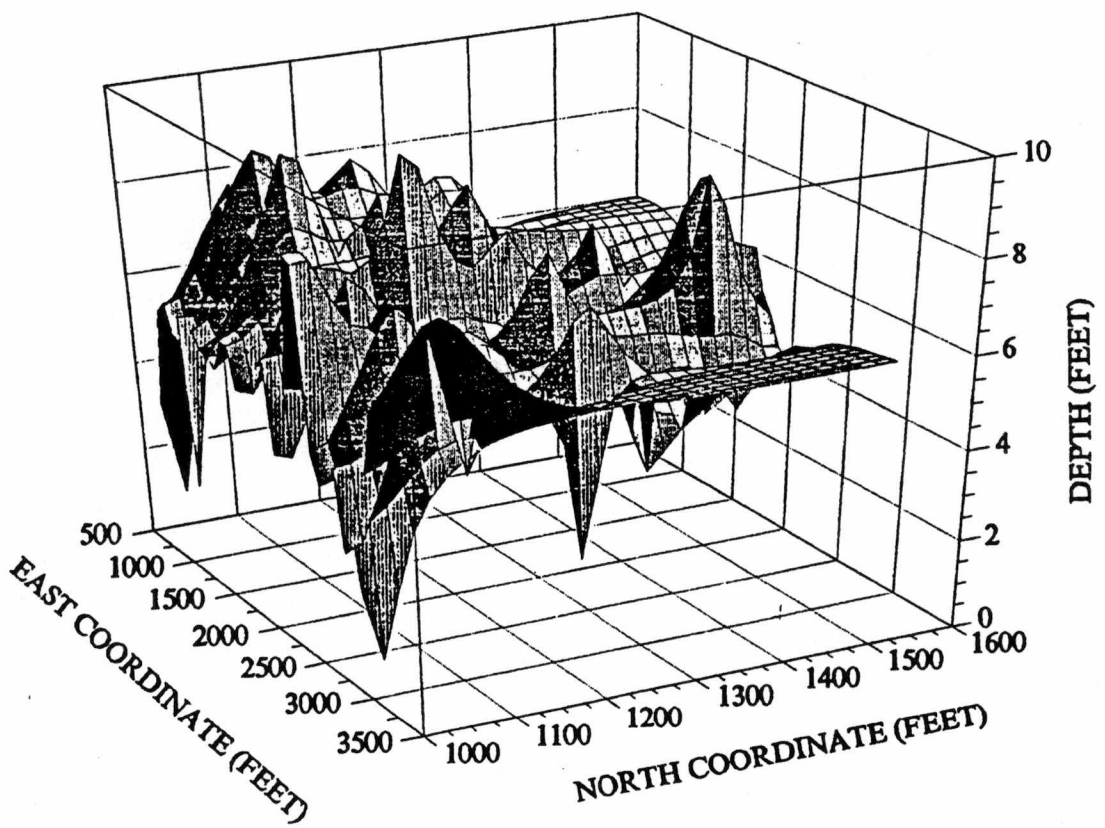


Figure 4.12 Depth of Th-232 Concentration at SLAPS

RA-226 Depth of Concentration at the Ballfield

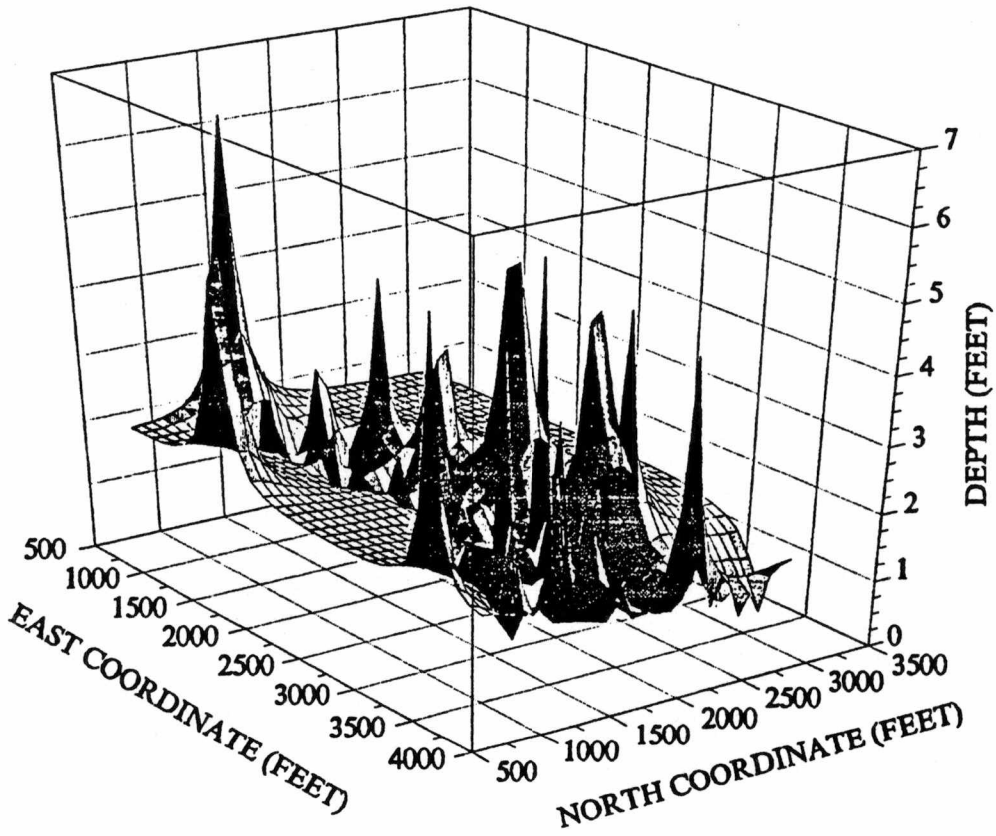


Figure 4.13 Depth of Ra-226 Concentration at the Ballfield

U-238 Depth of Concentration at the Ballfield

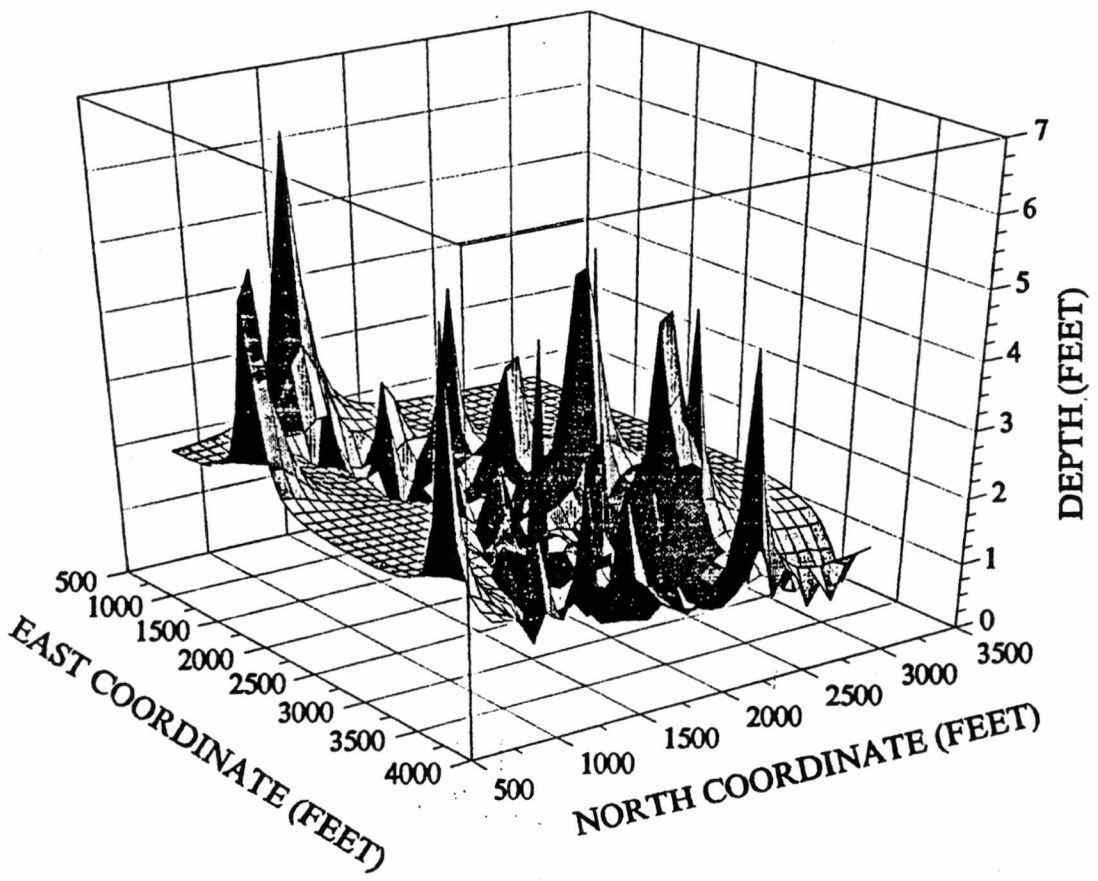


Figure 4.14 Depth of U-238 Concentration at the Ballfield

TH-230 Depth of Concentration at the Ballfield

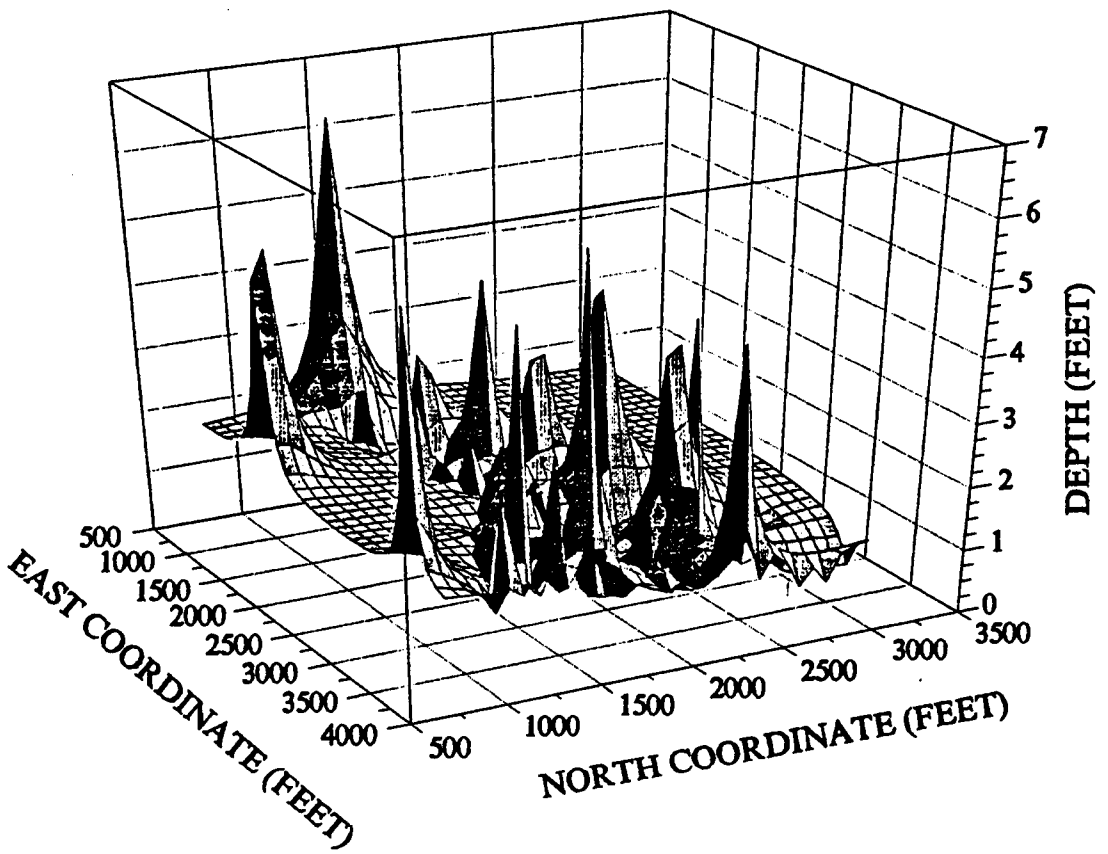


Figure 4.15 Depth of Th-230 Concentration at the Ballfield

TH-232 Depth of Concentration at the Ballfield

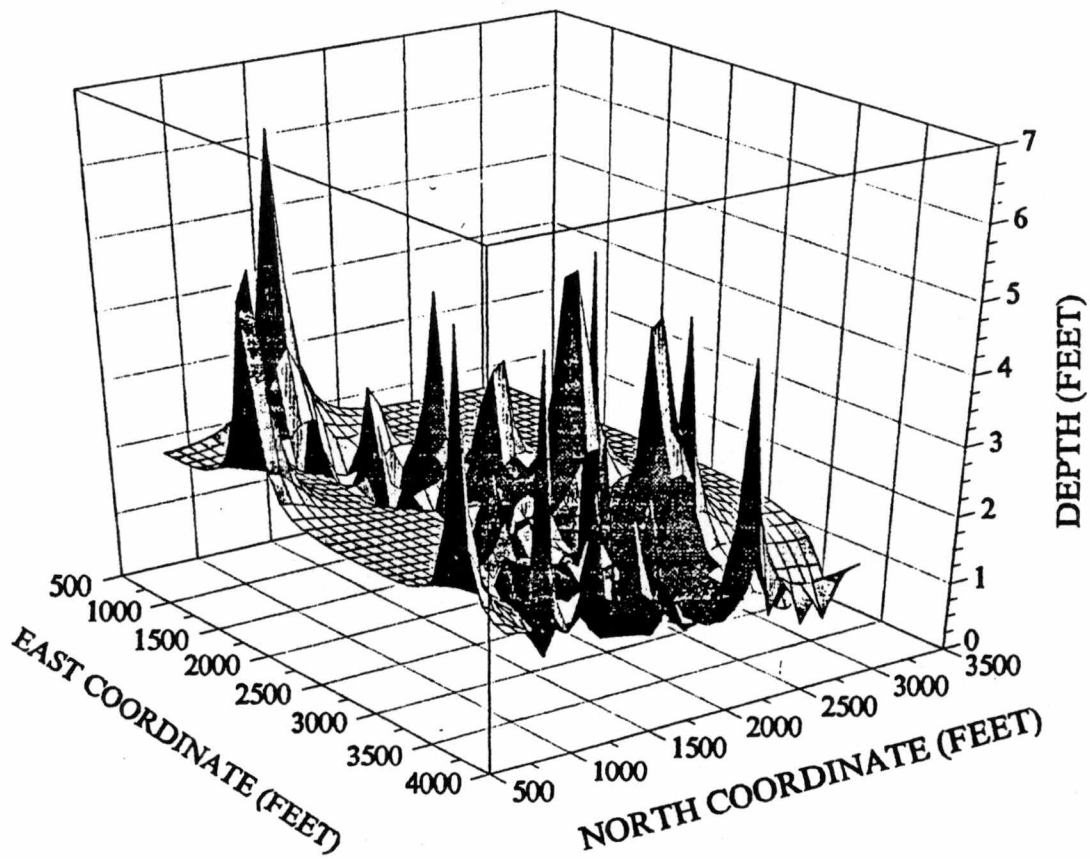


Figure 4.16 Depth of Th-232 Concentration at the Ballfield

Table 4.1 General Site Characteristics of SLAPS

	U - 238	Ra - 226	Th - 232	Th - 230
Average maximum depth of contamination (ft)	7.52	7.51	7.43	7.57
Average maximum depth of contamination greater than 15 pCi/g (ft)	5.99	4.37	3.13	5.92
Average concentration (pCi/g)	64.29	67.15	3.93	115.98
Average concentration greater than 15 pCi/g	84.27	335.34	32.68	334.45
Total area contaminated (Acres)	8.94	8.94	8.94	6.96
Area contaminated greater than 15 pCi/g (Acres)	8.42	3.87	0.52	4.38
Volume of contamination (yd3)	1.087E5	1.086E5	1.075E5	8.524E4
Volume of contamination greater than 15 pCi/g (yd3)	8.15E4	2.73E4	2.61E3	4.20E4
Total Activity (Ci)	9.56	9.98	.578	13.5
Total Mass (grams)	2.86E7	10.1	5.25E6	668.59
Half-life (years)	4.5E9	1.6E3	1.4E10	7.7E4

Table 4.2 General Site Characteristics of the Ballfield

	U - 238	Ra - 226	Th - 232	Th - 230
Average maximum depth of contamination (ft)	2.51	2.53	2.55	2.35
Average maximum depth of contamination greater than 15 pCi/g (ft)	.8125	.25	0.0	.507
Average concentration (pCi/g)	7.48	2.19	1.80	19.94
Average concentration greater than 15 pCi/g	21.63	66.75	0.0	87.25
Total area contaminated (Acres)	50.11	49.68	49.25	55.30
Area contaminated greater than 15 pCi/g (Acres)	1.73	0.864	0.0	15.98
Volume of contamination (yd3)	2.03E5	2.03E5	2.03E5	2.10E5
Volume of contamination greater than 15 pCi/g (yd3)	2.27E3	349.4	0.0	1.31E4
Total Activity (Ci)	2.077	0.608	0.5	5.73
Total Mass (grams)	6.22E6	0.614	4.56E6	283.78
Half-life (years)	4.5E9	1.6E3	1.4E10	7.7E4

volume of contamination at SLAPS and the ballfield combined was about 279,000 yd^3 (DOE 1993).

It should be noted that the volume of contamination does not coincide with the information from the FUSRAP documents. However, it is not possible to obtain a very accurate estimate of the volume of contaminated soil since many of the measurements of concentration are questionable. About one-half of the values listed are cited as "less than" a given value. Thus, the actual values is not known with any degree of certainty. Tables 4.3 and 4.4, shows the characteristics of SLAPS and the ballfields without the use of the questionable "less than" values.

4.1.3 RESRAD

By making a detail analysis of the data, I found the recreational scenario to be the best scenario to use for the SLAPS site. One of the main reasons the recreational scenario was chosen was because of the geology at SLAPS. Since the soil is made of clays and other materials, which have low porosities, the water movement at SLAPS is slow. Therefore, the probability of having a well or some type of irrigation system for domestic or agricultural use is very low. This reduces the chance of using the site as a residential area greatly because not having an effective irrigation system or drinking water well reduces the chance of having a garden and livestock. The SLAPS site is also considered to be a recreational site because its area was already designed to support a ballfield.

Figures 4.17 through 4.20 provides the time-dependent DSR at SLAPS (SLAPS and the ballfield) from Ra-226, U-238, Th-232, and Th-230 for four water independent pathways generated by RESRAD. The four most important water independent pathways

Table 4.3 General Site Characteristics of SLAPS (without less than values)

	U - 238	Ra - 226	Th - 232	Th - 230
Average maximum depth of contamination (ft)	7.06	7.68	9.31	7.30
Average maximum depth of contamination greater than 15 pCi/g (ft)	6.26	4.37	4.5	5.92
Average concentration (pCi/g)	179.10	150.31	3.04	115.96
Average concentration greater than 15 pCi/g	225.59	333.67	63	334.40
Total area contaminated (Acres)	2.15	6.01	4.38	6.96
Area contaminated greater than 15 pCi/g (Acres)	1.89	3.87	.086	4.38
Volume of contamination (yd3)	2.45E4	7.47E4	6.60E4	8.22E4
Volume of contamination greater than 15 pCi/g (yd3)	1.91E4	2.73E4	625.5	4.20E4
Total Activity (Ci)	7.90	20.2	.361	9.53
Total Mass (grams)	2.36E7	20.4	3.28E6	471.98
Half-life (years)	4.5E9	1.6E3	1.4E10	7.7E4

Table 4.4 General Site Characteristics of the Ballfield (without less than values)

	U - 238	Ra - 226	Th - 232	Th - 230
Average maximum depth of contamination (ft)	2.91	2.43	2.49	2.25
Average maximum depth of contamination greater than 15 pCi/g (ft)	0.25	0.25	0.0	0.51
Average concentration (pCi/g)	7.28	2.20	1.85	19.95
Average concentration greater than 15 pCi/g	26.0	66.75	0.0	87.25
Total area contaminated (Acres)	9.50	49.68	47.52	55.30
Area contaminated greater than 15 pCi/g (Acres)	1.30	0.86	0.0	15.98
Volume of contamination (yd3)	4.47E4	1.95E5	1.91E5	2.01E5
Volume of contamination greater than 15 pCi/g (yd3)	5.24E2	3.49E2	0.0	1.31E5
Total Activity (Ci)	5.86	7.72	6.36	72.2
Total Mass (grams)	1.75E7	7.80	5.77E7	3.58E3
Half-life (years)	4.5E9	1.6E3	1.4E10	7.7E4

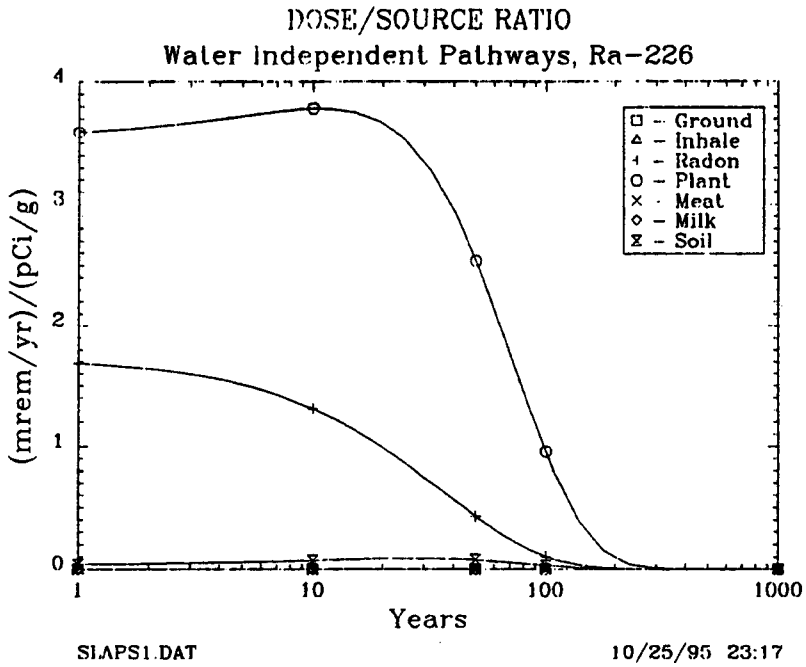


Figure 4.17 Dose to Source Ratio at SLAPS from Ra-226

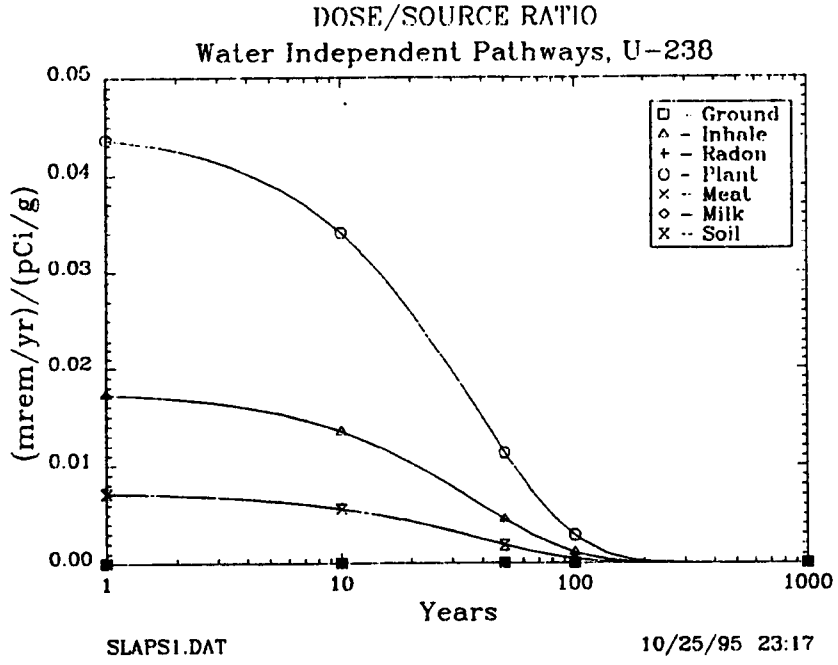


Figure 4.18 Dose to Source Ratio at SLAPS from U-238

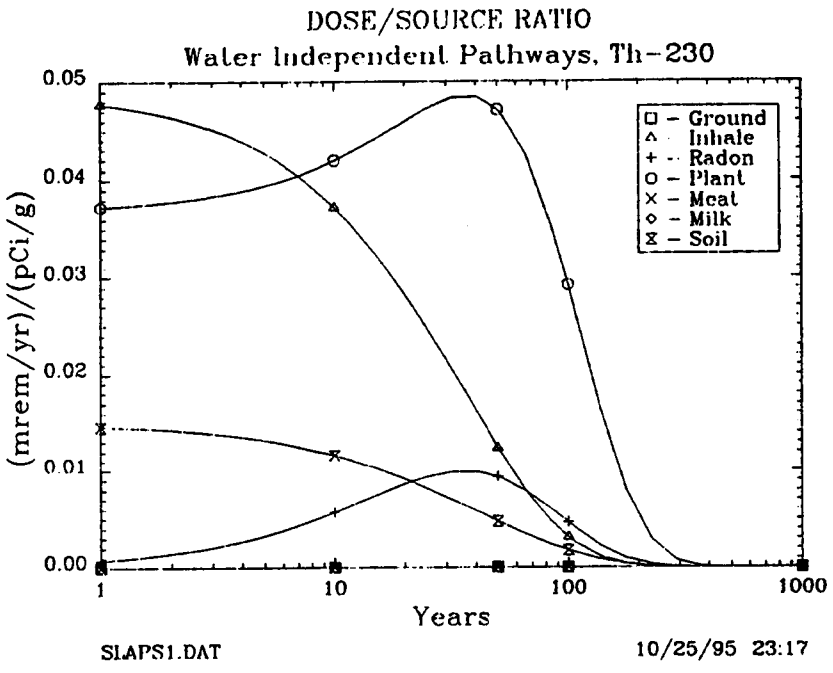


Figure 4.19 Dose to Source Ratio at SLAPS from Th-230

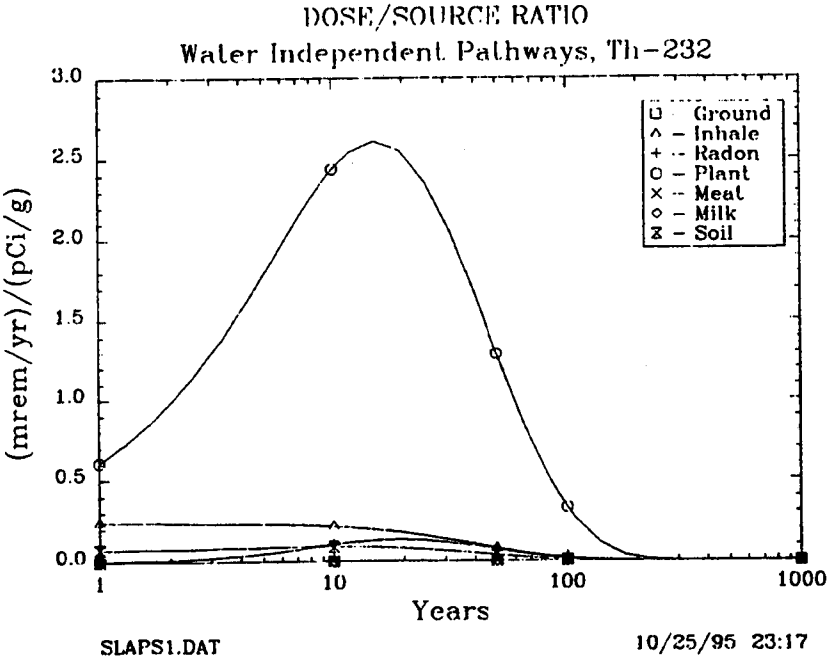


Figure 4.20 Dose to Source Ratio at SLAPS from Th-232

were: inhalation, plant ingestion, soil ingestion, and Radon. By looking at Figures 4.17 through 4.20, the plant ingestion pathway is the most dominant pathway. Since SLAPS is considered to be a recreational area, the aquatic, meat, and milk ingestion pathways were neglected.

4.1.3.1 Sensitivity Analysis

As mentioned in Chapter 3, the sensitivity analysis for this study was done by using the computer model RESRAD Version 5.6. By doing this sensitivity analysis the most sensitive parameters were found. The most sensitive parameters found in this study varied according to pathway. Table 4.5 provides a description of all the sensitive parameters.

In Chapter 3 it was mentioned that the most sensitive parameters were determined by perturbing each parameter in the model by a certain amount and determining the influence of the perturbation on the predictive quantity. For this study, each parameter was perturbed by 100% of the original parameter value. And, the fractional change of the calculated value (dose/year) divided by the fractional change of the parameter determined the influence of the perturbation, and this value was called the sensitivity coefficient. Table 4.6 shows the sensitivity coefficients for each radionuclide and each sensitive parameter according to pathway at fifty years from now.

4.1.3.2 Uncertainty Analysis

In Chapter 3, it was mentioned that a range was determined for each of the sensitive parameters. This range specified the lowest and highest value the sensitive parameters should go according to this study. This range also specified the .1% and 99.9% limits of a lognormal distribution. Table 4.7 shows the sensitive parameters and

Table 4.5 Description of Sensitive Parameters

Sensitive Parameter	Description
Contaminated Zone Thickness	The distance between the uppermost and lowermost soil samples that have radionuclide concentrations clearly above background.
Contaminated Zone Density	The ratio of mass to volume for the soil which is in the contaminated zone.
Evapotranspiration Coefficient	The ratio of the total volume of water leaving the ground as the result of evapotranspiration to the total volume of water available within the root zone of the soil during a fixed period of time.
Uncontaminated/Unsaturated Zone Thickness	The portion of the uncontaminated zone that lies below the bottom of the contaminated zone and above the water table.
Uncontaminated/Unsaturated Total Porosity	The ratio of the pore volume to the total volume of the uncontaminated/unsaturated zone.
Uncontaminated/Unsaturated Effective Porosity	The ratio of the part of the pore volume where the water can circulate to the total volume of a representative sample of the uncontaminated zone.
Mass Loading for Inhalation	The concentration of soil particles in the air.
Soil Ingestion Rate	The accidental ingestion rate of soil material or soil dust.
Contaminated Zone Total Porosity	The ratio of the pore volume to the total volume of the contaminated zone.
Building Foundation Thickness (Radon)	The average thickness of the building shell structure in the subsurface of the soil.
Building Foundation Total Porosity (Radon)	The ratio of the pore volume to the total volume of the building foundation.
Building Air Exchange Rate (Radon)	The total volume of air contained on the building that is being exchanged with outside air per unit of time.
Building Room Height (Radon)	The average height of the building.
Radon Emanation Coefficient	The fraction of the total amount of radon produced by radium decay that escapes from the soil particles and gets into the pores of the medium.

Table 4.6 Sensitivity Coefficients

Parameter	Pathway	Radionuclide Sensitivity Coefficients			
		Ra-226	Th-230	Th-232	U-238
Contaminated Zone Thickness	Inhalation Water Independent	0.31	0.60	0.58	0.60
	Radon Water Independent	1.16	1.16	0.47	1.03
	Plant Ingestion Water Independent	0.46	0.55	0.51	0.60
	Soil Ingestion Water Independent	0.40	0.58	0.55	0.60
Density of Contaminated Zone	Inhalation Water Independent	0.42	0.59	0.56	0.59
	Radon Water Independent	1.49	1.49	0.47	1.03
	Plant Ingestion Water Independent	0.45	0.53	0.51	0.60
	Soil Ingestion Water Independent	0.39	0.57	0.55	
Total Porosity of Contaminated Zone	Radon Water Independent	0.43	0.43	0.04	0.45

Table 4.6 (continued)

Parameter	Pathway	Radionuclide Sensitivity Coefficients			
		Ra-226	Th-230	Th-232	U-238
Evapotranspiration Coefficient	Inhalation Water Independent	2.06	2.79	2.69	2.79
	Radon Water Independent	2.79	2.79	2.23	2.16
	Plant Ingestion Water Independent	2.23	2.57	2.39	2.79
	Soil Ingestion Water Independent	1.94	2.70	2.58	2.79
Contaminated Fraction of Plant Food	Plant Ingestion Water Independent	1.00	1.00	1.00	1.00
Mass Loading Inhalation Factor	Inhalation Water Independent	1.00	1.00	1.00	1.00
Soil Ingestion Rate	Soil Ingestion Water Independent	1.00	1.00	0.99	1.00

Table 4.6 (continued)

Parameter	Pathway	Radionuclide Sensitivity Coefficients			
		Ra-226	Th-230	Th-232	U-238
Thickness of Uncontaminated/Unsaturated Strata	Inhalation Water Independent	0.75	1.15	1.09	1.15
	Radon Water Independent	1.15	1.15	0.88	0.83
	Plant Ingestion Water Independent	0.83	1.02	0.95	1.15
	Soil Ingestion Water Independent	0.70	1.10	1.03	1.15
Total Porosity of Uncontaminated/Unsaturated Strata	Inhalation Water Independent	0.41	0.59	0.56	0.59
	Radon Water Independent	0.59	0.59	0.45	0.43
	Plant Water Independent	0.45	0.53	0.48	0.59
	Soil Ingestion Water Independent	0.38	0.57	0.53	0.59

Table 4.6 (continued)

Parameter	Pathway	Radionuclide Sensitivity Coefficients			
		Ra-226	Th-230	Th-232	U-238
Effective Porosity of Uncontaminated/Unsaturated Strata	Inhalation Water Independent	0.75	1.15	1.09	1.15
	Radon Water Independent	1.15	1.15	0.88	0.83
	Plant Ingestion Water Independent	0.83	1.02	0.95	1.15
	Soil Ingestion Water Independent	0.70	1.10	1.03	1.15
Building Foundation Thickness (Radon)	Radon Water Independent	0.66	0.66	0.00	0.66
Building Foundation Total Porosity (Radon)	Radon Water Independent	0.33	0.33	0.00	0.33
Building Air Exchange Rate (Radon)	Radon Water Independent	1.28	1.28	0.04	1.28
Building Room Height (Radon)	Radon Water Independent	0.95	0.95	0.00	0.95

their ranges. It should be noted again, that the sensitive parameters vary according to pathway.

By using the ranges of the sensitive parameters in the RESRAD-Probabilistic computer model a cumulative probability distribution was established. This cumulative probability distribution was established for each important pathway according to each radionuclide. When doing this probability distribution the radionuclides was given a concentration of 1 pCi/g. This was done because the site had many different concentration levels. Figures 4.21 to Figure 4.36 are graphs that show the peak dose rate (mrem/yr) with a probability of not being exceeded. Table 4.8 gives the peak dose rate, for each radionuclide according to each pathway, with a 90% probability of not being exceeded.

4.2 FINDINGS

The SLAPS and ballfield sites cannot be considered clean until the dose standards provided by the EPA and DOE are established. The level of radionuclides (pCi/g) that may remain in the soil and still meet the EPA 10^{-4} lifetime risk may be achieved by taking 4 mrem/yr and dividing it by the values in Table 4.8. These values are for SLAPS and the ballfield combined, and may be found in Table 4.9. By taking the values in Table 4.9 and multiplying them by 25, the DOE 100 mrem/yr exposure limit may be obtained.

Since the SLAPS and ballfields were looked at for the recreational scenario, the inhalation pathway is very important. Soil ingestion is also an important pathway to consider for the recreational scenario, but soil ingestion is not as likely to occur compared to soil inhalation. If the SLAPS and ballfield site were to be residential areas, the plant

Table 4.7 Uncertainty Ranges of Sensitive Parameters

Sensitive Parameters	Uncertainty Range
Contaminated Zone Thickness	0.05 to 5.5 meters
Contaminated Zone Density	1.6 to 2 g/cm^3
Evapotranspiration Coefficient	0.70 to 0.90
Uncontaminated/Unsaturated Zone Thickness	3.0 to 5.0 meters
Uncontaminated/Unsaturated Total Porosity	.30 to .45
Uncontaminated/Unsaturated Effective Porosity	.06 to .20
Contaminated Fraction of Plant Food	.1 to .6
Mass Loading for Inhalation	.00006 to .0002 g/m^3
Contaminated Zone Total Porosity	.30 to .45
Building Foundation Thickness (Radon)	.1 to .2 meters
Building Foundation Total Porosity (Radon)	.09 to .2
Building Air Exchange Rate (Radon)	.4 to .6 1/hour
Building Room Height (Radon)	2.4 to 3.05 meters
Radon Emanation Coefficient	0.01 to 1.0

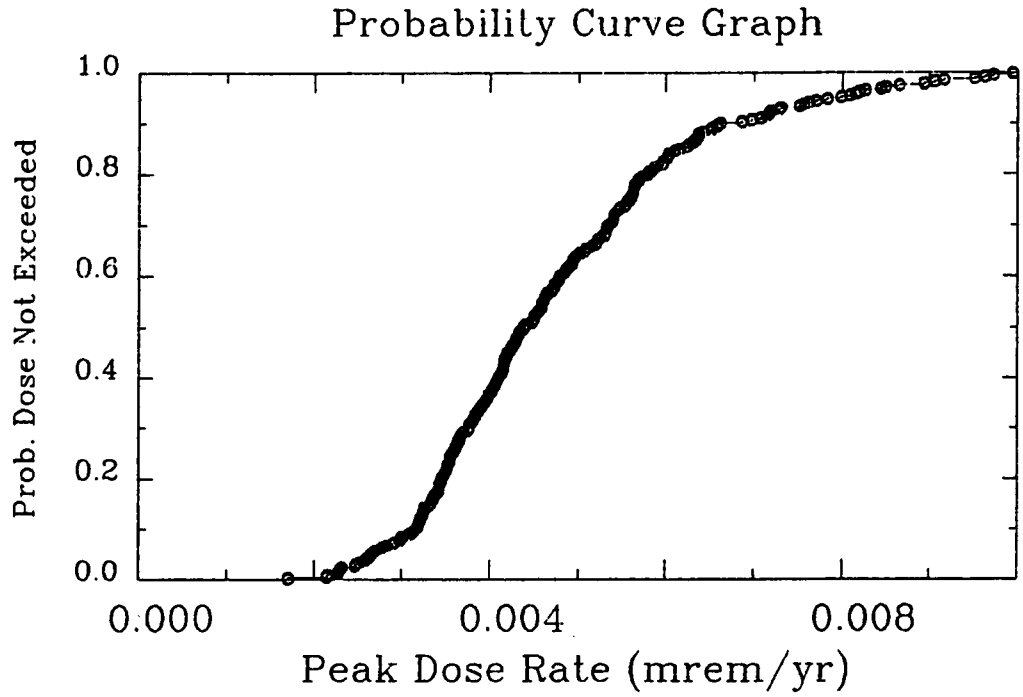


Figure 4.21 Cumulative Distribution Function for Dose from Inhalation at SLAPS Based on 1 pCi/g of Ra-226 in Soil

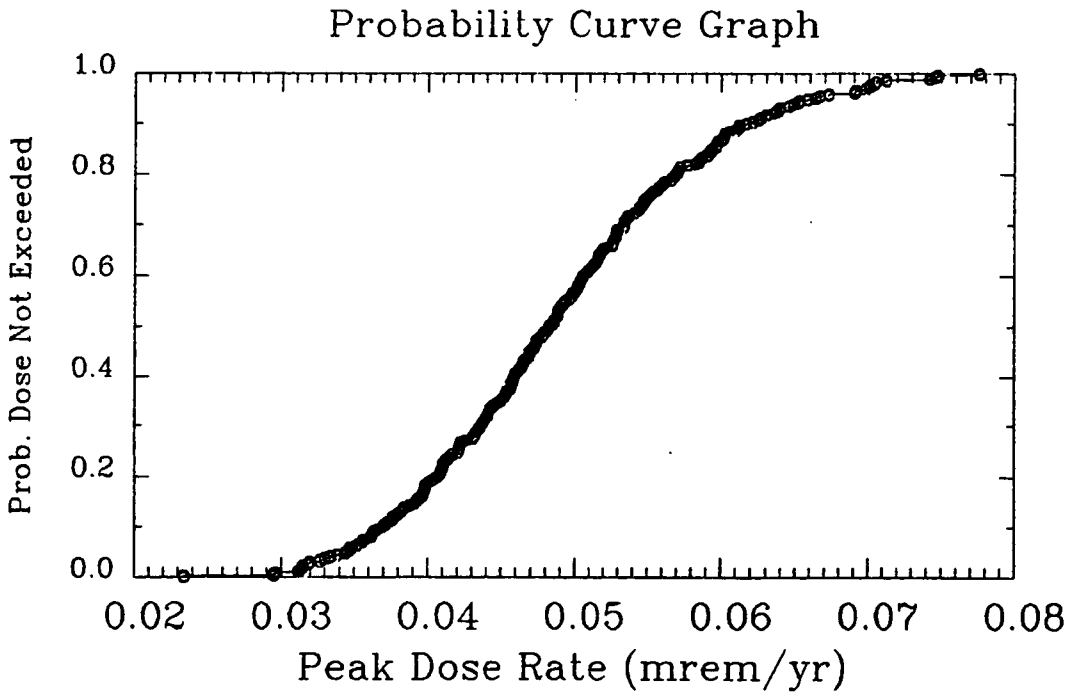


Figure 4.22 Cumulative Distribution Function for Dose from Inhalation at SLAPS Based on 1 pCi/g of U-238 in Soil

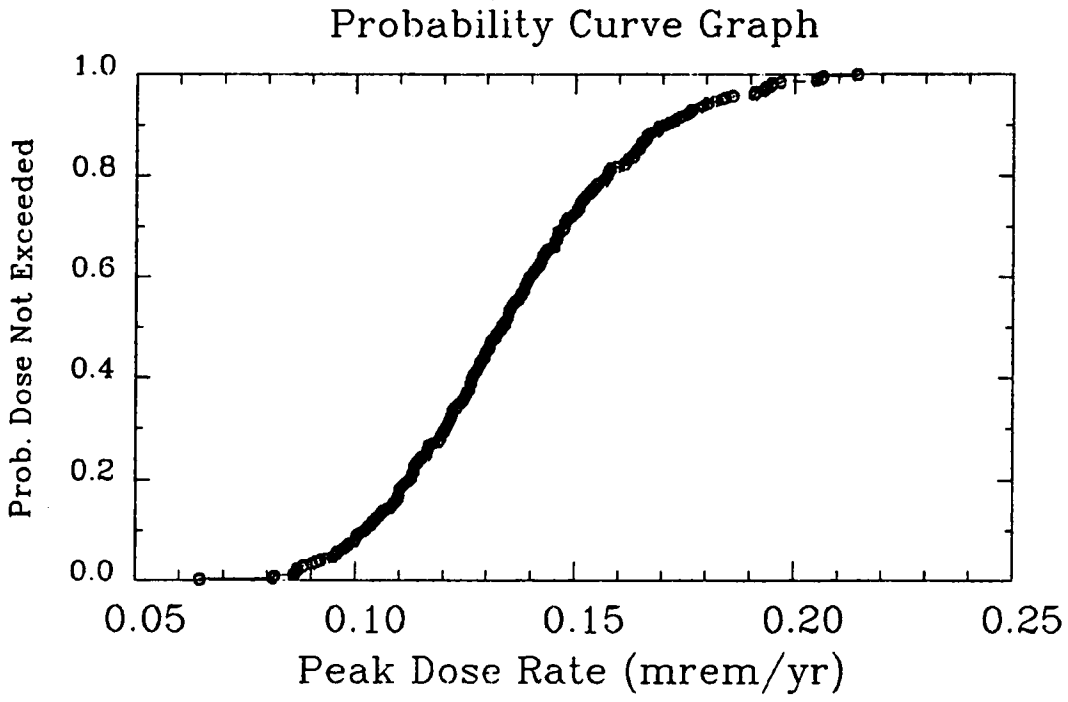


Figure 4.23 Cumulative Distribution Function for Dose from Inhalation at SLAPS Based on 1 pCi/g of Th-230 in Soil

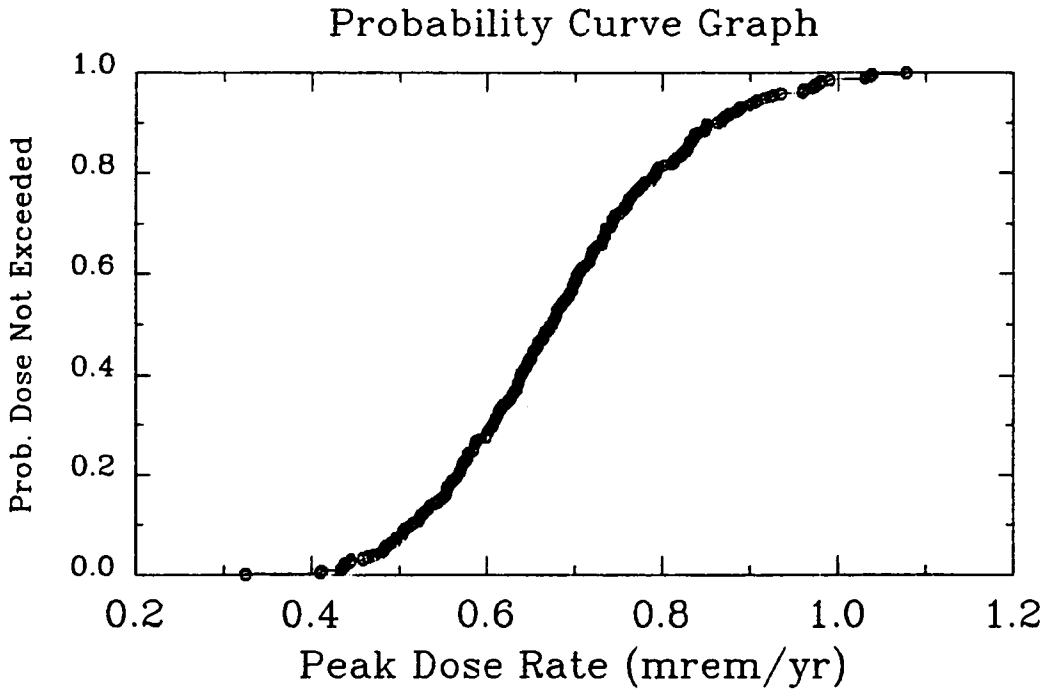


Figure 4.24 Cumulative Distribution Function for Dose from Inhalation at SLAPS Based on 1 pCi/g of Th-232 in Soil

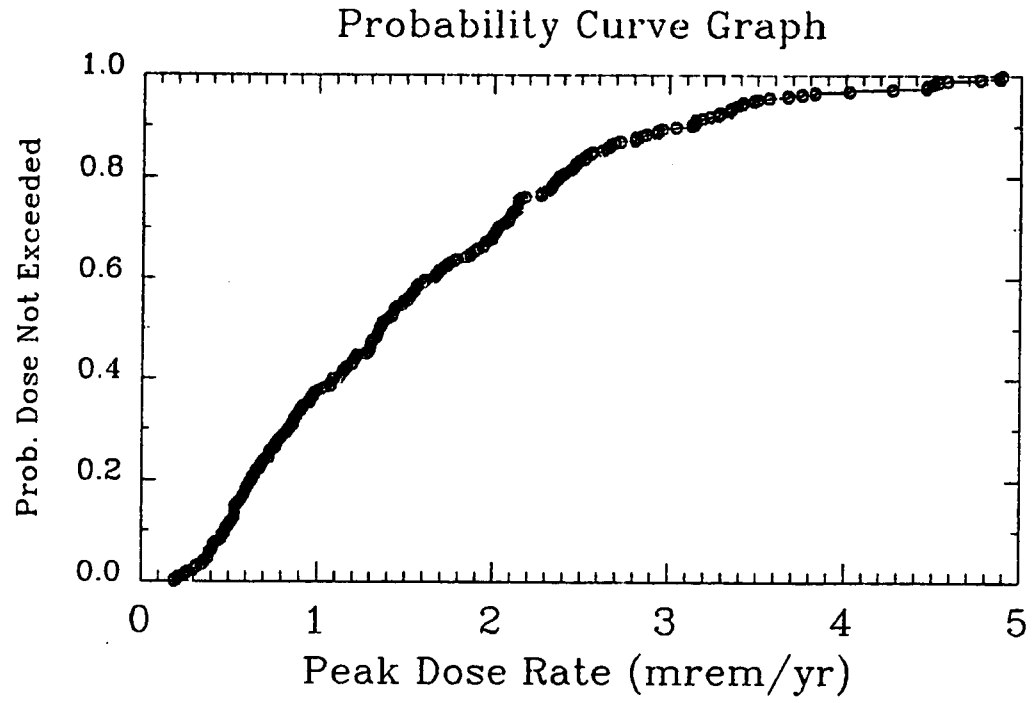


Figure 4.25 Cumulative Distribution Function for Dose from Consumption of Plants at SLAPS Based on 1 pCi/g of Ra-226 in Soil

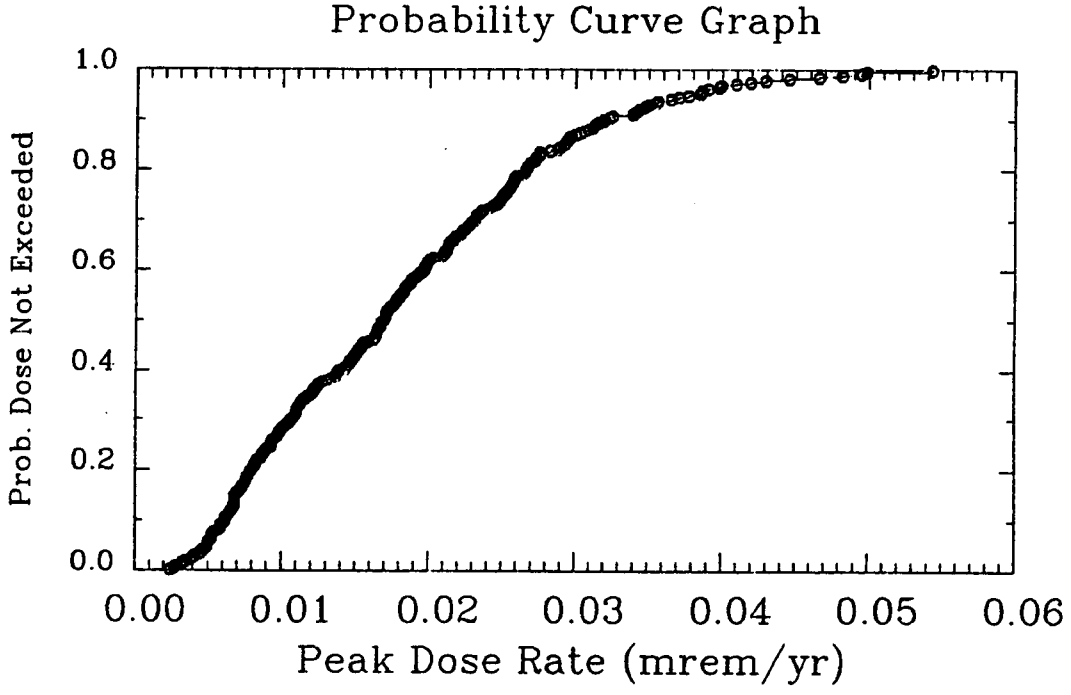


Figure 4.26 Cumulative Distribution Function for Dose from Consumption of Plants at SLAPS Based on 1 pCi/g of U-238 in Soil

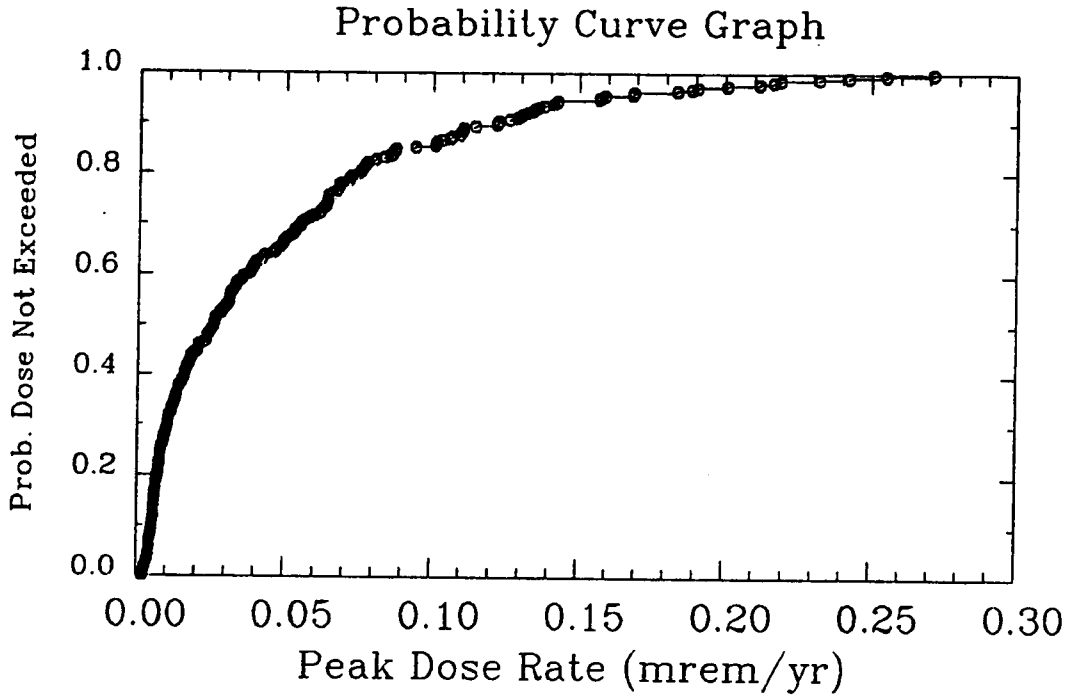


Figure 4.27 Cumulative Distribution Function for Dose from Consumption of Plants at SLAPS Based on 1 pCi/g of Th-230 in Soil

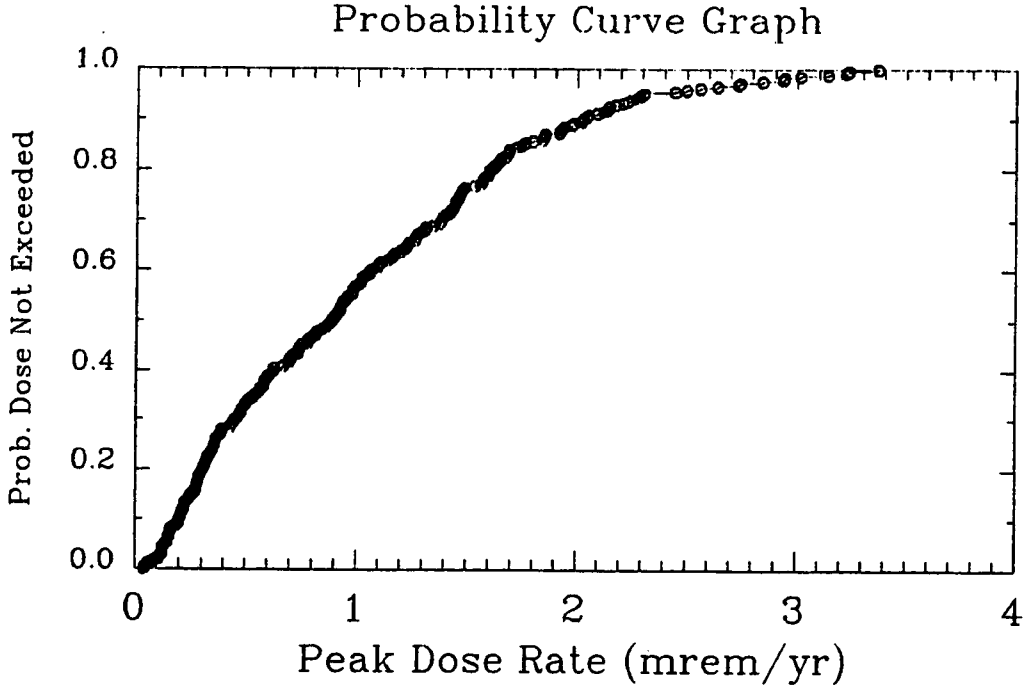


Figure 4.28 Cumulative Distribution Function for Dose from Consumption of Plants at SLAPS Based on 1 pCi/g of Th-232 in Soil

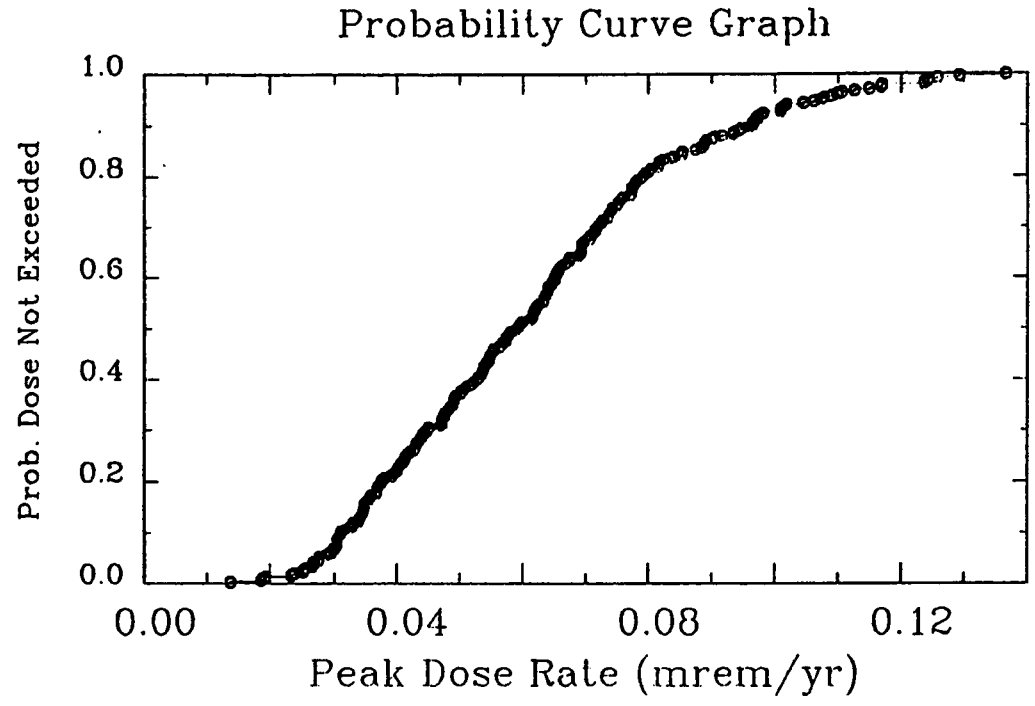


Figure 4.29 Cumulative Distribution Function for Dose from Ingestion of Soil at SLAPS Based on 1 pCi/g of Ra-226 in Soil

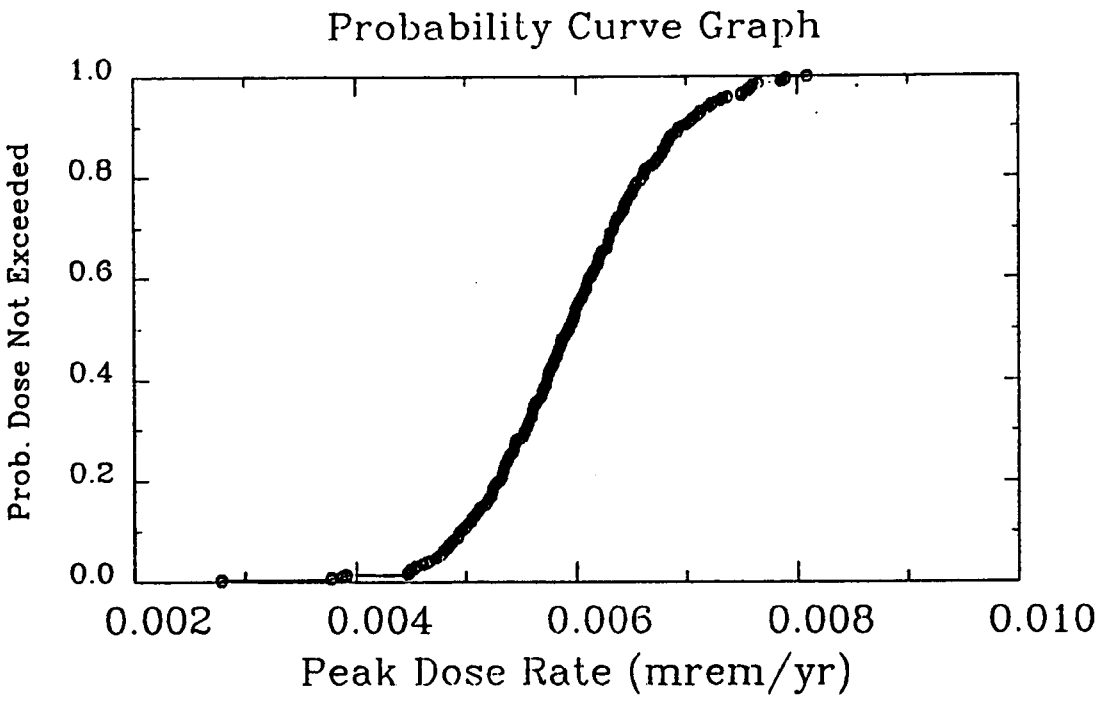


Figure 4.30 Cumulative Distribution Function for Dose from Ingestion of Soil at SLAPS Based on 1 pCi/g of U-238 in Soil

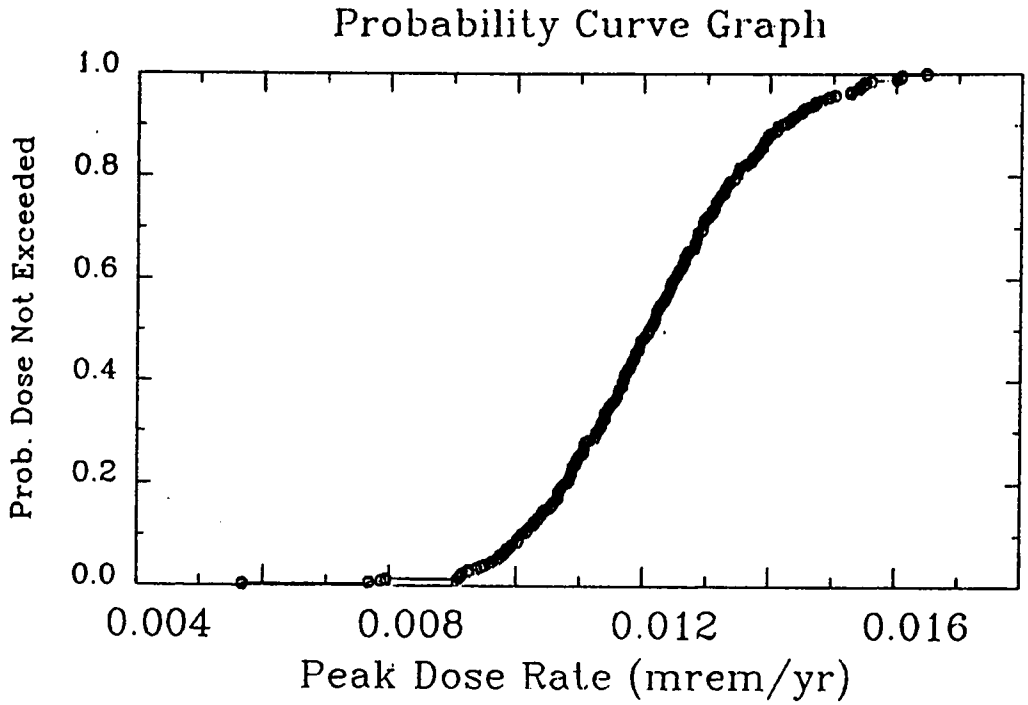


Figure 4.31 Cumulative Distribution Function for Dose from Ingestion of Soil at SLAPS Based on 1 pCi/g of Th-230 in Soil

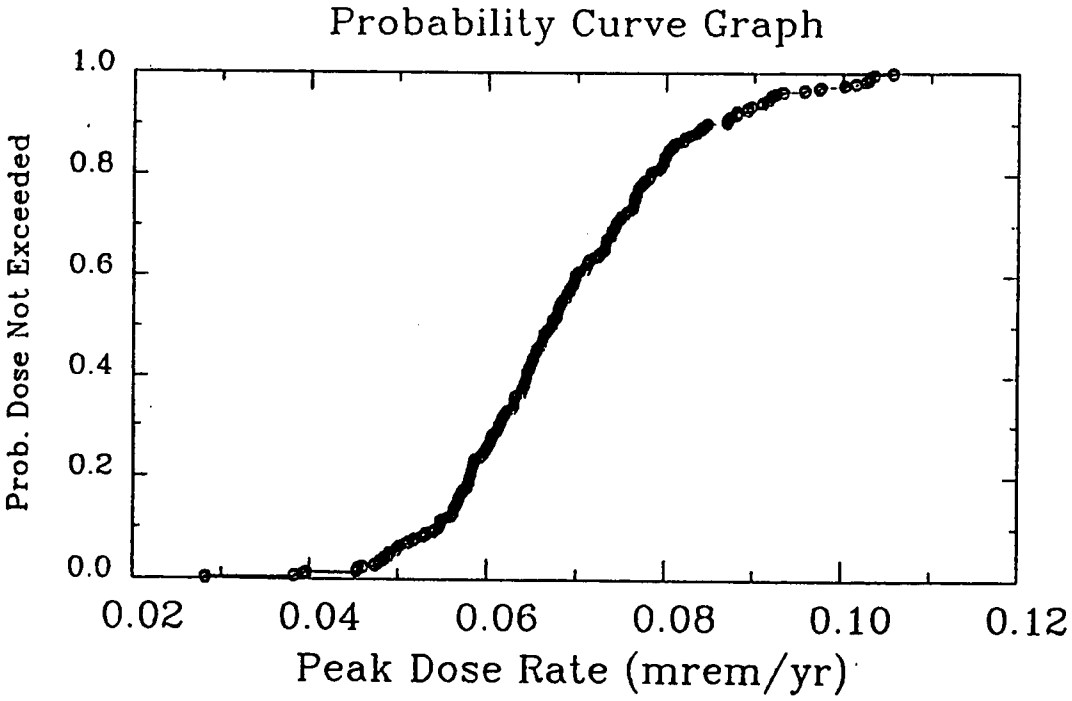


Figure 4.32 Cumulative Distribution Function for Dose from Ingestion of Soil at SLAPS Based on 1 pCi/g of Th-232 in Soil

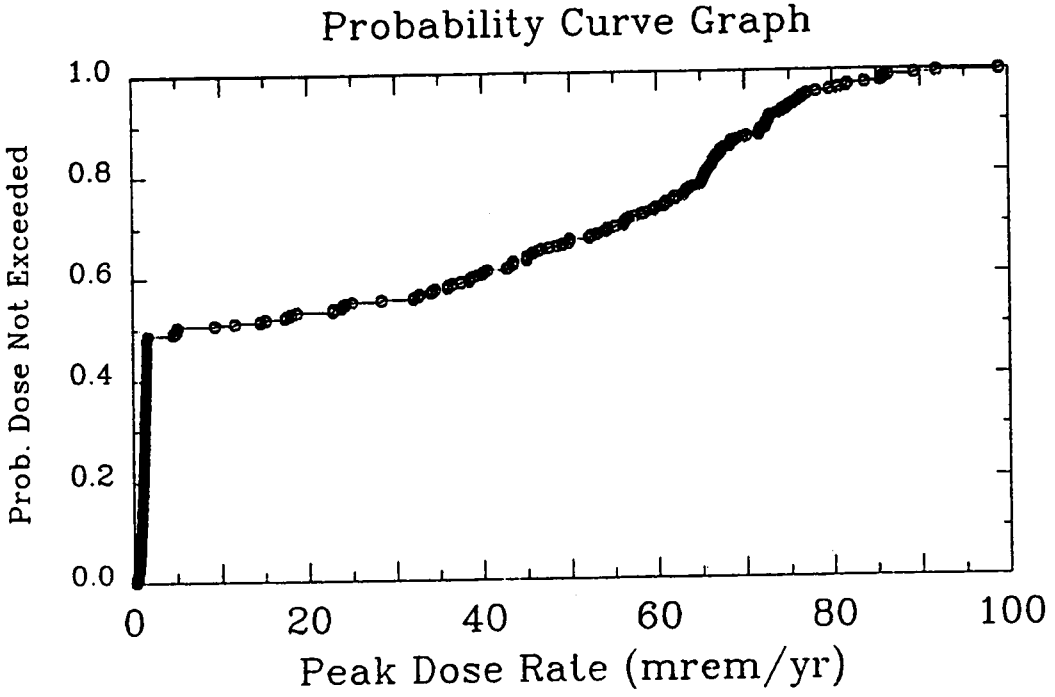


Figure 4.33 Cumulative Distribution Function for Dose from Inhalation of Radon at SLAPS Based on 1 pCi/g of Ra-226 in Soil

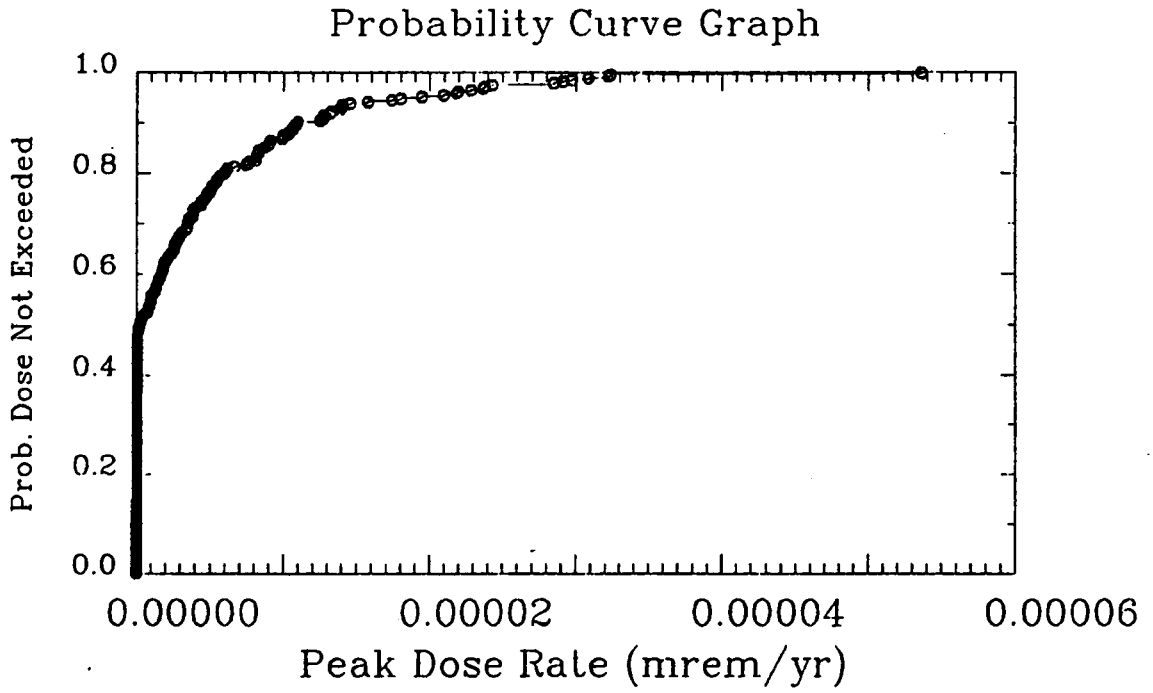


Figure 4.34 Cumulative Distribution Function for Dose from Inhalation of Radon at SLAPS Based on 1 pCi/g of U-238 in Soil

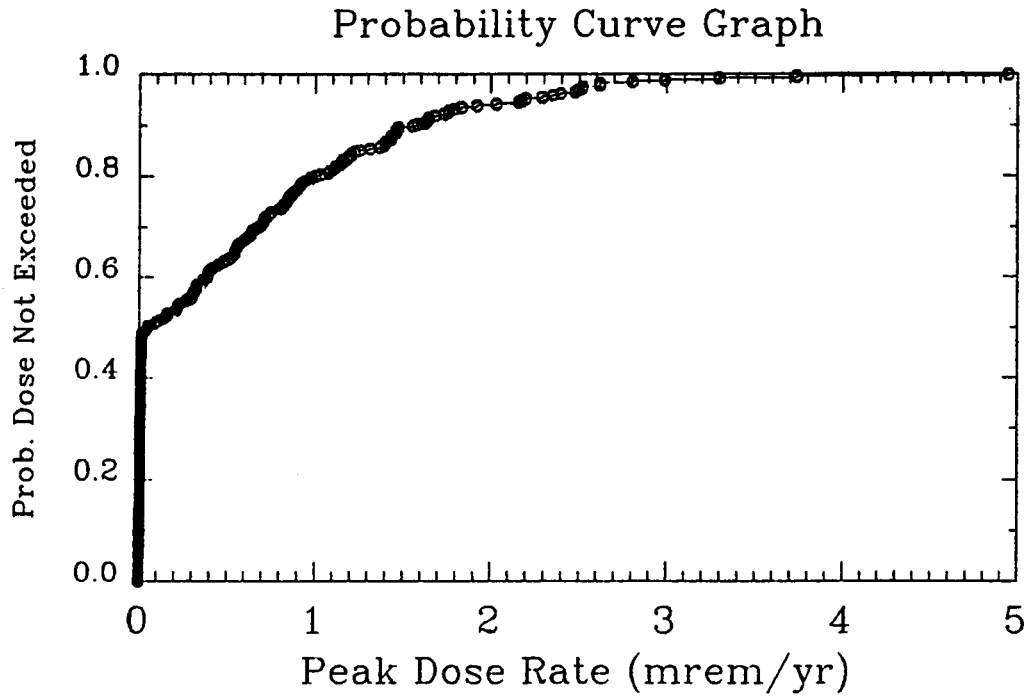


Figure 4.35 Cumulative Distribution Function for Dose from Inhalation of Radon at SLAPS Based on 1 pCi/g of Th-230 in Soil

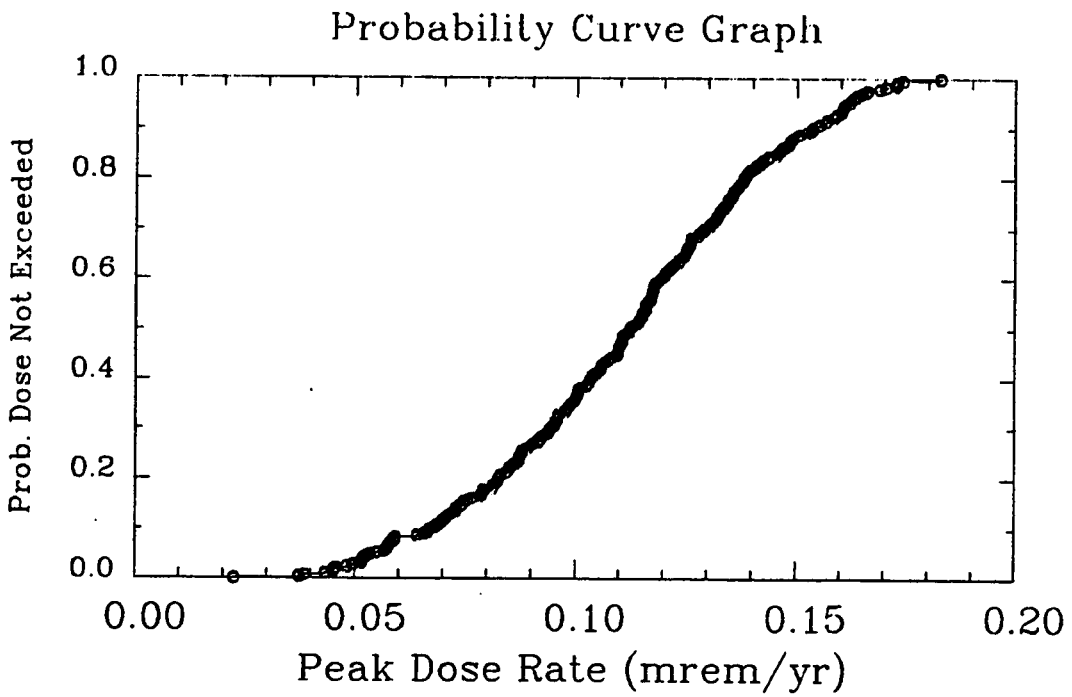


Figure 4.36 Cumulative Distribution Function for Dose from Inhalation of Radon at SLAPS Based on 1 pCi/g of Th-232 in Soil

Table 4.8 Uncertainty Analysis Results

	Peak Dose Rate (mrem/yr) with a 90% Probability of not being exceeded			
Pathway	**Ra-226**	**U-238**	**Th-230**	**Th-232**
Inhalation	0.0062	0.061	0.17	0.85
Plant Ingestion	3.0	0.032	0.11	2
Soil Ingestion	0.095	0.007	0.014	0.085
Radon	70	0.00001	1.4	0.15

Table 4.9 Contamination Permissible for 10^{-4} Risk According to Radionuclide and Pathway Uncertainty Analysis (pCi/g)

Pathway	**Ra-226**	**U-238**	**Th-230**	**Th-232**
Inhalation	645.16	65.57	23.53	4.71
Plant Ingestion	1.33	125	36.36	2
Soil Ingestion	42.11	571.43	285.71	47.06
Radon	0.057	400000	2.86	26.67

ingestion and the Radon pathway would be important.

It should be noted that not all of the SLAPS and ballfield areas are contaminated. It is more accurate to characterize each of these areas as contaminated to varying degrees depending on precise location. It has been discovered that at SLAPS about 37,000 yd^3 of contaminated soil exceeds dose limits necessary for a recreational scenario. The ballfield has about 5,000 yd^3 of contaminated soil that exceeds dose limits necessary for a recreational area.

The dose limit for a residential area is much more stringent than the dose limits for a recreational area. Therefore, a larger volume of contamination would have to be cleaned up to meet the EPA and DOE dose limits. It was estimated that about 106,000 yd^3 of contaminated soil exceeded the dose limits required for a residential area at SLAPS. About 176,000 yd^3 of contaminated soil at the ballfield exceeded the dose limits required for a residential area.

It can be seen that the radionuclides present at SLAPS and the ballfield exceed the EPA and DOE limits. Therefore, remediation would be required. It can also be seen that, if the sites were used for residential areas more remediation would be required than if they were used for recreational purposes. Therefore, using SLAPS and the ballfields for a recreational area would be an ideal scenario.

4.3 OFF-SITE CONTAMINATION

In Chapter 3, it was mentioned that CAP-88 was used to calculate the off-site dose. Table 4.10 shows the doses found off-site at different distances. It was determined from these results that the off-site dose not exceed the basic radiological dose limit

(BRDL) of 100 mrem/yr. Therefore a sensitivity analysis and an uncertainty analysis was not done on CAP-88.

Table 4.10 Offsite Doses

Distance (miles)	Concentration (mrem/yr)			
	U-238	**Ra-226**	**Th-232**	**Th-230**
.25	1.35E-3	9.45E-5	4.27E-4	3.80E-3
.50	3.32E-4	2.25E-5	1.05E-4	9.36E-4
1.0	9.9E-5	6.51E-6	3.14E-5	2.79E-4
2.0	2.73E-5	1.88E-6	8.60E-6	7.66E-5
3.5	1.01E-5	7.33E-7	3.18E-6	2.84E-5
5	5.17E-6	3.92E-7	1.61E-6	1.44E-5

5. TREATMENT OPTIONS

5.1 REMEDIATION REQUIREMENTS

Uranium and thorium processing residues at FUSRAP sites are classified as byproduct material under section 11(e)1 of the Atomic Energy Act of 1954. Since these residues are diffuse, naturally occurring radioactive materials with low radionuclide concentration (EPA 1989b), they are not considered low-level radioactive wastes (LLW). This means that disposal options are greater than for LLW. FUSRAP residues can be disposed in LLW disposal facilities or commercial byproduct disposal facilities. However, radionuclides such as Uranium-238 are much longer-lived than those in LLW and for most FUSRAP sites have a much larger volume which makes the disposal expensive.

5.2 ASSESSMENT OF TREATMENT METHODS

Some of the principal treatment methods under consideration for FUSRAP sites are physical separation, soil washing, and solvent flushing. The objective of these methods is the re-use of treated material through the physical removal of contaminants by water, surfactants or chelating agents (chemicals that bind with metal and other ions).

5.2.1 Physical Separation

One of the first steps in a sequence of treatments such as soil washing is physical separation. Physical separation, also known as solids separation or classification and sorting, uses gravity, radiometric or other mechanical force to separate contaminated material. The main principal behind physical separation is that the majority of contaminants in soil tend to adhere in fine particles due to their increased surface area

relative to volume. Therefore, physical separation used in "coarse" and "fine" soil particles can produce a "clean" product stream of coarse particles (Feldman 1994).

5.2.2 Soil Washing

Soil washing generally uses water and surfactants and chelating agents to flush or rinse contaminants from soil. Contaminated solutions generated by soil washing may be costly and difficult to dispose if they are highly concentrated and if hazardous materials are present. Testing indicates that the amount of soil requiring disposal at an approved facility can be reduced by between 65 and 95 percent by soil washing. Soil washing can be used to effectively remove radionuclides from soil with little risk from airborne concentration. However, secondary wastes are generated that must be properly treated and disposed (Feldman 1994).

5.2.3 Solvent Flushing

Chemical solvent flushing uses organic solvents, acids, other agents or other toxic chemicals to remove radionuclides and chemical contaminants. Solvent flushing may be applied to both in- and ex- situ situations. But, solvent flushing is usually an in-situ process. There are several disadvantages of using solvent flushing as a treatment method. One disadvantage is that the efficiency of this method is relatively low, only one-half of the uranium in ore can be removed using this process. Another disadvantage of this method is that significant amounts of solvent may be left in the ground after completion of the extraction. Granular soils with relatively high hydraulic conductivities tend to respond best to solvent flushing. Silts and clays however tend to be more of a problem due to the difficulty in getting solvents to flow through their soil columns (Feldman 1994).

5.3 SUGGESTED TREATMENT METHOD

By looking at the results in Chapter 4, it might be suggested that the contaminated soil be shipped off the site. But, the only problem with this is that SLAPS has a large volume of contaminated soil. Therefore, shipping off the dirt would be very expensive. And, volume reduction would probably be the best method to treat the contaminated soil at SLAPS. As mentioned in the previous sections of this chapter, physical separation, soil washing, and solvent flushing are the best methods used for volume reduction. Solvent flushing would not be a good method to use at SLAPS because the soil is made up of mostly silts and clays and therefore it would make it hard for the solvents to flow through the soil columns. Physical separation combined with soil washing would probably be the best method to use at the SLAPS site.

Physical separation combined with soil washing is also an expensive process, but it still would be less expensive and provide more benefits than shipping off the contaminated soil. One of the benefits of using physical separation combined with soil washing is that soil can be reused at the site. Also, since it has been suggested that the SLAPS site would be used as a recreational facility, the danger of ingesting any plants which might be contaminated from chemicals used during the clean-up method is very small.

6. CONCLUSIONS

6.1 RADIOLOGICAL ASSESSMENT FINDINGS

If SLAPS and the ballfield were to be used for a recreational or residential area, the DOE and EPA dose limits could not be exceeded. These limits have been set to protect the public from any harmful radioactive exposure.

By considering the results in Chapter 4, remediation would be required at SLAPS and the ballfield for these sites to be used as recreational or residential areas. It was discovered that if the SLAPS and ballfield sites were used as recreational areas, about 37,000 yd^3 of contaminated soil at SLAPS and about 5,400 yd^3 of contaminated soil at the ballfield would exceed the DOE and EPA dose limits. And if the two sites were used as residential areas about 106,000 yd^3 contaminated soil at SLAPS and about 176,000 yd^3 of contaminated soil at the ballfield would exceed the dose limits. The concentrations limits that satisfied the DOE and EPA dose limits for SLAPS and the ballfield, as a recreational area, are 65 pCi/g for U-238, 645 pCi/g for Ra-226, 23 pCi/g for Th-230 and 4 pCi/g for Th-232. And the concentration limits necessary for SLAPS and the ballfield to be used as residential areas are 125 pCi/g of U-238, 1 pCi/g of Ra-226, 36 pCi/g of Th-230, and 2 pCi/g of Th-232.

By looking at the volumes of contamination that exceeds the DOE and EPA dose limits, more remediation would be required for the residential scenario than the recreational scenario. Therefore, using SLAPS and the ballfield as a residential area would be more expensive to clean up. Because of today's economy a cheaper method of

clean-up is always better than an expensive method. Therefore, there is a greater chance for the SLAPS and ballfield to be cleaned up for recreational purposes.

6.2 RECOMMENDATIONS FOR FUTURE BRAs

When doing a baseline risk assessment, it is important that there is specific and accurate information provided. The baseline risk assessment done by FUSRAP for SLAPS and the ballfield did not provide all of the necessary information needed to do a very accurate job. Because of the information provided by FUSRAP, a lot of estimation and assumptions had to be made.

There are several things that could be done to improve the BRA done by the FUSRAP site. One thing that could have been improved was the concentration data provided by FUSRAP. This data contained "less than" values for much of the concentration data. For this study, it was assumed that concentrations listed as "less than" were equal to the "less than" value. FUSRAP should have provided the measurement result with uncertainty estimates on concentration instead of an estimate of concentrations ("less than" values). Another thing the FUSRAP BRA was lacking was detail plots like the PSI plots presented in this paper. If these plots were present in the BRA, one could get a better idea on contaminant concentrations, distributions, and volumes. And if possible, combining the graphs with detailed site maps to show both the location of contaminant concentrations and the proximity to known landmarks would be a great help. One more thing that should be incorporated in a BRA is a uncertainty analysis for the most reasonable exposure scenarios. An uncertainty analysis provides the best estimates of exposures from certain type of activities.

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APPENDICES

APPENDIX A

A DESCRIPTION OF THE DOSE/SOURCE RATIO

A.1 DOSE/SOURCE CONCENTRATION RATIOS

The dose an individual would receive annually per unit of a particular isotope in soil is the dose/source concentration ratio. "The dose/source (D/S) concentration ratios are calculated by first expressing them as products of dose conversion factors [dose/exposure-parameter (d/E) ratios], environmental transport factors [exposure-parameter/source-concentration (E/S) ratios], and source factors (ratios of the concentration of a radionuclide at a given time to the initial concentration)." (Yu 1993)

The DSR for RESRAD is expressed as,

$$DSR_{ip}(t) = \sum_{j} DCF_{j,x(p)} \times BRF_{i,j} \times \sum_{q} ETF_{jp,pq}(t) \times SF'_{ij,pq}(t) \qquad \text{A.1}$$

where,

$DCF_{j,x(p)}$ = dose conversion factor for the jth principal radionuclide and x(p)th exposure pathway [(mrem/yr)/(pCi/cm^3) for external radiation from the contaminated zone; mrem/pCi for inhalation of radionuclides].

$BRF_{i,j}$ = a branching factor (dimensionless) that is the fraction of the total decay of radionuclide i that results in the ingrowth of radiomuclide j.

$ETF_{ij,pq}(t)$ = environmental transport factor for the jth principal radionuclide and pth environmental pathway at time t (g/cm^3 for external radiation from the contaminated zone; g/yr for internal radiation from ingestion or inhalation of radionuclides).

$SF'_{ij,pq}(t)$ = factor for ingrowth and decay and leaching of the jth principal radionuclide at time t

from the *i*th principal radionuclide present initially (dimensionless).

x(p) = index label for exposure pathways, which is a function of the environmental pathway p [for p=1 (external radiation from the ground), x(p)=1; for p=2 and 3 (inhalation of dust and radon), x(p)=2; and for p=4,5,6,7,8, and 9 (ingestion of plants, meat, milk, fish, water, and soil, respectively), x(p)=3].

p = index label for environmental pathways.

q = index label for pathway components.

i,j = index labels for principal radionuclides (Yu 1993).

A.1.1 DOSE CONVERSION FACTORS

The RESRAD manual defines the dose conversion factor (DCF) as,

$$DCF_{ix} = \frac{H_{E,ix}}{E_{ix}} \qquad \text{A.2}$$

where,

$H_{E,ix}$ = annual effective dose equivalent resulting from exposure to external radiation (x=1) from the *i*th principal radionuclide and its associated radionuclides (mrem/yr) or the annual committed effective dose equivalent resulting from exposure for 50 years to internal radiation from the amount of the *i*th principal radionuclide and its associated radionuclides inhaled (x=2) or ingested (x=3) in 1 year (mrem/pCi), and

E_{ix} = exposure parameter for the *i*th principal radionuclide [concentration of the *i*th principal radionuclide in a standard source (for external radiation pathways) or the annual quantity of the *i*th principal radionuclide inhaled or ingested (for internal

radiation pathways)](pCi/cm^3 for external radiation [x=1] from the contaminated zone; pCi/yr for internal radiation from inhalation [x=2] or ingestion [x=3]) (Yu 1993).

An internal dose conversion factor for any radionuclide includes the contribution from the ingrowth following ingestion or inhalation. The internal dose conversion factor for a principal radionuclide includes, in addition, the contribution from inhalation or ingestion of associated radionuclides along with the principal radionuclide. The additional contribution is significant only for associated radionuclides with half-lives that are not small compared to the biological half-life. The dose conversion factor for external radiation for a principal radionuclide is defined here to include the dose from all of its associated radionuclides, which are assumed to be in secular equilibrium (Yu 1993).

A.3 ENVIRONMENTAL TRANSPORT FACTORS

RESRAD defines the ETF as a time-dependent ratio. This ratio is,

$$ETF_{ij,pq}(t) = \frac{E_{ij,pq}(t)}{S_i(0) \times SF'_{ij,pq}(t)} \qquad \text{A.3}$$

where,

$E_{ij,pq}(t)$ = exposure parameter value at time t for the *j*th principal radionuclide (or radiation therefrom) transported through the pqth environmental pathway (pCi/cm^3 for external radiation from the contaminated zone; pCi/yr for internal radiation).

p = index label for environmental pathways.

q = index label for the component of the environmental pathways.

$S_i(0)$ = average concentration of the *i*th principal radinuclide in a uniformly contaminated

zone at time 0 (pCi/g).

$SF'_{ij,pq}(t)$ = an adjusting factor to modify the soil concentration (Yu 1993).

The exposure parameter for external radiation from the contaminated zone is the concentration of the *i*th principal radionuclide in the ground, adjusted for occupancy and the size and depth of the contaminated zone by means of multiplying factors. The exposure parameter for internal radiation pathways is the annual quantity of the *i*th principal radionuclide that is inhaled or ingested after migrating through the pth environmental pathway. There are only two internal exposure pathways (inhalation and ingestion); several environmental pathways can contribute to each (Yu 1993).

A.4 SOURCE FACTORS

Source factors are correction factors for the source term (the radionuclide concentration in the contaminated zone). These factors correct for the contribution which come from ingrowth and the removal resulting from radioactive decay and leaching. "If leaching is negligible, the source factor reduces to a factor that accounts for ingrowth and decay only. This factor is called the ingrowth-and-decay factor, $ID_{ij}(t)$" (Yu 1993).

Radionuclides are divided into two groups: those with half-lives longer than six months (principal radionuclides) and those with half-lives of six months or less (associated radionuclides). It is assumed that the associated radionuclides are in secular equilibrium with their principal radionuclides and that the leach rate of the associated radionuclides is the same as the leach rate of their principal radionuclide. Hence, only the source factors for the principal radionuclides need to be calculated (Yu 1993).

Let $S_{ii}(0)$ be the initial concentration of the *i*th principal radionuclide and let $S_{ij}(t)$ be the concentration at time t of the jth principal radionuclide that results from ingrowth from the initial inventory of the *i*th principal radionuclide. $S_{ii}(t)$ is the concentration of the undecayed portion that is available for leaching of the *i*th principal radionuclide. [$S_{ii}(t)$, which does not include any contribution from ingrowth, should be distinguished from

$$S_i(t) = \sum_j S_{ji}(t) \qquad \textbf{A.4}$$

which does include the contribution from ingrowth.] $S_{ij}(0) = 0$ unless i=j, and $S_{ij}(t) = 0$ unless i=j or the jth principal radionuclide is a decay product of the *i*th principal radionuclide. The source factor is defined as,

$$SF_{ij}(t) = \frac{S_{ij}(t)}{S_i(0)} \qquad \textbf{A.5}$$

The initial values of the source factors are $SF_{ij}(0) = 0$ unless i=j, and $SF_{ii}(0) = 1$, For t>0, $SF_{ij}(t) = 0$ unless i=j or the jth principal radionuclide is a decay product of the *i*th principal radionuclide. When i=j, the inequality $1 > SF_{ii}(t) > 0$ will be satisfied for t>0 (Yu 1993).

"Equations for calculating source factors and ingrowth-and-decay factors are given below. Branching radionuclides are a common complication, and there are four possible cases to consider: (1) only associated radionuclides are involved; (2) a principal radionuclide parent branches to associated radionuclide daughters; (3) an associated radionuclide parent branches to at least one principal radionuclide daughter; and (4) a principal radionuclide parent branches to at least one principal daughter" (Yu 1993). Cases 1 and 2, mentioned above, cover most of the radionuclides in the RESRAD code.

Case 3 does not occur at all. Assuming that all associated radionuclides are in equilibrium with their principal radionuclide parents, branching should not be considered in deriving source factors and ingrowth-and-decay factors.

Assuming a first-order ion-exchange leaching, the equation for ingrowth and decay and leaching of a nonbranching chain is,

$$\frac{dA_k}{dt} = \lambda_k A_{k-1} - (\lambda_k + L_k) A_k \qquad \textbf{A.6}$$

where,

A_k = activity concentration of the kth radionuclide in the chain (pCi/g),

λ_k = $\ln(2)/T_{1/2,k}$ = radioactive decay constant of the kth radionuclide (yr^{-1}),

$T_{1/2,k}$ = radioactive decay half-life of the kth radionuclide (yr), and

L_k = leach rate of the kth radionuclide (yr^{-1}) (Yu 1993);

The solution to Eq. A.5 is

$$A_k(t) = \sum_{i=0}^{k} a_{kl} + \exp\left[-(\lambda_{l+} L_l)t\right] \qquad \textbf{A.7}$$

where,

$$a_{\infty} = A_0(0) \qquad \textbf{A.8}$$

$$a_{kl} = \left[\frac{\lambda_k}{(\lambda_k + L_k - \lambda_l - L_k)}\right] a_{(k-1),p} \quad l = 0,1, \ldots, k-1 \qquad \textbf{A.9}$$

and,

$$a_{kk} = A_k(0) - \sum_{l=0}^{k-1} a_{kl} \qquad \textbf{A.10}$$

The source factor $SF_{ij}(t)$ can be calculated as,

$$SF_{ij}(t) = \frac{A_{i(ij)}(t)}{A_0(0)} \qquad \textbf{A.11}$$

where l(ij) is the sequence number for the jth principal decay product of the ith principal radionuclide, numbered from the *i*th principal radionuclide [l(ii) = 0]. The ingrowth-and-decay factor $ID_{ij}(t)$ when the leach rates L_l and L_k are set to zero.

APPENDIX B

HAND CALCULATIONS FOR VEGETABLE INTAKE

B.1 HAND CALCULATION METHODOLOGY

One scenario that is always looked at when doing a dose assessment of a radiologically-contaminated site is whether the site may be used to consume vegetables. Even though the SLAPS site is likely to be used as recreational facility, vegetable consumption is always possible. Radiation doses from vegetable intake may be calculated by using the following equation:

$$D_v = (C_s)(CR)(I_v)(DCF) \qquad \textbf{B.1}$$

where,

D_v = committed effective dose equivalent (CEDE) from eating vegetables (mrem/yr),

C_s = concentration in soil (pCi/g),

CR = concentration ratio (pCi/kg dry plant)/(pCi/kg dry soil),

I_v = intake of vegetables (g/yr), and

DCF = dose conversion factor for CEDE (mrem/pCi).

Calculations for the CEDE were performed for several commonly consumed plants which might be grown in the U-238, Ra-226, Th-232, and Th-230 contaminated soil at SLAPS.

To calculate radiation doses as accurately as possible, area-specific soil contaminant concentrations would need to be used for the soil concentration variable (C_s). This is done because vegetables grown on areas of the site with the highest levels of

contamination would be several orders of magnitude higher than if grown on areas of moderate contamination.

The concentration ratio (CR) variable is the concentration of contamination in the dry edible portion of a plant divided by the concentration of contamination in the dry soil. This ratio is used to determine the amount of contaminated material transferred to plants. Table B.1 shows some CR values and demonstrates that these values may vary among plant types for a given radionuclide. CR values are usually based on data for a particular soil type and chemical form of the radionuclide. The contaminated materials at SLAPS are probably highly insoluble since they are the radiological residues of chemical processing. Therefore, contaminated soils at SLAPS may perform very differently relative to uptake than what is expected based on generic published data.

Table B.1 Concentration Ratios (pCi/g dry plant edible part/pCi/g dry soil)

Isotope	Potatoes	Carrots	Beans	Fruits	Leafy
Ra-226	2.4×10^{-2}	1.7×10^{-1} to 2.9×10^{-1}		3.5×10^{-3}	4.4×10^{-1} to 7.5×10^{-1}
U-238	9.0×10^{-4} to 9.9×10^{-3}	3.0×10^{-4}	3.0×10^{-4}		
Th-232/ Th-230	1.2×10^{-4} to 2.0×10^{-3}	3.0×10^{-4}	1.0×10^{-3}	1.7×10^{-3}	

Source: Till, John E., and Robert H. Meyer. *Radiological Assessment: A Textbook on Environmental Dose Analysis*. NUREG/CR-332, ORNL-5968. Washington, D.C.: U.S. Nuclear Regulatory Commission, September 1983.

Assumptions relative to type of food intake have a significant impact on dose estimates for radionuclides. Consuming ten kilograms of leafy vegetables grown in soil with a radium concentration of one pCi/g would give you a CEDE of about one mrem/year. Several areas of SLAPS have soil concentrations of a few hundred pCi/g, this results in an unacceptable dose when Ra-226 with this amount of concentration is uniformly distributed over a sufficiently large area for food production. Therefore, if this site was intended for growing leafy vegetables for personal consumption this contamination would have to be removed from these areas. In contrast, the dose from consuming potatoes grown in soil with 1000 pCi/g of U-238 is minimal. The vegetable intake parameter (I_v) is subject to wide variation given that it is dependent upon individual food preferences.

Dose Conversion Factors (DCFs) are units of absorbed dose based on the type of radiation (e.g., alpha or beta particles or gamma radiation). Table B.2 provides the isotope-specific DCF values. There are two types of DCF values, soluble and insoluble. When radionuclides are absorbed into a food that is then consumed, the radionuclide form is probably soluble. If the radionuclide is ingested by direct consumption of soil, its form is probably insoluble.

For the calculations of commonly consumed vegetables grown in U-238, Ra-226, Th-230, and Th-232 contaminated soils, the soil concentration variables was set at 1 pCi/g. To determine the CEDE for specific areas of the site, the radionuclide concentration where the produce is grown should be used. The CR and DCF values presented in Tables B.1 and B.2, respectively were not values published by FUSRAP

literature, but was values published by different sources (Till, 1983 and ICRP, 1990a,b). To improve the CEDE values for SLAPS, CR and DCF values specific to SLAPS should be used. So, since these values were not in the FUSRAP literature, they were not used in this calculation.

Table B.2 Dose Conversion Factors for Ingestion of Radionuclides (mrem/pCi intake)

Isotope	Ingestion
Ra-226	8.31×10^{-4}
U-238	2.38×10^{-5} (insoluble) 9.55×10^{-5} (soluble)
Th-232	1.73×10^{-3}
Th-230	2.87×10^{-4}

Source: *International Commission on Radiological Protection. Recommendations of the International Commission on Radiological Protection, Publication 60.* New York: Pergamon Press, 1990.

B.2 HAND CALCULATION RESULTS

The results from the hand calculation which uses Equation B.1 are provided in Table B.3 for soluble and insoluble chemical forms of contaminants. Doses from Ra-226 are usually at least 100 times greater than for those from U-238, Th-232, or Th-230. The results form hand calculations are about a factor of three less than those from RESRAD.

Table B.3 Dose from Consumption of Plants (mrem/yr) Based on Hand Calculations with a Soil Concentration of 1 pCi/g*

Isotope	Potatoes (50kg)	Carrots (1kg)	Beans (20kg)	Fruits (30kg)	Leafy (1 kg)
Ra-226	4.1×10^{-1}	5.78×10^{-2} to 9.86×10^{-2}		3.57×10^{-2}	1.32×10^{-1} to 2.81×10^{-1}
U-238	7.0×10^{-5} to 1.2×10^{-2}	4.68×10^{-7} to 7.53×10^{-6}	9.38×10^{-6} to 1.51×10^{-4}		
Th-232	5.2×10^{-4} to 3.12×10^{-3}	1.56×10^{-6}	1.04×10^{-4}	2.65×10^{-4}	
Th-230	3.15×10^{-6} to 1.89×10^{-3}	9.45×10^{-6}	6.30×10^{-5}	1.61×10^{-4}	

* Intake per year is shown in parentheses by the plant type.

APPENDIX C

HAND CALCULATIONS FOR DUST INHALATION

C.1 HAND CALCULATION METHODOLOGY

Recreational use of the Berkeley ball fields adjacent to SLAPS is a good scenario for describing radiological dose from the inhalation of dust. Recreational use of these ball fields would result in an exposure from inhalation during games. The dose to which a given individual would be exposed from the total number of games played per year can be estimated from the following equation:

$$D_y = I_h \, C_{sa} \, T_g \, G_y \, DCF \qquad \text{C.1}$$

where,

D_y = dose from total number of games played per year ((mrem/yr)/(pCi/gm)),

I_h = inhalation rate (m^3/min) (1 m^3 = 1000 liters),

C_{sa} = mass loading of soil in air (g/m^3),

T_g = duration of game (min/game),

G_y = number of games (games/year), and

DCF = dose conversion factor for inhalation (mrem/pCi)

Inhalation rates for adult males vary from about 0.02 m^3/min (20 l/min) for light activity to a maximum of about 0.1 m^3/min (100 l/min) for vigorous exercise. A value of about 0.03m^3/min is assumed for an entire game, the duration of which is about 2 hours. The amount of dust suspended in air varies over time, but background levels are about 2 x

10^{-5} g/m^3. For the purpose of this calculation, it is assumed that the mass loading increases by a factor of 1000 during the course of a game. Therefore, the mass loading is assumed to be 2 x 10^{-2} g/m^3. Occupancy times may be occasional for relatively small fractions of a day (less than ten percent), but dust generation could be significant for short periods of time.

Table C.1 shows that the DCFs for inhalation vary by a factor of ten as a function of translocation class (D,W,or Y). The translocation classes D, W, and Y, which stand for "days," "weeks," and "years," respectively, define the clearance time of radionuclides inhaled in the lungs. Solubility of the radionuclide usually determines the clearance times. For this calculation, a conservative value for the DCF was selected without regard to particular isotope or solubility.

It should be noted that tabulated values for DCFs for inhalation assume a mean activity-averaged particle size diameter for one micron. If particle sizes are as large as ten microns, they are marginally respirable, and the effective DCFs for inhalation are much smaller. It should also be noted that in Table C.1, DCFs range from about 2 x 10^{-4} to about 2 x 10^{-3}. For this dust inhalation calculation, a conservative DCF value of 2 x 10^{-3} is used.

C.2 HAND CALCULATION RESULTS

By using Equation C.1, it was discovered that a dose of about 2 mrem (10 mrem over 5 years) would be received from playing ball at the Berkeley ball fields adjacent to SLAPS. EPA's 10^{-4} lifetime risk guideline for radiologically-contaminated sites and a .05 cancer rate per Sv (100 rem/Sv) is equivalent to a 200 mrem lifetime dose. Therefore, if a

person was exposed to 10 mrem over the course of playing ball for 5 years with an allowed lifetime dose of 200 mrem, the ball field soil concentration could not exceed 20 pCi/g (200 mrem / 10 mrem) / (pCi/g)) to meet EPA exposure level.

Table C.1 Dose Conversion Factors for Inhalation of Radionuclides (mrem/pCi intake)

Isotope	Inhalation*
Ra-226	8.02×10^{-3} (W)
U-238	8.51×10^{-4} (D) 6.53×10^{-3} (W) 1.18×10^{-1} (Y)
Th-232	8.17×10^{-1} (W) 7.83×10^{-1} (Y)
Th-230	1.66×10^{-1} (W) 1.97×10^{-1} (Y)

* D, W, and Y denote translocation class

Source: *International Commission on Radiological Protection. Recommendations of the International Commission on Radiological Protection, Publication 60.* New York: Pergamon Press, 1990.

APPENDIX D

SLAPS INPUT DATA

Table D.1 SLAPS Concentration Data

COORDINATE		DEPTH		URANIUM-238		RADIUM-226		THORIUM-232		THORIUM-230	
EAST	NORTH	START	FINISH	pCi/g	ERROR	pCi/g	ERROR	pCi/g	ERROR	pCi/g	ERROR
775	1025	0	0.5	<78.4	0	<3.8	0	<3.8	0	-a-	0
780	1200	0	0.5	<37	0	<2	0	<2.6	0	-a-	0
800	1297	0	0.5	<33	0	<1.8	0	<2.8	0	-a-	0
950	1350	0	0.5	<36.8	0	<2	0	<3.2	0	-a-	0
1155	1000	0	0.5	<29	0	<2.1	0	<2.9	0	-a-	0
1198	1011	0	0.5	<90.8	0	37	1.2	<3.9	0	-a-	0
1300	1408	0	0.5	<30.6	0	<1.9	0	<3.3	0	-a-	0
1600	1472	0	0.5	<304	0	480	6.6	<13.4	0	-a-	0
1700	1300	0	0.5	<48.6	0	-a-	0	-a-	0	-a-	0
1700	1493	0	0.5	-a-	0	59.2	1.8	<4.9	0	-a-	0
1700	1493	0	0.5	<105	0	-a-	0	-a-	0	-a-	0
1950	1533	0	0.5	<406	0	1184	14	<20.4	0	-a-	0
1975	1570	0	0.5	<160.2	0	93.8	2.3	<6.8	0	-a-	0
2125	1555	0	0.5	<144.4	0	58.2	1.8	<6.3	0	-a-	0
2150	1510	0	0.5	<462	0	1818	20	<25.2	0	-a-	0
2288	1450	0	0.5	<57.6	0	<2.8	0	<3.4	0	-a-	0
2363	1420	0	0.5	<114.2	0	<5	0	<4.4	0	-a-	0
2525	1002	0	0.5	<27.2	0	1.6	0	<3.3	0	-a-	0
2550	1289	0	0.5	<37.8	0	<2	0	<3.9	0	-a-	0
2675	1002	0	0.5	<32.8	0	<1.6	0	<3	0	-a-	0
2800	1121	0	0.5	<42.8	0	<1.9	0	<3.7	0	-a-	0
2900	1012	0	0.5	<32.8	0	<1.7	0	<3.4	0	-a-	0
2938	1020	0	0.5	<127.4	0	39.4	1.4	<4.9	0	-a-	0
800	1011	0	1	<78.4	0	<3.9	0	<4.3	0	-a-	0
800	1011	1	2	<37.4	0	<1.7	0	<3.4	0	20	2
800	1011	2	3	<28.8	0	<1.6	0	<3	0	1.8	0.7
808	1197	0	2	<39.6	0	<2.9	0	<2.9	0	-a-	0

Table D.1 (continued)

COORDINATE		DEPTH		URANIUM-238		RADIUM-226		THORIUM-232		THORIUM-230	
EAST	NORTH	START	FINISH	pCi/g	ERROR	pCi/g	ERROR	pCi/g	ERROR	pCi/g	ERROR
808	1197	2	3	<7	0	4	1	1.3	0.7	110	10
808	1197	4	6	<47.2	0	<3.3	0	<3	0	120	10
808	1197	6	8	<4	0	1	0.3	1.3	0.5	-a-	0
808	1197	8	10	<11	0	1	1	<2	0	0.6	0.2
808	1197	10	11.5	<4	0	1.3	0.3	1.3	0.5	-a-	0
808	1303	0	0.6	<57	0	<3	0	<4.2	0	-a-	0
808	1303	4	6	<36.6	0	<1.8	0	<3.5	0	3	0.4
808	1303	6	8	<34.8	0	<1.8	0	<3.3	0	6	0.8
813	1099	0	1	40	9	20	5	3	1	-a-	0
813	1099	2	3	84	22	69	3	<1	0	-a-	0
813	1099	4	5	1200	100	2700	100	63	2	-a-	0
813	1099	7	8.5	53	11	31	2	1.8	1.2	-a-	0
813	1099	9.5	10.5	9	4	1.4	0.4	<1	0	-a-	0
813	1099	10.5	11.5	13	5	0.8	0.6	<1	0	7	1
813	1099	11.5	12.5	<35.2	0	<2.4	0.0 <	2.7	0	1.3	0.7
813	1099	13.5	14.5	9	4	1.2	0.4	2.1	0.6	-a-	0
813	1099	15.5	16.5	<5	0	2.4	0.4	0.9	0.5	-a-	0
896	1306	0	5	<46.6	0	<3	0	<3.1	0	-a-	0
896	1306	5	8	<29.6	0	<2.3	0	<2.8	0	0	0
896	1306	8	12	<30.8	0	<2.6	0	<2.8	0	0	0
899	1015	0	2	<26.2	0	<1.5	0	<2.7	0	-a-	0
899	1015	2	4	<31	0	<1.6	0	<3	0	31	3
899	1015	5	7	<34	0	<2.2	0	<3.1	0	1.4	0.3
900	1102	0	2	<36.4	0	<2.6	0	<3.1	0	-a-	0
900	1102	2.4	4.3	<7	0	1.6	0.4	1.5	0.6	-a-	0
900	1102	4.3	6.3	<260	0	220	3.9	<7.6	0	-a-	0
900	1102	6.3	8.3	<6	0	1.4	0.4	0.6	0	16	3

Table D.1 (continued)

COORDINATE		DEPTH		URANIUM-238		RADIUM-226		THORIUM-232		THORIUM-230	
EAST	NORTH	START	FINISH	pCi/g	ERROR	pCi/g	ERROR	pCi/g	ERROR	pCi/g	ERROR
900	1102	8.3	9.8	<30.6	0	<2	0	<2.7	0	7	1
900	1102	9.8	11.6	<5	0	<0.3	0	<0.4	0	-a-	0
900	1102	13	14.5	<10	0	1.3	0.4	3	1	-a-	0
900	1199	0	1.5	<5	0	1.3	0.4	1.3	0.6	-a-	0
900	1199	1.5	3	<30.4	0	<1.9	0	<3	0	0	0
900	1199	3	4.5	170	20	45	2	1.7	1.5	-a-	0
900	1199	4.5	6	<39	0	<1.8	0	<3.1	0	-a-	0
900	1199	6	7.5	19	6	1.6	0.5	1.5	0.7	-a-	0
900	1199	8.5	9.5	<11	0	2.6	0.7	3	1	-a-	0
900	1199	10.5	12	<4	0	1	0.3	1.6	0.5	-a-	0
997	1210	0	2	<8	0	1.7	0.4	1.5	0.6	-a-	0
997	1210	4.5	6.5	61	8	6	1	<0.5	0	36	2
997	1210	6.5	8.5	<33	0	<2.5	0.0 <	2.8	0	8.6	0.7
997	1210	8.5	9.5	<4	0	1.4	0.4	1.1	0.5	-a-	0
997	1210	10.5	11.5	<9	0	1.9	0.5	3	1	-a-	0
997	1210	12.5	13.5	<6	0	1.1	0.5	1.2	0.7	-a-	0
1000	1016	0	1.5	<26.2	0	<1.8	0.0 <	2.7	0	-a-	0
1000	1016	3	5	<30.2	0	<1.8	0.0 <	3.1	0	1.8	0.6
1000	1016	5	7	<30.2	0	<1.8	0.0 <	3.2	0	-a-	0
1002	1310	2	3.5	<73.6	0	<2.8	0.0 <	3.6	0	-a-	0
1002	1310	3.5	5.5	<42.4	0	<1.7	0.0 <	3.3	0	5.4	0.8
1002	1310	5.5	7	<39.2	0	1.8	0.0 <	3.6	0	9	3
1005	1101	0	1	<9	0	1.2	0.5	1.1	0.6	-a-	0
1005	1101	1	2	<31.4	0	<2.4	0.0 <	2.5	0	-a-	0
1005	1101	2	3	9	6	7	1	1.4	0.7	-a-	0
1005	1101	4	5	47	7	12	1	1.3	1.2	-a-	0
1005	1101	10	11.5	190	20	15	1	3	2	-a-	0

Table D.1 (continued)

COORDINATE		DEPTH		URANIUM-238		RADIUM-226		THORIUM-232		THORIUM-230	
EAST	NORTH	START	FINISH	pCi/g	ERROR	pCi/g	ERROR	pCi/g	ERROR	pCi/g	ERROR
1005	1101	13	14.5	<6	0	2.2	0.5	1.5	0.6	-a-	0
1005	1101	14.5	16	<6	0	1.1	0.9	2	2	3	1
1005	1101	16	17.5	<48.4	0	<3.9	0	<3	0	29	2
1085	1102	0	1.8	<4	0	1.3	0.4	0.8	0.5	-a-	0
1085	1102	3.5	5.5	<6	0	1.4	0.4	2.7	0.7	-a-	0
1085	1102	7.5	9.5	700	100	5	1	1.5	0.7	-a-	0
1085	1102	11.5	13	<4	0	1.1	0.4	1.1	0.5	-a-	0
1085	1102	14.5	16	<7	0	1.3	0.4	1.4	0.5	-a-	0
1100	1198	0	1	<27.4	0	<2.1	0	<2.8	0	-a-	0
1100	1198	1	2	<6	0	1.5	0.7	1.3	1	-a-	0
1100	1198	3	4.5	<10	0	4	1	2	1	-a-	0
1100	1198	4.5	6	<28.2	0	<2.1	0	<2.4	0	-a-	0
1100	1198	6	7.5	<5	0	1.9	0.5	1.1	0.6	-a-	0
1100	1198	7.5	9	<80.4	0	53.2	1.9	<4.3	0	-a-	0
1100	1198	9	10.5	<4	0	0.9	0.4	0.9	0.6	1.2	0.3
1100	1198	10.5	12	<26.6	0	<2.1	0	<2.8	0.6	3.8	0.6
1100	1198	12	13	<5	0	1.3	0.5	0.8	0.6	-a-	0
1100	1198	14	15	<8	0	0.8	0.4	2.6	0.7	-a-	0
1102	1016	0	1	<173.4	0	122	2.7	<7.5	0	-a-	0
1102	1016	2	3	<115.2	0	51.4	1.7	<5.4	0	-a-	0
1102	1016	3	4	<30.8	0	<1.5	0	<2.8	0	3.6	1.6
1102	1016	4	5	<49	0	<3.2	0	<3.6	0	120	10
1102	1016	6	7	<11	0	4	2	3	3	32	2
1102	1016	7	8	<10	0	3	2	3	2	1.7	1
1102	1016	9	10	<12	0	4	2	3	2	16	1
1198	1011	0.5	1.5	<33	0	<2	0	<3.4	0	-a-	0
1198	1011	4	5.5	<34.4	0	<1.7	0	<3.4	0	17	1

Table D.1 (continued)

COORDINATE		DEPTH		URANIUM-238		RADIUM-226		THORIUM-232		THORIUM-230	
EAST	NORTH	START	FINISH	pCi/g	ERROR	pCi/g	ERROR	pCi/g	ERROR	pCi/g	ERROR
1198	1011	5.5	6.5	<34.2	0	<1.8	0	<3.3	0	1.6	0.2
1200	1100	0	1	<9	0	1.5	0.4	2	0.7	-a-	0
1200	1100	3	5	<6	0	1.8	0.5	1.7	0.7	-a-	0
1200	1100	6	7	<4	0	1.6	0.4	1.3	0.6	-a-	0
1200	1100	7	8	<115.2	0	102.2	2.6	<5.5	0	-a-	0
1200	1100	8	9	<14	0	36	3	<2	0	-a-	0
1200	1100	9	10	9	4	1.2	0.4	0.7	0.4	5	1
1200	1100	10	11	<32.8	0	<2.1	0	<2.6	0	7	2
1200	1100	12	13.5	<7	0	1.3	0.4	1.7	0.6	-a-	0
1200	1100	15	16.5	<7	0	1.3	0.5	1.7	0.7	-a-	0
1200	1199	0	2.5	<5	0	1.2	0.5	1	0.7	-a-	0
1200	1199	4.5	6	<7	0	1.7	0.4	2.1	0.7	-a-	0
1200	1199	7.5	9	78	19	86	3	2	2	-a-	0
1200	1199	9	10.5	15	7	12	2	<0.5	0	1000	100
1200	1295	0	5	706	38	131.8	2.9	<6.2	0	-a-	0
1200	1295	5	6.5	<125.4	0	116.4	2.7	<5.9	0	-a-	0
1200	1295	6.5	8	<117.2	0	118.6	2.7	<6.1	0	-a-	0
1200	1295	8	10	<129.2	0	116	2.7	<6	0	-a-	0
1200	1295	10	11	<42	0	<2.4	0	<3	1.5	0.7	0
1200	1295	11	12	<38.2	0	<2.1	0	<2.9	0	2	1
1200	1295	12	13	<34.8	0	<1.6	0	<3	0	2	0.5
1200	1392	0	1	<48	0	<1.9	0	<3.6	0	6	0.8
1200	1392	3	4	<101	0	<2	0	<3.4	0	0.6	0.3
1200	1392	4	5	<45.6	0	<2	0	<3.5	0	0.6	0.2
1298	1008	0	2	<29.2	0	<1.7	0	<3	0	-a-	0
1298	1008	5	6	<33.2	0	<2	0	<3.3	0	34	2
1298	1008	6	7	<30.8	0	<1.7	0	-a-	0	2.4	0.6

Table D.1 (continued)

COORDINATE		DEPTH		URANIUM-238		RADIUM-226		THORIUM-232		THORIUM-230	
EAST	NORTH	START	FINISH	pCi/g	ERROR	pCi/g	ERROR	pCi/g	ERROR	pCi/g	ERROR
1298	1098	0	1	<28.2	0	<2.5	0	<2.6	0	-a-	0
1298	1098	1	2	<5	0	1.9	0.7	<0.5	0	-a-	0
1298	1098	2.5	3.5	<4	0	1.6	0.4	1.3	0.6	2	2
1298	1098	3.5	4.5	<30.6	0	2.5	0	<3	0	7	2
1298	1098	6.5	7.5	190	20	<230	20	<0.5	0	-a-	0
1298	1098	8.5	10	40	9	42	2	3	1	-a-	0
1298	1098	10	11.5	<56	0	<4.1	0	<3	0	-a-	0
1298	1098	11.5	13	12	7	5	1	1.5	0.7	-a-	0
1299	1200	0	2	<7	0	2.2	0.5	1.8	0.7	-a-	0
1299	1200	3	3.8	270	20	77	3	5	2	-a-	0
1299	1200	5	6	<3	0	1	0.4	2.7	0.7	7	2
1299	1200	6	7	0	0	3	1	4	14	1.7	1.2
1299	1200	7	8	<7	0	1.7	0.5	1.9	0.8	-a-	0
1299	1200	9	10.5	<5	0	1.3	0.4	1.2	0.6	-a-	0
1300	1302	0	5	<35.4	0	<2.4	0	<2.8	0	-a-	0
1300	1302	5	9	<31.2	0	<2.4	0	<3.1	0	-a-	0
1300	1302	9	13	<28.2	0	<2.1	0	<3.1	0	-a-	0
1305	1401	0	1.5	<39.2	0	<2.8	0	<3.3	0	-a-	0
1305	1401	1.5	3	<56.2	0	<2.6	0	<2.8	0	29	2
1305	1401	3	4	<49.6	0	<2.4	0	<2.8	0	5	1
1330	1074	0	2	<85.6	0	<4.7	0	<3.4	0	-a-	0
1330	1074	4	6	<61.2	0	<4.5	0	<3.3	0	140	10
1330	1074	6	8	<36.2	0	<2.1	10	<3.4	0	5.1	0.6
1398	1011	0	2	<42.6	0	<2.4	0	<3.3	0	-a-	0
1398	1011	5	6	<31.2	0	<1.9	0	<3.3	0	0.6	0.4
1398	1011	6	7	<32.4	0	<1.7	0	<4	0	5.1	0.9
1398	1102	2	4	<12	0	3.4	0.7	3	1	-a-	0

Table D.1 (continued)

COORDINATE		DEPTH		URANIUM-238		RADIUM-226		THORIUM-232		THORIUM-230	
EAST	NORTH	START	FINISH	pCi/g	ERROR	pCi/g	ERROR	pCi/g	ERROR	pCi/g	ERROR
1398	1102	4	6	<29.2	0	<1.8	0	<3.5	0	-a-	0
1398	1102	6	7	100	20	48	3	2	1	-a-	0
1398	1102	7	8	1170	109	5620	56	<50.4	0	-a-	0
1398	1102	8	9	1600	100	1700	100	<5	0	-a-	0
1398	1102	9	10	800	100	1	0.5	1.5	0.8	6	1
1398	1102	10	12	<53	0	<2.1	0	<3.9	0	0	1
1398	1102	12	13.5	<43.2	0	<2	0	<4	0	-a-	0
1398	1102	13.5	15	13	4	2.1	0.4	1	0.5	-a-	0
1400	1351	1	2	<12	0	6	2	<3	0	140	10
1400	1351	4	5.3	24	10	4	2	<3	0	46	1
1400	1397	0	1	<41.2	0	<2.6	0	<3.5	0	-a-	0
1400	1397	2	4	<32.8	0	<1.8	0	<3.5	0	4.1	0.8
1400	1397	4	6	<25.2	0	<1.4	0	<3.2	0	1	0.3
1402	1196	0	1	<45.6	0	<2.9	0	<3.4	0	-a-	0
1402	1196	1	2	<6	0	1.9	0.5	2.4	0.7	-a-	0
1402	1196	2.5	3.8	<10	0	1.4	0.5	1.3	0.5	26	1
1402	1196	3	4	620	70	590	60	<3	0	-a-	0
1402	1196	4.5	5.5	<31.4	0	<2	0	<3.3	0	19	2
1402	1196	5	6	<5	0	1.6	0.4	1.6	0.5	-a-	0
1402	1196	6.5	8.5	<8	0	1.6	0.4	2.1	0.8	-a-	0
1402	1196	10.5	12.5	<3	0	0.5	0.3	1.3	0.5	-a-	0
1402	1300	0	2	<34.2	0	<2.2	0	<3.5	0	-a-	0
1402	1300	3.5	5.5	<31.4	0	<1.6	0	<3.1	0	0.8	0.1
1402	1300	5.5	7.5	<26.6	0	<1.6	0	<2.9	0	1.2	0.2
1497	1094	0	5	<5	0	2.8	0.5	1	0.6	-a-	0
1497	1094	5	9	<212	0	262	4.3	<8.5	0	-a-	0
1497	1094	9	13	27	10	7	1	1.3	1	-a-	0

Table D.1 (continued)

COORDINATE		DEPTH		URANIUM-238		RADIUM-226		THORIUM-232		THORIUM-230	
EAST	NORTH	START	FINISH	pCi/g	ERROR	pCi/g	ERROR	pCi/g	ERROR	pCi/g	ERROR
1498	1008	0	1	<29.6	0	<1.8	0	<3.5	0	-a-	0
1498	1008	3	4	<72.6	0	<1.7	0	<3.8	0	1	0.3
1498	1008	4	5	<54.8	0	<1.9	0	<3.7	0	12	1
1500	1200	0	8	60	20	59	3	<1	0	-a-	0
1500	1200	8	12	<25.4	0	<1.9	0	<2.5	0	-a-	0
1500	1200	12	16	<9	0	2.1	0.8	3	1	-a-	0
1500	1300	0	1	<43.6	0	<2.2	0	<4.1	0	-a-	0
1500	1300	4	5	<53.2	0	<1.5	0	<3	0	5.2	1.5
1500	1300	5	6	<42.2	0	<1.6	0	<2.9	0	1.4	0.3
1500	1400	1	2.5	<12	0	2	2	4	0.3	1.1	0.9
1500	1400	2.5	4	<14	0	2	2	<3	0	1	0.9
1595	1200	0	1.5	<30	0	22	2	1.5	1	-a-	0
1595	1200	3	4.5	37	6	23	5	0.9	0.7	-a-	0
1595	1200	4.5	5.5	<9	0	5	2	<1	0	130	10
1595	1200	5.5	6.6	<39.6	0	<2.7	0	<2.9	0	130	10
1595	1200	8	9	<11	0	<3	0	<3	0	2.5	0.4
1595	1200	11	12.5	<4	0	1.1	0.3	1.4	0.5	-a-	0
1599	1009	0	2	<63.8	0	<4.7	0	<3.3	0	-a-	0
1599	1009	2	4	<50.8	0	<4.4	0	<2.3	0	130	10
1599	1009	4	6	<32.4	0	<2.4	0	<2.8	0	71	2
1599	1009	8	9.5	<14	0	3	2	2	2	4.3	0.7
1600	1102	0	2	<31.6	0	<2.6	0	<3.1	0	-a-	0
1600	1102	3.2	4.5	1000	100	900	100	<4	0	-a-	0
1600	1102	4.5	5.5	<238	0	252	4.1	<7.9	0	-a-	0
1600	1102	5.5	6.5	<9	0	6	2	<2	0	180	10
1600	1102	6.5	7.5	<35	0	<2.7	0	<2.5	0	370	10
1600	1102	7.5	8.5	<6	0	2	0.4	1.4	0.7	-a-	0

Table D.1 (continued)

COORDINATE		DEPTH		URANIUM-238		RADIUM-226		THORIUM-232		THORIUM-230	
EAST	NORTH	START	FINISH	pCi/g	ERROR	pCi/g	ERROR	pCi/g	ERROR	pCi/g	ERROR
1600	1102	8.5	9.5	-a-	0	-a-	0	-a-	0	22	1
1600	1102	9.5	10.5	<6	0	1.7	0.6	1.3	0.8	-a-	0
1600	1102	11.5	13	<5	0	1.2	0.3	1.4	0.5	-a-	0
1600	1300	0	0.6	<93.6	0	41	1.6	<3.6	0	-a-	0
1600	1300	2	3.5	<56	0	<5	0	<3	0	420	10
1600	1300	3.5	5	<34	0	<2.9	0	<3.6	0	48	2
1600	1300	5	6	<15	0	8	2	<4	0	46	5
1600	1403	1	2	15	6	4	1	<2	0	78	2
1600	1403	2	3	<8	0	3	2	<2	0	4.9	0.6
1600	1403	4	5	<8	0	1	1	<2	0	-a-	0
1697	1012	2	4	26	13	<1	0	4	2	10	1
1697	1012	4	5	<13	0	2	1	3	2	13	2
1699	1197	6	7	<3	0	1.5	0.4	1	0.5	2.6	0.6
1699	1197	7	8	<13	0	<3	0	<3	0	10	1
1699	1197	9	10	<5	0	2	0.6	1.5	0.7	-a-	0
1699	1197	12	13.5	<5	0	1	0.3	0.6	0.5	-a-	0
1700	1300	0	2.5	<48.6	0	<3.3	0	<3.1	0	-a-	0
1700	1300	4	8	-a-	0	<3.9	0	<3	0	0	0
1700	1300	8	12	-a-	0	<2.3	0	<2.9	0	-a-	0
1702	1401	5	6	100	30	3	2	5	3	15	1
1702	1401	6	7	<20	0	27	6	7	3	560	10
1702	1401	8	9	<13	0	4	2	3	3	4.9	0.6
1704	1487	0	2	<51	0	<3.3	0	<3.6	0	-a-	0
1704	1487	2	4	<34	0	<1.7	0	<3	0	25	2
1704	1487	4	6	<28	0	<1.7	0	<3.4	0	3.5	0.8
1705	1101	1	3	<5	0	0.6	0.4	1.1	0.5	-a-	0
1705	1101	5	6.5	<9	0	2	1	<1	0	11	1

Table D.1 (continued)

COORDINATE		DEPTH		URANIUM-238		RADIUM-226		THORIUM-232		THORIUM-230	
EAST	NORTH	START	FINISH	pCi/g	ERROR	pCi/g	ERROR	pCi/g	ERROR	pCi/g	ERROR
1705	1101	6.5	7.5	<13	0	<3	0	<3	0	1.7	0.3
1705	1101	7.5	8.5	<5	0	2	0.4	0.9	0.6	-a-	0
1705	1101	9.5	11	<6	0	1.5	0.4	1.7	0.6	-a-	0
1800	1007	2	2.7	<16	0	15	4	<3	0	1100	100
1800	1007	4	5	25	11	3	2	4	2	19	4
1800	1007	5	6	<14	0	6	2	<3	0	10	1
1800	1196	3	4	<35.8	0	<3.1	0	<3.5	0	1.8	0.2
1800	1196	4	5	<8	0	2	2	3	2	7.8	0.7
1800	1405	0	1	<41.2	0	<3.1	0	<3.3	0	-a-	0
1800	1405	4	5.5	<352	0	1740	14	<18.9	0	-a-	0
1800	1405	5.5	6.5	<44.4	0	<3.4	0	<3.1	0	450	10
1800	1405	6.5	7.5	<42	0	<3.1	0	<3.2	0	120	10
1800	1405	8.5	9.5	-a-	0	-a-	0	-a-	0	79	2
1800	1405	10.5	11.5	<14	0	5	3	3	2	250	10
1801	1500	0	1	<67.4	0	76.8	1.3	<3.6	0	2160	82.8
1801	1500	1	2	<18.4	0	818	7.1	<10	0	2440	570
1801	1500	2	3	<17.9	0	<1.2	0	<2	0	2.7	0.4
1801	1500	3	4	<16.8	0	<1.2	0	<2.2	0	1.1	0.3
1801	1500	4	5	<18.1	0	<1.3	0	3.8	0.5	-a-	0
1801	1500	5	6	<17.1	0	<1.2	0	<2.2	0	-a-	0
1801	1500	6	7	<17.9	0	<1.2	0	<2	0	-a-	0
1801	1500	7	8	<47.5	0	<2.9	0	<6	0	-a-	0
1801	1500	8	9	<45.4	0	<3	0	<5.6	0	-a-	0
1801	1500	9	10	<40.8	0	<2.5	0	<4.1	0	-a-	0
1801	1500	10	11	<38.6	0	<2.5	0	<5.6	0	-a-	0
1801	1500	11	12	<41	0	<3	1	<4.3	0	-a-	0
1803	1294	0	1.6	<158.6	0	149.6	2.7	<7.2	0	-a-	0

Table D.1 (continued)

COORDINATE		DEPTH		URANIUM-238		RADIUM-226		THORIUM-232		THORIUM-230	
EAST	NORTH	START	FINISH	pCi/g	ERROR	pCi/g	ERROR	pCi/g	ERROR	pCi/g	ERROR
1803	1294	2	4	<26.6	0	<1.5	0	<1.5	0	3.7	0.7
1803	1294	4	6	<33.6	0	<1.7	0	<3.4	0	3.7	1.7
1803	1294	10	12	39	17	27	5	<4	0	860	10
1808	1102	4	5	<13	0	4	2	<3	0	4	0.7
1808	1102	5	6	<11	0	2	1	4	3	12	1
1897	1194	0	2	<24.8	0	<1.6	0	<3.2	0	-a-	0
1897	1194	6	8	<75.6	0	59.6	1.8	<5.4	0	-a-	0
1897	1194	8	10	<45.2	0	<3.9	0	<3.7	0	1	0.3
1897	1194	10	12	<92.6	0	73	2	<6.1	0	1	0.3
1899	1309	0	1	<28.4	0	<2.4	0	<3.2	0	-a-	0
1899	1309	2	3	<73.6	0	<4.8	0	<3.9	0	1500	100
1899	1309	3	4	<35.2	0	<2.8	0	<2.9	0	18	1
1899	1309	4	6	-a-	0	-a-	0	-a-	0	23	1
1899	1309	7	8	<11	0	2	1	4	3	36	2
1899	1309	9	10.5	<10	0	5	2	<2	0	10	1
1900	1008	3	4	18	9	2	2	3	2	5.4	0.6
1900	1008	4	5	<16	0	5	2	3	3	120	10
1900	1008	6	7	<13	0	2	2	5	3	7.1	1.8
1900	1099	4	5	<10	0	3	1	<3	0	2.3	0.4
1900	1099	5	6	<8	0	3	1	<2	0	0.8	0.5
1900	1400	0	1	<38.4	0	<2.9	0	<3.2	0	-a-	0
1900	1400	1	2	<29.4	0	<2.5	0	<2.8	0	-a-	0
1900	1400	2	3	<36	0	<2.6	0	<2.9	0	-a-	0
1900	1400	3	4	<316	0	898	9	<13.6	0	-a-	0
1900	1400	4	5	<46	0	<2.3	0	<3.2	0	-a-	0
1900	1400	6	7	<13	0	<3	0	5	3	3	1
1900	1400	7	8	<12	0	<3	0	<3	0	5	1

Table D.1 (continued)

COORDINATE		DEPTH		URANIUM-238		RADIUM-226		THORIUM-232		THORIUM-230	
EAST	NORTH	START	FINISH	pCi/g	ERROR	pCi/g	ERROR	pCi/g	ERROR	pCi/g	ERROR
1915	1500	0	1	<31	0	<2.5	0	<3.3	0	-a-	0
1915	1500	3	4	<46.2	0	<2.4	0	<2.5	0	-a-	0
1915	1500	4	5	<43.6	0	<4	0	<3	0	-a-	0
1915	1500	8	9	<182.2	0	318	4.8	<8.8	0	-a-	0
1915	1500	9	10	<70.4	0	33.8	1.4	<3.8	0	-a-	0
1915	1500	10	11	<39.6	0	<3.2	0	<2.2	0	-a-	0
1915	1500	12	13	-a-	0	-a-	0	-a-	0	32	1
1915	1500	13	14	<14	0	3	2	<2	0	26	2
1915	1500	14	15	<12	0	2	2	2	2	45	3
1996	1011	0	1.6	<28	0	<1.7	0	<3.4	0	-a-	0
1996	1011	3	5	<38.8	0	<1.7	0	<3.3	0	58	2
1996	1011	5	7	<66.2	0	<3.3	0	<3.4	0	800	10
1996	1011	9	11	<7	0	3	1	3	2	2.1	1.1
1997	1207	0	2	<38.6	0	<2.3	0	<2.8	0	-a-	0
1997	1207	4	5	<48.4	0	<4.8	0	<3.7	0	85	3
1997	1207	5	6	<35.4	0	-a-	0	<3.3	0	4	1
2000	1100	0	4	<52.8	0	<4	0	<3.5	0	-a-	0
2000	1100	4	8	<43.8	0	<3	0	<2.7	0	-a-	0
2000	1100	8	12	<28.2	0	<1.8	0	<3.2	0	-a-	0
2000	1400	2.5	4.5	<9	0	2	1	4	2	9	1
2000	1400	4.5	5.5	<10	0	9	2	<3	0	140	10
2000	1400	6.5	7.5	<13	0	2	2	3	3	27	1
2000	1500	10	11	-a-	0	-a-	0	-a-	0	110	10
2000	1500	11	12	<14	0	<2	0	<2	0	55	4
2003	1303	4	5	<13	0	3	2	6	3	80	10
2003	1303	5	6	<11	0	4	2	3	2	120	10
2003	1303	7	8	<16	0	3	2	5	3	58	2

Table D.1 (continued)

COORDINATE		DEPTH		URANIUM-238		RADIUM-226		THORIUM-232		THORIUM-230	
EAST	NORTH	START	FINISH	pCi/g	ERROR	pCi/g	ERROR	pCi/g	ERROR	pCi/g	ERROR
2096	1098	0	1	<120	0	33.4	1.4	<4.6	0	-a-	0
2096	1098	4	5	<38.6	0	<2.4	0	<3.3	0	71	5
2096	1098	5	6	<46.2	0	<2.8	0	<4	0	120	10
2096	1098	7	8	<9	0	4	2	<2	0	10	1
2100	1012	0	2	<50.6	0	<3.1	0	<3.4	0	-a-	0
2100	1012	2	4	<31.8	0	<2	0	<2.6	0	4.6	1.2
2100	1012	4	5	<33.8	0	<2	0	<3.2	0	7	1
2100	1200	0	1	<29	0	<2.3	0	<3.3	0	-a-	0
2100	1200	5.5	7	<40	0	<3.9	0	<3.3	0	3.4	0.3
2100	1200	7	8	<39.2	0	<4.6	0	<2.8	0	4.5	0.3
2100	1400	0	1.5	<288	0	838	8.6	-a-	0	-a-	0
2100	1400	1.5	2.5	-a-	0	530	6.4	<10.6	0	-a-	0
2100	1400	2.5	3.5	<123.2	0	90.6	2.4	<10.6	0	-a-	0
2100	1400	3.5	4.5	-a-	0	<3.2	0	<2.7	0	13	1
2100	1400	4.5	5.5	<41.4	0	<2.5	0	-a-	0	-a-	0
2100	1400	5.5	7	<10	0	-a-	0	3	2	84	3
2100	1400	8	9	<14	0	4	2	<4	0	15	1
2100	1500	0	1	<41.2	0	<3.3	0	<3.5	0	-a-	0
2100	1500	1	2	<346	0	1518	13	<18.2	0	-a-	0
2100	1500	2	3	<22.6	0	316	4.7	<8.4	0	-a-	0
2100	1500	3	4	<43.6	0	<2.2	0	<3.1	0	-a-	0
2100	1500	4	5	<133.4	0	67.8	2.1	<4.9	0	-a-	0
2100	1500	5	6	<38.6	0	<2.5	0	<3.1	0	1.7	0.4
2100	1500	6	7	<33.4	0	<2.2	0	<2.9	0	27	1
2100	1500	7	8	<35.2	0	<2.5	0	<2.9	0	11	1
2100	1500	8	9	<31.4	0	<2	0	<3.2	0	-a-	0
2104	1301	0	4	<137.2	0	46.2	1.7	<4.6	0	-a-	0

Table D.1 (continued)

COORDINATE		DEPTH		URANIUM-238		RADIUM-226		THORIUM-232		THORIUM-230	
EAST	NORTH	START	FINISH	pCi/g	ERROR	pCi/g	ERROR	pCi/g	ERROR	pCi/g	ERROR
2104	1301	4	8	<31.4	0	<2.6	0	<3.5	0	-a-	0
2104	1301	8	12	<26.8	0	<2.1	0	<2.1	0	-a-	0
2199	1299	0	1	<28.4	0	<2.3	0	<3	0	-a-	0
2199	1299	1	2	<128	0	48.8	1.8	<4.1	0	-a-	0
2199	1299	2	2.5	<169.8	0	94.4	2.4	<5	0	-a-	0
2199	1299	2.5	4	<26	0	<2	0	<2.8	0	7.2	0.6
2199	1299	4	5	<49.4	0	<3.3	0	<3	0	560	10
2199	1299	6	7	<27.4	0	<1.9	0	<2.7	0	3.9	0.4
2200	1100	0	1	<27.8	0	<2.1	0	<3.2	0	-a-	0
2200	1100	4	5	<122.4	0	57.6	1.9	<4.6	0	-a-	0
2200	1100	5	6	<44.8	0	<3	0	<3.6	0	130	10
2200	1100	6	7	<28.8	0	<2.4	0	<2.8	0	31	2
2200	1100	7	8	-a-	0	-a-	0	-a-	0	32	2
2200	1100	9	10	<10	0	<2	0	<3	0	15	1
2200	1100	11	12	<8	0	<2	0	3	2	1.4	0.5
2200	1200	0	1	<40.8	0	<2.8	0	3.2	0	-a-	0
2200	1200	7	8	<61	0	35.4	1.5	3.8	0	-a-	0
2200	1200	8	9	<38.6	0	<4	0	3.2	0	1.9	0.5
2200	1200	9	10	<44.6	0	<5.3	0	3.6	0	6	1
2200	1400	0	1	<31.8	0	<2.1	0	2.6	0	-a-	0
2200	1400	2	3	<132	0	82.8	2.3	5	0	-a-	0
2200	1400	3	4	<182.4	0	228	4	7.9	0	-a-	0
2200	1400	4	5	<50.6	0	<4	0	3.4	0	150	10
2200	1400	5	6	<31.6	0	<2.3	0	2.7	0	4.6	0.6
2202	1485	0	1	<53	0	<4.4	0	3.8	0	-a-	0
2202	1485	4	5	<48.2	0	<2.5	0	3.3	0	13	1
2202	1485	5	6	<35.8	0	<2.2	0	2.5	0	9	1

Table D.1 (continued)

COORDINATE		DEPTH		URANIUM-238		RADIUM-226		THORIUM-232		THORIUM-230	
EAST	NORTH	START	FINISH	pCi/g	ERROR	pCi/g	ERROR	pCi/g	ERROR	pCi/g	ERROR
2205	1021	0	1.2	<29.8	0	<1.8	0	3	0	-a-	0
2205	1021	1.2	3	<77.6	0	<4.6	0	4	0	1100	100
2205	1021	3	5	<29	0	<1.4	0	2.9	0	1.1	0.5
2300	1101	0	1	<29.4	0	<2.1	0	3.1	0	-a-	0
2300	1101	3	4	<37.2	0	<4.1	0	2.7	0	2600	100
2300	1101	4	5	<49	0	<3.2	0	3	0	71	2
2300	1101	6	7	-a-	0	-a-	0	-a-	0	30	1
2300	1101	8	9	<9	0	1	1	3	2	1.8	0.4
2300	1101	11	12	<10	0	1	1	2	0	1.9	0.8
2300	1400	0	1	<33.6	0	<4.2	0	3	0	3.9	0.4
2300	1400	2	3.5	<158	0	74.2	2.2	4.8	0	-a-	0
2300	1400	3.5	5	<53.2	0	<3.3	0	3.2	0	100	10
2300	1400	5	6	<31.2	0	<2.1	0	2.8	0	11	1
2302	1300	0	1	<30.2	0	<3.8	0	3	0	-a-	0
2302	1300	1	2	<44.6	0	<3.1	0	3.1	0	1900	100
2302	1300	2	3	<31.6	0	<2.3	0	3.1	0	5	0.7
2305	1200	0	1	<57.2	0	<3.5	0	<3.8	0	5	0.7
2305	1200	2	3.5	<50.4	0	<4	0	<3	0	1700	100
2305	1200	3.5	5	<51.4	0	4.7	2	<3.1	0	1200	100
2305	1200	9	10	<11	0	2	2	4	3	15	2
2305	1200	11	12	<17	0	3	2	<4	0	10	1
2313	1010	5	6	37	15	2	2	3	3	-a-	0
2313	1010	6	8	14	4	2.7	0.8	3	1	-a-	0
2313	1010	8	10	<6	0	1.5	0.5	1	0.7	-a-	0
2313	1010	10	12	<7	0	1.3	0.4	1.6	0.8	-a-	0
2398	1101	6	7	<9	0	3	1	<2	0	21	2
2398	1101	7	8	<9	0	3	1	<2	0	4	0.7

Table D.1 (continued)

COORDINATE		DEPTH		URANIUM-238		RADIUM-226		THORIUM-232		THORIUM-230	
EAST	NORTH	START	FINISH	pCi/g	ERROR	pCi/g	ERROR	pCi/g	ERROR	pCi/g	ERROR
2399	1382	0	1	<244	0	158.2	3.2	<6.4	0	-a-	0
2399	1382	1	2	<208	0	161.2	3.3	<7	0	-a-	0
2399	1382	2	3.5	<29.2	0	<1.9	0	<2.1	0	13	3
2399	1382	3.5	4.5	<32.2	0	<2.3	0	<3.1	0	910	10
2399	1382	6.5	7.5	-a-	0	-a-	0	-a-	0	2	0.3
2400	1010	5	6	13	5	1.3	0.7	2	1	-a-	0
2400	1010	6	7	8	5	1.2	0.5	1.6	0.9	-a-	0
2400	1010	7	8	11	4	1.4	0.5	1.3	0.7	-a-	0
2400	1010	8	10	12	4	1.9	0.5	3	1	-a-	0
2400	1010	10	12	<5	0	1.1	0.5	1.3	0.6	-a-	0
2400	1300	0	1	<29.6	0	<2.2	0	<2.9	0	-a-	0
2400	1300	1	2	<93.8	0	<4.7	0	<2.9	0	750	10
2400	1300	2	3	<63	0	<4.1	0	<2.8	0	-a-	0
2400	1300	3	4	-a-	0	-a-	0	-a-	0	320	10
2400	1300	5.5	6	-a-	0	-a-	0	-a-	0	19	2
2400	1300	7	8	<12	0	3	1	<3	0	15	2
2400	1300	11	11.5	<11	0	<2	0	3	2	1.6	0.7
2401	1202	0	1	<46.6	0	<3.1	0	<2.6	0	-a-	0
2401	1202	4	5	<36.4	0	<3.4	0	<2.7	0	38	0.2
2401	1202	5.5	7	<32	0	<3	0	<3.1	0	5.5	0.5
2401	1202	8	9	<12	0	5	2	<3	0	3.1	0.4
2401	1202	9	10	<9	0	2	1	2	2	1.9	0.2
2500	1009	0	2	<26.2	0	<1.6	0	<3.1	0	-a-	0
2500	1009	2	4	<35.4	0	<1.4	0	<3.1	0	2.7	0.7
2500	1009	4	6	<30.2	0	<1.7	0	<3.2	0	1.8	0.4
2500	1200	0	1	<29.4	0	<2.1	0	<3.4	0	-a-	0
2500	1200	1	2	<36	0	<2	0	<2.9	0	-a-	0

Table D.1 (continued)

COORDINATE		DEPTH		URANIUM-238		RADIUM-226		THORIUM-232		THORIUM-230	
EAST	NORTH	START	FINISH	pCi/g	ERROR	pCi/g	ERROR	pCi/g	ERROR	pCi/g	ERROR
2550	1650	2	3	<8	0	2.2	0.6	2	0.8	1.5	1.1
2550	1700	0	0.5	<8	0	0.9	0.4	3	1	4.1	0.7
2550	1750	0	0.5	<4	0	0.9	0.4	0.7	0.5	5.1	0.7
2550	1750	0.5	1	-a-	-a-	-a-	-a-	-a-	-a-	4	0.6
2550	1800	0	0.5	8	2	0.9	0.4	2	0.6	3.2	0.8
2558	1850	0	0.5	-a-	-a-	-a-	-a-	-a-	-a-	4.2	0.5
2558	1850	0.5	1	-a-	-a-	-a-	-a-	-a-	-a-	3.2	0.6
2559	1900	0	0.5	-a-	-a-	-a-	-a-	-a-	-a-	5	0.7
2559	1900	0.5	1	-a-	-a-	-a-	-a-	-a-	-a-	3.2	0.4
2563	1950	0	0.5	-a-	-a-	-a-	-a-	-a-	-a-	4.3	0.5
2563	1950	0.5	1	-a-	-a-	-a-	-a-	-a-	-a-	5	1.1
2563	2000	0	0.5	-a-	-a-	-a-	-a-	-a-	-a-	4.1	0.6
2563	2000	0.5	1	-a-	-a-	-a-	-a-	-a-	-a-	2.3	0.6
2564	2050	0	0.5	-a-	-a-	-a-	-a-	-a-	-a-	3.4	0.5
2564	2050	0.5	1	-a-	-a-	-a-	-a-	-a-	-a-	11	1
2570	2100	0	0.5	-a-	-a-	-a-	-a-	-a-	-a-	1.9	0.7
2570	2100	0.5	1	-a-	-a-	-a-	-a-	-a-	-a-	9	0.8
2578	2150	0	0.5	-a-	-a-	-a-	-a-	-a-	-a-	2.9	0.4
2578	2150	0.5	1	-a-	-a-	-a-	-a-	-a-	-a-	2.5	0.4
2582	2200	0	0.5	-a-	-a-	-a-	-a-	-a-	-a-	4.8	0.7
2582	2200	0.5	1	-a-	-a-	-a-	-a-	-a-	-a-	5.1	0.5
2585	2250	0	0.5	-a-	-a-	-a-	-a-	-a-	-a-	1.8	0.3
2585	2250	0.5	1	-a-	-a-	-a-	-a-	-a-	-a-	1.1	0.3
2590	2400	0	0.5	-a-	-a-	-a-	-a-	-a-	-a-	1.8	0.3
2590	2400	0.5	1	-a-	-a-	-a-	-a-	-a-	-a-	1.7	0.3
2593	2300	0	0.5	-a-	-a-	-a-	-a-	-a-	-a-	2.5	0.4
2593	2300	0.5	1	-a-	-a-	-a-	-a-	-a-	-a-	35	2

Table D.1 (continued)

COORDINATE		DEPTH		URANIUM-238		RADIUM-226		THORIUM-232		THORIUM-230	
EAST	NORTH	START	FINISH	pCi/g	ERROR	pCi/g	ERROR	pCi/g	ERROR	pCi/g	ERROR
2594	2350	0	0.5	-a-	-a-	-a-	-a-	-a-	-a-	1.9	0.4
2594	2350	0.5	1	-a-	-a-	-a-	-a-	-a-	-a-	1.1	0.3
2600	1500	0	0.5	6	3	2.6	0.6	1.4	0.8	77	2
2600	1550	0	1	<7	0	2	0.7	<1	0	3.6	0.5
2600	1550	1	2	<10	0	1.3	0.5	3	1	1.3	0.3
2600	1550	2	3	<5	0	1.2	0.7	1.6	0.8	2.1	0.6
2600	1600	0	0.5	<5	0	1	0.4	1.3	0.6	11	1
2600	1650	0	0.5	<8	0	1.5	0.5	2.6	0.8	6.1	0.7
2600	1700	0	0.5	<6	0	1.7	0.5	1.3	0.7	33	2
2600	1750	0	1	<7	0	1.9	0.6	2.2	0.8	8.8	1.2
2600	1750	1	2	<5	0	1.4	0.6	1.2	0.7	-a-	-a-
2600	1750	2	3	<10	0	1.5	0.6	1.4	0.9	2.9	0.7
2600	1800	0	0.5	<8	0	1.7	0.5	0.7	0.6	10	1
2600	2000	0	0.5	<8	0	1.7	0.6	2	0.7	1.5	0.3
2600	2200	0	0.5	<6	0	1.7	0.6	2	1	1.9	0.4
2650	1500	0	0.5	<5	0	1.3	0.5	2.1	0.7	4	1
2650	1550	0	0.5	<6	0	1.3	0.5	1.3	0.7	14	1
2650	1600	0	0.5	<8	0	1.3	0.5	2.3	0.7	14	1
2650	1650	0	1	<7	0	1.6	0.6	2.7	0.9	10	1
2650	1650	1	2	<8	0	2.2	0.7	2	1	-a-	-a-
2650	1650	2	3	<6	0	1.8	0.7	2	1	2.7	0.5
2650	1700	0	0.5	<5	0	1.1	0.5	1.5	0.7	4.3	0.6
2650	1750	0	0.5	<5	0	1.2	0.5	0.9	0.7	5.4	0.7
2700	1450	0	0.5	<9	0	2.8	0.6	2	0.7	60	2
2700	1500	0	0.5	<5	0	2	0.5	1.4	0.6	5.3	0.6
2700	1550	0	1	<5	0	1.3	0.6	1.6	0.8	2	0.7
2700	1550	1	2	<7	0	1.6	0.7	1.4	0.9	-a-	-a-

Table D.1 (continued)

COORDINATE		DEPTH		URANIUM-238		RADIUM-226		THORIUM-232		THORIUM-230	
EAST	WEST	START	FINISH	pCi/g	ERROR	pCi/g	ERROR	pCi/g	ERROR	pCi/g	ERROR
2700	1550	2	3	<5	0	1.7	0.6	2.4	0.8	1.8	0.7
2700	1600	0	0.5	<6	0	1.4	0.6	2.1	0.8	26	1
2700	1650	0	0.5	<6	0	1.7	0.5	2.4	0.8	18	1
2700	1690	0	1	<12	0	2.3	0.7	3	1	2.9	0.5
2700	1690	4	5	<9	0	1.5	0.5	1.4	0.7	2.3	0.4
2700	1690	9	10	<8	0	1.2	0.4	1.3	0.7	2	0.6
2700	1700	0	0.5	<5	0	1	0.5	0.9	0.7	12	1
2700	1750	0	1	<7	0	1.3	0.6	1.5	0.9	2.7	0.5
2700	1750	1	2	<5	0	1.4	0.6	2	0.8	-a-	-a-
2700	1750	2	3	<8	0	1.8	0.7	2	1	2	0.5
2700	1800	0	0.5	<8	0	0.8	0.5	3	1	1.9	0.4
2700	2000	0	0.5	<7	0	2.3	0.8	2	1	5.6	0.8
2700	2200	0	0.5	<6	0	0.9	0.5	1.2	0.8	0.9	0.4
2750	1450	0	1	<7	0	1	0.7	3	1	2.7	0.8
2750	1450	1	2	<8	0	2.6	0.8	2	1	-a-	-a-
2750	1450	2	3	<16	0	2.2	0.8	2	1	9	2
2750	1500	0	0.5	<10	0	0.8	0.5	3	1	8	1
2750	1550	0	0.5	<6	0	0.9	0.5	1.7	0.7	24	2
2750	1600	0	0.5	<5	0	1.2	0.5	1.5	0.7	12	1
2750	1650	0	1	<6	0	1.4	0.5	1.8	0.8	4.4	0.8
2750	1650	1	2	<6	0	2.2	0.7	1.1	1	-a-	-a-
2750	1650	2	3	<7	0	<1	0	1	0	2	0.8
2750	1700	0	0.5	<9	0	0.9	0.5	3	1	6.5	0.6
2795	1476	0	1	<9	0	1.6	0.5	2.6	0.9	16	1
2795	1476	4	5	<6	0	1.3	0.5	1.3	0.7	1.3	0.5
2795	1476	0	5.5	<8	0	1.1	0.5	1.9	0.8	4.9	0.8
2800	1450	0	0.5	<6	0	1.5	0.5	1.9	0.7	11	1

Table D.1 (continued)

COORDINATE		DEPTH		URANIUM-238		RADIUM-226		THORIUM-232		THORIUM-230	
EAST	NORTH	START	FINISH	pCi/g	ERROR	pCi/g	ERROR	pCi/g	ERROR	pCi/g	ERROR
2800	1550	1	2	<10	0	1.4	0.5	2	1	1.2	0.4
2800	1550	2	3	<6	0	1.1	0.5	1.4	0.7	1.3	0.4
2800	1600	0	0.5	<4	0	1	0.5	1.5	0.7	6.5	0.7
2800	1650	0	0.5	<5	0	0.9	0.5	1.8	0.7	3.5	0.5
2800	1700	0	0.5	<6	0	1.9	0.5	2.4	0.7	8.1	0.6
2800	1800	0	0.5	<8	0	1.1	0.5	1.1	0.5	10	1
2800	2000	0	0.5	<6	0	1.2	0.6	1	0.8	3.3	0.5
2800	2200	0	0.5	<10	0	1.4	0.8	3	1	1.7	0.5
2813	2448	0	1	<10	0	1.2	0.5	<1	0	2.3	0.4
2813	2448	4	5	<10	0	3	0.7	3	1	3.6	0.6
2813	2448	0	13	<11	0	1.2	0.7	2.9	0.9	10	1
2839	1939	0	0.5	<11	0	1	0.6	1.7	0.8	1.2	0.3
2850	1400	0	0.5	<7	0	1	0.6	1.2	0.8	23	1
2850	1450	0	1	<7	0	1.4	0.7	1.3	1	4.2	0.9
2850	1450	1	2	<7	0	2.4	0.7	2	1	-a-	-a-
2850	1450	2	3	<6	0	2	0.6	1.7	1	2.1	0.5
2850	1500	0	0.5	<7	0	1.2	0.5	1.5	0.8	13	1
2850	1550	0	0.5	<9	0	1.1	0.5	2.3	0.9	37	2
2850	1600	0	0.5	<5	0	2	0.5	1.4	0.7	14	1
2850	1650	0	1	<6	0	2	0.7	2	1	5.8	1
2850	1650	1	2	<11	0	1.6	0.6	2	1	-a-	-a-
2850	1650	2	3	<6	0	1.2	0.6	1.9	0.9	2.5	0.6
2850	1700	0	0.5	<6	0	0.8	0.5	1.3	0.7	13	1
2863	2014	0	0.5	<10	0	2	0.6	3	1	2	0.6
2896	1956	0	0.5	<10	0	1.6	0.6	3	1	1.2	0.4
2900	1400	0	0.5	<8	0	1.5	0.4	1.6	0.7	12	1
2900	1450	0	0.5	<4	0	1.4	0.5	1.5	0.6	12	1

Table D.1 (continued)

COORDINATE		DEPTH		URANIUM-238		RADIUM-226		THORIUM-232		THORIUM-230	
EAST	NORTH	START	FINISH	pCi/g	ERROR	pCi/g	ERROR	pCi/g	ERROR	pCi/g	ERROR
2900	1500	0	0.5	<7	0	2.2	0.6	1.5	0.8	13	1
2900	1500	2	3	<12	0	3	1	3	2	1.4	0.3
2900	1550	0	1	<8	0	1.8	0.8	2	1	10	1
2900	1550	1	2	<12	0	1.9	0.7	2	1	-a-	-a-
2900	1550	2	3	<12	0	3	1	3	2	1.4	0.3
2900	1600	0	0.5	<9	0	1.5	0.5	2.1	0.8	7	1
2900	1650	0	0.5	5	4	2.5	0.5	1.4	0.7	6	1
2900	1800	0	0.5	<6	0	0.9	0.6	1.7	0.8	1.3	0.5
2900	2000	0	0.5	<8	0	0.9	0.7	1.4	0.9	1	0.4
2900	2200	0	0.5	<7	0	1.5	0.6	1.5	0.6	1.7	0.4
2936	1927	0	0.5	<9	0	1.7	0.5	3	1	1.4	0.4
2950	1450	0	1	<14	0	2.1	0.7	1.3	0.7	4.3	1.4
2950	1450	1	2	<7	0	1.2	0.7	2	1	-a-	-a-
2950	1450	2	3	<15	0	1.4	0.6	<1	0	2.9	0.7
2950	1500	0	0.5	5	3	1	0.5	1.1	0.7	8	1
2950	1550	0	0.5	<9	0	1.3	0.5	2.4	0.8	8	1
2950	1600	0	0.5	6	3	1.2	0.5	2.1	0.7	10	1
2950	1650	0	1	<11	0	2.2	0.6	2	1	5	1.1
2950	1650	1	2	<7	0	1.2	0.7	<1	0	-a-	-a-
2950	1650	2	3	<7	0	1.6	0.7	2	1	1.3	0.6
2950	2227	0	0.5	<6	0	1.5	0.5	2	0.8	1.4	0.3
2990	2264	0	0.5	<8	0	1.8	0.7	2	1	2.4	0.7
2992	2231	0	0.5	<9	0	1.7	0.6	1.5	0.8	1.5	0.3
2995	1865	0	1	<9	0	1.1	0.7	2	1	7.7	0.8
2995	1865	4	5	<5	0	1.3	0.5	1.6	0.8	1.5	0.4
2995	1865	0	13	<4	0	1.9	0.5	<1	0	1.1	0.3
3000	1350	0	1	<6	0	1	0.6	1	0.9	9	1

Table D.1 (continued)

COORDINATE		DEPTH		URANIUM-238		RADIUM-226		THORIUM-232		THORIUM-230	
EAST	NORTH	START	FINISH	pCi/g	ERROR	pCi/g	ERROR	pCi/g	ERROR	pCi/g	ERROR
2500	1200	2	4	<256	0	193.8	3.8	7.5	3.8	-a-	0
2500	1200	4	5.5	<74.8	0	73	2.2	<5.1	0	-a-	0
2500	1200	5.5	7	<29.8	0	<3	0	<2.5	0	16	2
2500	1200	7	8	<44.6	0	<4.8	0	<3.6	0	1.8	0.4
2500	1300	0	4	<174.4	0	85.6	2.3	<5.1	0	-a-	0
2500	1300	4	8	<36	0	<2.2	0	<2.6	0	-a-	0
2500	1300	8	12	<27.4	0	<2	0	<2.6	0	-a-	0
2501	1096	0	4	<49.6	0	<1.9	0	<3.7	0	-a-	0
2501	1096	5	9	<199.6	0	404	5.8	<12	0	-a-	0
2501	1096	9	13	<37.2	0	<1.5	0	<3	0	-a-	0
2596	1008	2.5	3.5	<12	0	1	1	4	2	1.7	0.4
2596	1008	3.5	4.5	<7	0	3	1	2	1	1.6	0.5
2601	1104	0	1	<11	0	3	1	<3	0	1.5	1
2601	1104	2	3.5	27	13	9	3	<3	0	140	10
2601	1104	4	5	14	10	<2	0	<2	0	1.5	0.3
2602	1196	0	1	<27	0	<1.7	0	<2.9	0	-a-	0
2602	1196	4	5	<50	0	<1.7	0	<3.1	0	2.8	0.5
2602	1196	5	6	<45.4	0	<1.4	0	<3.2	0	2.8	0.5
2695	1176	3	4	32	26	36	5	7	3	2100	100
2695	1176	4	5	17	8	2	1	3	2	7	1
2700	1008	2	3.8	<23	0	<2	0	<2	0	3	1
2700	1008	4	6	<11	0	4	2	<3	0	2	0.7
2700	1101	0	1	<33.2	0	<1.8	0	<3.3	0	-a-	0
2700	1101	4	6	<94.2	0	<2.7	0	<3.6	0	200	10
2700	1101	6	8	<50.8	0	<1.9	0	<3.2	0	63	6
2700	1101	10	12	<12	0	3	2	3	2	0.6	0.2
2798	1102	0	4	<88.8	0	<2.6	0	<3.5	0	-a-	0

Table D.1 (continued)

COORDINATE		DEPTH		URANIUM-238		RADIUM-226		THORIUM-232		THORIUM-230	
EAST	NORTH	START	FINISH	pCi/g	ERROR	pCi/g	ERROR	pCi/g	ERROR	pCi/g	ERROR
2798	1102	4	8	<55	0	<1.7	0	<3.4	0	-a-	0
2798	1102	8	12	<30.8	0	<1.6	0	<3.7	0	-a-	0
2800	1008	0	1	<45.6	0	<1.7	0	<3	0	-a-	0
2800	1008	2	3	<39.8	0	<1.6	0	<3.2	0	2.3	0.8
2800	1008	3	4	<43.8	0	<1.7	0	<2.9	0	1.4	0.3
2900	1012	2	3.5	<45	0	<1.7	0	<3.1	0	32	2
2900	1012	3.5	5.5	<29.6	0	<1.7	0	<4	0	1.4	0.6
3098	1073	0	4	<25.8	0	<1.5	0	<3.3	0	-a-	0
3098	1073	4	8	<27	0	<1.6	0	<3.3	0	-a-	0
3098	1073	8	12	<31.2	0	<1.8	0	<3.5	0	-a-	0
560	1561	0	0.5	5.3	0	1.7	0.5	1	0.2	42.8	3.3
560	1561	4	6	3	0	0.6	0	0.8	0	1.2	0.5
560	1561	10	12	2.1	0	0.8	0.1	1.2	0.1	0.6	0.4
850	1500	0	0.5	<6	0	1.4	0.5	1.1	0.7	10	1
900	1500	0	0.5	8	5	2.4	0.6	0.7	0.6	80	3
926	1578	0	1	<12	0	3	1	2	1	5.7	0.8
926	1578	4	5	<10	0	2.7	0.6	2	0.8	1.3	0.3
926	1578	0	9.5	<10	0	<0.6	0	2.6	0.9	19	1
950	1500	0	0.5	<9	0	2.5	0.6	2.8	0.9	86	2
950	1550	0	0.5	<5	0	1.2	0.4	1.5	0.7	4.9	0.7
950	1600	0	0.5	<4	0	1.1	0.4	1	0.6	4.6	0.7
950	1650	0	1	4	3	0.9	0.4	1.7	0.6	2.8	0.4
950	1650	1	2	<5	0	1.1	0.4	1.5	0.6	-a-	-a-
950	1650	2	3	<8	0	1.6	0.5	1.7	0.5	1.4	0.4
1000	1500	0	0.5	10	4	5	1	1.6	0.8	170	10
1000	1550	0	1	<6	0	1.7	0.5	1.3	0.6	4	0.7
1000	1550	1	2	<4	0	1.1	0.4	1.6	0.6	-a-	-a-

Table D.1 (continued)

COORDINATE		DEPTH		URANIUM-238		RADIUM-226		THORIUM-232		THORIUM-230	
EAST	NORTH	START	FINISH	pCi/g	ERROR	pCi/g	ERROR	pCi/g	ERROR	pCi/g	ERROR
1000	1550	2	3	<6	0	1	0.3	1.5	0.5	0.5	0
1000	1600	0	0.5	<4	0	0.7	0.4	0.8	0.6	3.5	0.6
1000	1650	0	0.5	<7	0	1.2	0.4	1.3	0.7	2.7	0.5
1000	1700	0	0.5	<4	0	0.6	0.3	1	0.5	2.7	1.1
1050	1600	0	0.5	<4	0	0.7	0.4	0.7	0.6	6.1	0.8
1050	1650	0	1	<7	0	1.2	0.5	2.3	0.7	3	0.7
1050	1650	1	2	8	3	1.2	0.4	2.1	0.7	-a-	-a-
1050	1650	2	3	<6	0	1.4	0.5	1.7	0.7	0.8	0.4
1050	1700	0	0.5	<7	0	1.2	0.4	0.7	0.6	3.4	0.6
1050	1750	0	0.5	7	0	1.1	0.4	1.7	0.6	1.9	0.5
1100	1650	0	0.5	<4	0	1	0.4	1	0.7	4.6	0.6
1100	1700	0	0.5	<4	0	1	0.4	1	0.6	3.6	0.8
1100	1750	0	1	<6	0	1.1	0.3	2.2	0.7	1	0.7
1100	1750	1	2	<7	0	1.3	0.4	1.8	0.7	-a-	-a-
1100	1750	2	3	<6	0	1	0.4	1.9	0.6	1.4	0
1111	1821	0	1	<7	0	<1	0	1	1	3.1	0.6
1111	1821	4	5	<6	0	1.6	0.6	<1	0	1.3	0.4
1111	1821	0	6.5	<7	0	1.6	0.6	1.4	0.7	21	2
1150	1600	0	0.5	<9	0	1.2	0.5	1.4	0.6	6	1.2
1150	1650	0	1	<14	0	1.3	0.5	2.4	0.9	4	0.7
1150	1650	1	2	<5	0	1.5	0.5	1.8	0.8	-a-	-a-
1150	1650	2	3	<8	0	1.1	0.5	2.2	0.7	1.1	0.5
1150	1700	0	0.5	<8	0	1.5	0.4	1.3	0.6	3.3	0.9
1150	1750	0	0.5	<4	0	0.8	0.4	1.2	0.6	2.5	0.7
1200	1600	0	0.5	<8	0	1.5	0.4	1.8	0.7	4.1	0.5
1200	1650	0	0.5	<4	0	0.9	0.4	1.6	0.6	5.3	0.6
1200	1700	0	0.5	<4	0	0.9	0.4	1.3	0.6	3.4	0.6

Table D.1 (continued)

COORDINATE		DEPTH		URANIUM-238		RADIUM-226		THORIUM-232		THORIUM-230	
EAST	NORTH	START	FINISH	pCi/g	ERROR	pCi/g	ERROR	pCi/g	ERROR	pCi/g	ERROR
1200	1750	0	1	<6	0	1.4	0.5	1.7	0.7	1.8	0.3
1200	1750	1	2	5	4	0.9	0.4	1.9	0.6	-a-	-a-
1200	1750	2	3	<8	0	1.1	0.4	2.2	0.8	1.2	0.5
1250	1600	0	0.5	<9	0	2.4	0.5	2.5	0.7	7.8	1.3
1250	1650	0	1	<9	0	1.5	0.5	1.7	0.7	2.4	0.4
1250	1650	1	2	<5	0	1.8	0.5	1.3	0.7	-a-	-a-
1250	1650	2	3	<8	0	1.9	0.5	1.1	0.7	1.3	0.6
1250	1700	0	0.5	<4	0	0.8	0.4	1	0.6	4.2	0.6
1250	1750	0	0.5	<8	0	1	0.4	1.2	0.5	3.6	0.6
1250	1800	0	0.5	<5	0	1	0.4	1.8	0.7	3.6	0.6
1300	1600	0	0.5	<4	0	1.2	0.4	1	0.6	5.3	0.6
1300	1650	0	0.5	<9	0	1.1	0.4	2.5	0.8	3.6	0.4
1300	1700	0	0.5	<4	0	1.5	0.4	1.6	0.5	4.3	0.6
1300	1750	0	1	<9	0	1.6	0.4	1.8	0.8	1.5	0.4
1300	1750	1	2	<6	0	1.6	0.5	1.4	0.7	-a-	-a-
1300	1750	2	3	6	3	1.1	0.4	1.2	0.7	1.2	0.5
1300	1800	0	0.5	<4	0	1.4	0.4	0.8	0.6	3.8	0.6
1350	1600	0	0.5	<8	0	1.4	0.4	2.6	0.8	5.2	1.1
1350	1650	0	1	<7	0	0.9	0.4	2	0.8	1.6	1.2
1350	1650	1	2	<6	0	0.8	0.4	1.5	0.6	-a-	-a-
1350	1650	2	3	<7	0	1.1	0.4	1.3	0.7	1.4	0.8
1350	1700	0	0.5	<8	0	0.9	0.4	1.3	0.6	5.1	1
1350	1750	0	0.5	<4	0	1	0.4	1.3	0.6	4.2	1
1350	1800	0	0.5	7	0	1.2	0.4	2.6	0.7	2.8	0.5
1400	1600	0	0.5	<5	0	1.3	0.4	1.7	0.6	23	2
1400	1650	0	0.5	<4	0	1.7	0.4	1	0.7	5.7	0.6
1400	1700	0	0.5	<7	0	1.6	0.4	1.8	0.7	2.9	0.5

Table D.1 (continued)

COORDINATE		DEPTH		URANIUM-238		RADIUM-226		THORIUM-232		THORIUM-230	
EAST	NORTH	START	FINISH	pCi/g	ERROR	pCi/g	ERROR	pCi/g	ERROR	pCi/g	ERROR
1400	1750	0	1	<8	0	0.9	0.4	1.3	0.7	2.1	1.1
1400	1750	1	2	<7	0	1.2	0.4	1.8	0.6	-a-	-a-
1400	1750	2	3	<7	0	1.1	0.4	2.1	0.7	1	0.8
1400	1800	0	0.5	<4	0	0.8	0.4	1.5	0.6	1.7	0.4
1403	1633	0	1	<11	0	1.6	0.6	3	1	4.1	0.6
1403	1633	4	5	<10	0	1.4	0.5	2	0.8	1.4	0.3
1403	1633	0	10	<8	0	1.6	0.6	1.8	0.9	1.7	0.5
1410	2006	0	1	<9	0	1.7	0.5	1.6	0.7	4.2	0.6
1410	2006	4	5	<8	0	1.4	0.5	1.9	0.8	1.3	0.5
1410	2006	8	8.5	<7	0	1.4	0.4	1.5	0.8	1	0.4
1426	853	0	0.5	3.6	0	0.8	0	0.7	0	0.7	0.5
1426	853	2	4	1.6	1.2	1	0.1	1.3	0.3	0.9	0.5
1426	853	10	12	5.7	0	0.7	0.2	0.6	0.1	0.9	0.5
1450	1600	0	0.5	6	0	1.6	0.4	1.4	0.5	67	2
1450	1650	0	1	<7	0	1.3	0.4	3	1	4.6	2.7
1450	1650	1	2	<6	0	0.9	0.3	1.7	0.5	-a-	-a-
1450	1650	2	3	<6	0	1.3	0.4	1.8	0.6	<1.3	0
1450	1700	0	0.5	5	0	1.1	0.4	0.7	0.7	2.5	0.4
1450	1750	0	0.5	4	0	0.9	0.5	2	0.6	4.2	0.6
1450	1800	0	0.5	7	0	1.1	0.4	1	0.6	2.2	0.5
1450	1850	0	1	<7	0	1.7	0.4	1.6	0.6	1.8	0.8
1450	1850	1	2	<4	0	1.2	0.4	1.5	0.5	-a-	-a-
1450	1850	2	3	<6	0	1	0.4	1.7	0.6	0.9	0.5
1500	1600	0	0.5	18	6	17	1	1.5	0.7	1200	100
1500	1650	0	0.5	4	0	1.3	0.4	1.7	0.6	1.5	0.4
1500	1700	0	0.5	8	0	1.5	0.4	2.4	0.7	5.5	0.7
1500	1750	0	1	<5	0	1	0.4	1.1	0.5	1.9	1.1

Table D.1 (continued)

COORDINATE		DEPTH		URANIUM-238		RADIUM-226		THORIUM-232		THORIUM-230	
EAST	NORTH	START	FINISH	pCi/g	ERROR	pCi/g	ERROR	pCi/g	ERROR	pCi/g	ERROR
1500	1750	1	2	<4	0	1.5	0.4	1.1	0.6	-a-	-a-
1500	1750	2	3	<5	0	1.4	0.5	1.9	0.6	0.6	0.6
1500	1800	0	0.5	4	0	1.4	0.4	0.9	0.6	2.5	0.4
1500	1850	0	0.5	8	0	1	0.5	2	0.6	3.7	1
1550	1600	0	0.5	42	8	43	2	2	1	2300	100
1550	1650	0	0.1	<5	0	1.2	0.4	1.8	0.7	3.5	0.9
1550	1650	1	2	<7	0	1	0.4	2.3	0.7	-a-	-a-
1550	1650	2	3	<4	0	1.1	0.4	1.8	0.6	1.2	0.8
1550	1700	0	0.5	<8	0	2.3	0.5	1.1	0.6	21	1
1550	1750	0	0.5	<5	0	1.1	0.4	1	0.6	6.8	0.7
1550	1800	0	0.5	<7	0	0.8	0.3	1.4	0.7	3.3	0.5
1550	1850	0	1	<4	0	0.9	0.4	1.3	0.6	1.6	0.9
1550	1850	1	2	<6	0	1.1	0.4	2.2	0.6	-a-	-a-
1550	1850	2	3	<3	0	1.4	0.3	1.4	0.5	1	0.6
1550	1900	0	0.5	-a-	-a-	-a-	-a-	-a-	-a-	4	0.5
1550	1900	0.5	1	-a-	-a-	-a-	-a-	-a-	-a-	3.8	1.2
1550	1950	0	0.5	-a-	-a-	-a-	-a-	-a-	-a-	2.5	0.4
1550	1950	0.5	1	-a-	-a-	-a-	-a-	-a-	-a-	1.3	0.3
1550	2000	0	0.5	-a-	-a-	-a-	-a-	-a-	-a-	2.8	0.5
1550	2000	0.5	1	-a-	-a-	-a-	-a-	-a-	-a-	2.8	0.4
1550	2050	0	0.5	-a-	-a-	-a-	-a-	-a-	-a-	2	0.3
1550	2050	0.5	1	-a-	-a-	-a-	-a-	-a-	-a-	1.3	0.4
1550	2100	0	0.5	-a-	-a-	-a-	-a-	-a-	-a-	2.5	0.5
1550	2100	0.5	1	-a-	-a-	-a-	-a-	-a-	-a-	1.4	0.3
1572	1791	0	1	<7	0	1.5	0.8	2	1	4	0.6
1572	1791	4	5	<5	0	1.2	0.4	1.5	0.6	1.8	0.4
1572	1791	0	9	<5	0	1.1	0.5	<1	0	1.4	0.4

Table D.1 (continued)

COORDINATE		DEPTH		URANIUM-238		RADIUM-226		THORIUM-232		THORIUM-230	
EAST	NORTH	START	FINISH	pCi/g	ERROR	pCi/g	ERROR	pCi/g	ERROR	pCi/g	ERROR
1600	1600	0	0.5	10	3	11	1	2	0.9	650	10
1600	1650	0	0.5	<7	0	1.3	0.4	2.1	0.6	4.7	0.5
1600	1700	0	0.5	<5	0	1	0.4	1.6	0.6	8	2
1600	1750	0	1	<4	0	1.1	0.4	1.9	0.6	2.4	0.6
1600	1750	1	2	<7	0	1.1	0.3	2.1	0.6	-a-	-a-
1600	1750	2	3	<4	0	1.1	0.4	0.9	0.5	1.6	0.8
1600	1800	0	0.5	<4	0	1.6	0.4	1.7	0.6	3.6	0.4
1600	1850	0	0.5	5	0	1.3	0.4	2	0.6	6.9	1.4
1613	1613	0	0.5	<27	0	190	10	4	3	-a-	-a-
1650	1700	0	0.5	<5	0	1.1	0.4	1	0.6	10	1
1650	1750	0	0.5	<4	0	1.5	0.4	0.6	0.5	2.8	0.4
1650	1800	0	0.5	<3	0	1.1	0.4	1.3	0.6	13	1
1650	1850	0	1	<7	0	0.8	0.3	1.9	0.6	6	2
1650	1850	1	2	<4	0	1	0.3	1.2	0.5	-a-	-a-
1650	1850	2	3	<4	0	0.6	0.3	0.7	0.5	1.8	0.9
1700	1700	0	0.5	<5	0	1.1	0.4	1.4	0.5	1.7	0.3
1700	1750	0	1	<7	0	2	0.4	1.2	0.6	1.9	0.6
1700	1750	1	2	<4	0	1	0.4	1.7	0.5	-a-	-a-
1700	1750	2	3	<4	0	1.1	0.4	0.9	0.6	1.4	0.9
1700	1800	0	0.5	<4	0	1.2	0.4	2	0.6	10	1
1700	1850	0	0.5	<5	0	1.1	0.4	0.9	0.6	8.4	0.8
1700	1900	0	0.5	<4	0	0.6	0.3	1.2	0.5	9.5	0.8
1750	1700	0	0.5	<8	0	0.7	0.4	1.2	0.7	8.6	0.7
1750	1750	0	0.5	<4	0	0.9	0.4	1.8	0.6	6.5	0.7
1750	1800	0	0.5	<4	0	0.7	0.4	0.9	0.6	8	0.7
1750	1850	0	1	<7	0	1.8	0.5	1.7	0.6	8	2
1750	1850	1	2	<4	0	0.9	0.4	1.6	0.5	-a-	-a-

Table D.1 (continued)

COORDINATE		DEPTH		URANIUM-238		RADIUM-226		THORIUM-232		THORIUM-230	
EAST	NORTH	START	FINISH	pCi/g	ERROR	pCi/g	ERROR	pCi/g	ERROR	pCi/g	ERROR
1750	1850	2	3	<7	0	1.2	0.4	2.2	0.7	3.5	1.2
1750	1900	0	0.5	<8	0	1.4	0.4	1.6	0.7	4.5	0.5
1787	2140	0	1	<6	0	1.2	0.5	1.3	0.7	2.6	0.9
1787	2140	4	5	<5	0	1.4	0.5	1.6	0.7	1.4	0.4
1787	2140	0	11	<6	0	1.9	0.6	3	1	2.5	0.5
1800	1700	0	0.5	<5	0	1.2	0.4	1.2	0.6	9.1	0.7
1800	1750	0	1	<4	0	1.2	0.4	1.3	0.6	5	1
1800	1750	1	2	<7	0	1.8	0.4	2	0.6	-a-	-a-
1800	1750	2	3	<4	0	1.3	0.3	1	0.5	1.6	1.1
1800	1800	0	0.5	<5	0	1.2	0.5	0.7	0.6	17	1
1800	1850	0	0.5	<8	0	2.1	0.5	2.2	0.7	19	1
1800	1900	0	0.5	<4	0	1.6	0.5	0.9	0.7	7.2	0.7
1850	1700	0	0.5	<6	0	1.2	0.5	1.8	0.7	7.5	0.6
1850	1750	0	0.5	<8	0	2.6	0.6	2.5	0.8	11	1
1850	1800	0	0.5	<4	0	1.5	0.4	2.4	0.6	5	0.5
1850	1850	0	1	<11	0	1.1	0.6	2.7	0.9	3.6	2.2
1850	1850	1	2	<7	0	1.4	0.5	2.2	0.9	-a-	-a-
1850	1850	2	3	<5	0	1.8	0.5	1.5	0.8	5.8	4.2
1850	1900	0	0.5	<0.8	0	2	0.5	2.7	0.8	8.4	1
1900	1700	0	0.5	<4	0	1.7	0.5	1.8	0.6	18	1
1900	1800	0	0.5	<4	0	1.2	0.4	1.2	0.6	2	0.4
1900	1850	0	0.5	8	4	1.4	0.4	2.5	0.7	9	1
1900	1900	0	0.5	<4	0	1.1	0.4	1.3	0.6	7.3	1.7
1910	1751	0	0.5	14.9	0	1.3	0.6	1.6	0.4	0.7	0.4
1910	1751	2	4	5.1	0	1.2	0.2	1.3	0.1	6	1.2
1910	1751	10	12	2.4	1.3	1.1	0.1	0.9	0.1	1.4	0.6
1950	1700	0	0.5	5	0	0.7	0.5	1.3	0.6	3	0.5

Table D.1 (continued)

COORDINATE		DEPTH		URANIUM-238		RADIUM-226		THORIUM-232		THORIUM-230	
EAST	NORTH	START	FINISH	pCi/g	ERROR	pCi/g	ERROR	pCi/g	ERROR	pCi/g	ERROR
1950	1750	0	0.5	<7	0	1.6	0.5	-a-	-a-	9	1
1950	1800	0	0.5	<8	0	1.1	0.4	2.5	0.6	2	0.4
1950	1850	0	1	<7	0	1.5	0.6	2.4	0.9	9.1	2.4
1950	1850	1	2	<9	0	1.7	0.5	2.2	0.8	-a-	-a-
1950	1850	2	3	<7	0	0.8	0.6	<1	0	6.1	1.4
1950	1900	0	0.5	<9	0	1.9	0.5	1.9	0.7	8.6	0.9
2000	1700	0	0.5	<6	0	1.4	0.5	1.9	0.7	33	2
2000	1750	0	1	<5	0	1.5	0.6	1.6	0.9	4.6	1.5
2000	1750	1	2	<10	0	1.2	0.5	<1	0	-a-	-a-
2000	1750	2	3	<5	0	0.7	0.5	1.8	0.8	1.9	1.1
2000	1790	0	1	<14	0	2.7	0.8	2	1	13	1
2000	1800	0	0.5	<4	0	1.5	0.4	1.8	0.6	14	2
2000	1850	0	0.5	<5	0	0.9	0.4	1.6	0.6	15	1
2000	1900	0	0.5	<8	0	2	0.5	1.4	0.6	17	1
2000	1950	0	1	<10	0	1.9	0.6	3	1	4.4	2
2000	1950	1	2	<5	0	1.4	0.5	2	0.9	-a-	-a-
2000	1950	2	3	<7	0	1.5	0.6	1.8	0.9	3.7	2.7
2050	1700	0	0.5	<6	0	2.2	0.6	1.3	0.7	52	2
2050	1800	0	0.5	<5	0	1.8	0.5	1.1	0.7	37	2
2050	1850	0	1	<10	0	1.4	0.6	2	0.9	2.8	1.6
2050	1850	1	2	<5	0	1.3	0.5	0.9	0.7	-a-	-a-
2050	1850	2	3	<7	0	1.3	0.6	2	1	2	1.6
2050	1900	0	0.5	<7	0	1.7	0.4	1.2	0.5	25	2
2050	1950	0	0.5	<5	0	1.1	0.4	1.3	0.6	14	1
2100	1700	0	0.5	<6	0	2.4	0.6	1.4	0.8	21	2
2100	1750	0	1	<11	0	2.4	0.7	3	1	18	3
2100	1750	1	2	<6	0	1.2	0.6	1.5	0.8	-a-	-a-

Table D.1 (continued)

COORDINATE		DEPTH		URANIUM-238		RADIUM-226		THORIUM-232		THORIUM-230	
EAST	NORTH	START	FINISH	pCi/g	ERROR	pCi/g	ERROR	pCi/g	ERROR	pCi/g	ERROR
2100	1750	2	3	<11	0	1.8	0.7	3	1	10	4
2100	1800	0	0.5	<9	0	1	0.5	2.6	0.8	28	5
2100	1850	0	0.5	<6	0	1.4	0.5	1.5	0.8	44	2
2100	1900	0	0.5	<8	0	1.3	0.4	2.5	0.8	13	5
2100	2000	0	0.5	<8	0	-a-	-a-	-a-	-a-	12	1
2100	2000	0.5	1	-a-	-a-	-a-	-a-	-a-	-a-	1.2	0.4
2100	2050	0	0.5	-a-	-a-	-a-	-a-	-a-	-a-	6.3	0.6
2100	2050	0.5	1	-a-	-a-	-a-	-a-	-a-	-a-	1.2	0.3
2100	2100	0	0.5	-a-	-a-	-a-	-a-	-a-	-a-	5.7	0.9
2100	2100	0.5	1	-a-	-a-	-a-	-a-	-a-	-a-	1.6	0.3
2100	2150	0	0.5	-a-	-a-	-a-	-a-	-a-	-a-	4.4	0.6
2100	2150	0.5	1	-a-	-a-	-a-	-a-	-a-	-a-	1.5	0.3
2100	2200	0	0.5	-a-	-a-	-a-	-a-	-a-	-a-	2.6	0.6
2100	2200	0.5	1	-a-	-a-	-a-	-a-	-a-	-a-	0.9	0.3
2100	2250	0	0.5	-a-	-a-	-a-	-a-	-a-	-a-	16	1
2100	2250	0.5	1	-a-	-a-	-a-	-a-	-a-	-a-	4.2	0.5
2120	1900	0	1	<8	0	1.3	0.8	2	1	9.3	1
2120	1900	4	5	<4	0	1.3	0.4	2.1	0.9	1.6	0.4
2120	1900	0	9.5	<6	0	1.8	0.6	0.9	0.9	1.5	0.4
2150	1750	0	0.5	<7	0	1.4	0.4	-a-	-a-	17	5
2150	1800	0	0.5	<4	0	1.3	0.4	2	0.6	18	5
2150	1850	0	1	<8	0	1.2	0.6	2.3	0.9	4.3	1.8
2150	1850	1	2	<5	0	1.7	0.6	2	1	-a-	-a-
2150	1850	2	3	<11	0	1.4	0.6	2	0.8	1.1	0.8
2150	1900	0	0.5	<5	0	1.5	0.5	1.7	0.7	26	5
2150	1950	0	0.5	<8	0	1.5	0.4	2.4	0.8	8	2
2200	1700	0	0.5	<6	0	1.7	0.5	1.5	0.8	43	2

Table D.1 (continued)

COORDINATE		DEPTH		URANIUM-238		RADIUM-226		THORIUM-232		THORIUM-230	
EAST	NORTH	START	FINISH	pCi/g	ERROR	pCi/g	ERROR	pCi/g	ERROR	pCi/g	ERROR
2200	1750	0	1	<8	0	1.4	0.6	1.1	0.9	6.7	1.7
2200	1750	1	2	<11	0	2.4	0.6	3	1	-a-	-a-
2200	1750	2	3	<6	0	1.3	0.6	<1	0	3	1.6
2200	1800	0	0.5	<8	0	1.6	0.4	1.7	0.7	10	2
2200	1850	0	0.5	<6	0	1.1	0.5	1.5	0.8	29	3
2200	1900	0	0.5	<5	0	0.7	0.5	1.2	0.7	22	2
2200	1950	0	1	<7	0	1.6	0.7	1.7	0.9	2.5	0.8
2200	1950	1	2	<5	0	1.6	0.6	<1	0	-a-	-a-
2200	1950	2	3	<10	0	1.3	0.5	3	1	2	0.7
2250	1700	0	0.5	<11	0	2.1	0.6	2.3	0.9	29	3
2250	1750	0	0.5	<8	0	1.5	0.4	1.9	0.7	12	3
2250	1850	0	1	<7	0	1.1	0.6	2	1	5.7	1
2250	1850	1	2	<10	0	1.3	0.5	3	1	-a-	-a-
2250	1850	2	3	<6	0	0.9	0.6	1.6	0.8	1.1	1
2250	1900	0	0.5	<5	0	1.7	0.5	-a-	-a-	1.4	0.9
2298	2258	0	1	<9	0	1.4	0.7	1.3	0.9	7.3	1
2298	2258	4	5	<4	0	<1	0	1.6	0.9	1.1	0.4
2298	2258	0	13	<5	0	1.3	0.5	<1	0	1.6	0.5
2300	1650	0	0.5	<6	0	1.3	0.6	1.8	0.7	49	3
2300	1700	0	0.5	<9	0	2	0.5	1.1	0.8	23	3
2300	1750	0	1	<7	0	1.5	0.7	1.7	0.8	3.9	0.8
2300	1750	1	2	<11	0	1.6	0.5	2	1	-a-	-a-
2300	1750	2	3	<6	0	1.4	0.5	1.1	0.7	1.5	0.5
2300	1850	0	0.5	<6	0	2	0.5	1.6	0.8	15	1
2300	1900	0	0.5	<5	0	1.5	0.5	1.8	0.7	1.3	0.6
2312	2261	0	1	<9	0	1.8	0.6	<1	0	5.6	0.8
2312	2261	4	5	<7	0	1.5	0.5	1.2	0.7	1.2	0.3

Table D.1 (continued)

COORDINATE		DEPTH		URANIUM-238		RADIUM-226		THORIUM-232		THORIUM-230	
EAST	NORTH	START	FINISH	pCi/g	ERROR	pCi/g	ERROR	pCi/g	ERROR	pCi/g	ERROR
2312	2261	0	13	<10	0	1.3	0.6	2	0.9	1.1	0.5
2331	1725	0	1	<5	0	1.3	0.6	<1	0	9.5	1.1
2331	1725	4	5	<6	0	0.9	0.6	3	1	13	1
2331	1725	0	8.5	<6	0	1.5	0.6	2	1	1.6	0.4
2350	1650	0	1	<12	0	2.1	0.7	1.4	0.9	4.5	0.8
2350	1650	1	2	<7	0	1.2	0.7	1.9	0.9	-a-	-a-
2350	1650	2	3	<12	0	2.4	0.7	3	1	4.2	0.8
2350	1700	0	0.5	<8	0	1	0.4	2.6	0.8	43	2
2350	1750	0	0.5	<5	0	1.5	0.4	0.8	0.6	14	1
2350	1800	0	0.5	<8	0	1.6	0.5	1.5	0.6	6.5	0.7
2350	1850	0	1	<9	0	1	0.6	1.5	0.8	1.1	0.7
2350	1850	1	2	<5	0	1.2	0.5	1.5	0.9	-a-	-a-
2350	1850	2	3	<8	0	1.8	0.7	2	1	1.6	0.6
2350	1900	0	0.5	<6	0	1.3	0.5	1.3	0.8	5.1	1.5
2400	1600	0	0.5	6	0	2.6	0.6	2.1	0.8	76	3
2400	1650	0	0.5	<6	0	1.7	0.6	2	0.8	9	1
2400	1700	0	0.5	<5	0	1.3	0.4	1.6	0.6	38	2
2400	1800	0	0.5	<8	0	1.2	0.4	1	0.7	15	2
2400	1850	0	0.5	<5	0	1.5	0.5	1.2	0.6	0.9	0.6
2400	1850	0.5	1	<5	0	1.1	0.5	<1	0	1.3	0.8
2400	1850	1	2	<6	0	1.6	0.5	2	1	-a-	-a-
2400	1850	2	3	<5	0	1.4	0.6	0.9	0.8	2.3	0.8
2450	1600	0	0.5	<6	0	1.2	0.5	1.7	0.7	14	2
2450	1650	0	1	<8	0	1.5	0.6	1.3	0.8	2.8	0.8
2450	1650	1	2	<6	0	<1	0	1.7	0.9	-a-	-a-
2450	1650	2	3	<7	0	1.2	0.5	1.5	0.9	1.6	0.5
2450	1700	0	0.5	<9	0	2	0.6	3	1	45	2

Table D.1 (continued)

COORDINATE		DEPTH		URANIUM-238		RADIUM-226		THORIUM-232		THORIUM-230	
EAST	NORTH	START	FINISH	pCi/g	ERROR	pCi/g	ERROR	pCi/g	ERROR	pCi/g	ERROR
2450	1750	0	0.5	<5	0	1.1	0.4	1.1	0.5	8	1
2450	1800	0	0.5	<5	0	1.1	0.4	<1	0	7	1
2450	1850	0	1	<6	0	1.3	0.7	2	1	2.7	0.7
2450	1850	1	2	<10	0	1.4	0.6	1.3	0.9	1.4	0.4
2450	1850	2	3	<9	0	3	1	3	1	2.1	0.6
2500	1550	0	0.5	6	5	2.9	0.7	2.5	0.8	81	5
2500	1600	0	0.5	<8	0	2	0.5	1.7	0.6	21	3
2500	1650	0	0.5	<9	0	1.3	0.4	2.5	0.9	1	0.5
2500	1700	0	0.5	<6	0	1.4	0.5	1.9	0.8	2	0.5
2500	1750	0	1	<6	0	1.1	0.6	2	1	2.1	0.7
2500	1750	1	2	<9	0	1.4	0.8	2	1	-a-	-a-
2500	1750	2	3	<5	0	1.4	0.6	1.5	0.9	1.4	0.5
2500	1800	0	0.5	<5	0	1.8	0.5	1.7	0.6	3.3	1.2
2523	1550	0	0.5	<5	0	1.8	0.5	1.7	0.6	20	2
2523	1550	0.5	1	-a-	-a-	-a-	-a-	-a-	-a-	3.6	0.5
2530	1520	0	0.5	-a-	-a-	-a-	-a-	-a-	-a-	31	2
2530	1520	0.5	1	-a-	-a-	-a-	-a-	-a-	-a-	31	2
2531	1600	0	0.5	-a-	-a-	-a-	-a-	-a-	-a-	30	2
2531	1600	0.5	1	-a-	-a-	-a-	-a-	-a-	-a-	10	1
2538	1650	0	0.5	-a-	-a-	-a-	-a-	-a-	-a-	18	1
2538	1650	0.5	1	-a-	-a-	-a-	-a-	-a-	-a-	1.5	0.4
2542	1700	0	0.5	-a-	-a-	-a-	-a-	-a-	-a-	21	1
2542	1700	0.5	1	-a-	-a-	-a-	-a-	-a-	-a-	4.1	1
2545	1800	0	0.5	-a-	-a-	-a-	-a-	-a-	-a-	5.5	0.5
2545	1800	0.5	1	-a-	-a-	-a-	-a-	-a-	-a-	16	1
2550	1650	0	1	<9	0	1.7	0.8	4	1	11	1
2550	1650	1	2	<7	0	1.3	0.7	2	1	-a-	-a-

Table D.1 (continued)

COORDINATE		DEPTH		URANIUM-238		RADIUM-226		THORIUM-232		THORIUM-230	
EAST	NORTH	START	FINISH	pCi/g	ERROR	pCi/g	ERROR	pCi/g	ERROR	pCi/g	ERROR
3000	1350	1	2	<12	0	1.8	0.6	3	1	-a-	-a-
3000	1350	2	3	<6	0	1.3	0.7	2	1	2.7	2.3
3000	1400	0	0.5	<5	0	1.3	0.4	0.8	0.7	8	2
3000	1450	0	0.5	<8	0	1.4	0.4	1	0.6	6	2
3000	1500	0	0.5	<5	0	1.2	0.5	1.3	0.7	4.8	0.8
3000	1550	0	1	<7	0	0.8	0.7	3	1	1.6	0.5
3000	1550	1	2	<13	0	2.4	0.8	5	1	-a-	-a-
3000	1550	2	3	<7	0	1.8	0.7	2	1	1.2	0.9
3000	1600	0	0.5	<5	0	1.7	0.5	1	0.7	7	1
3000	1800	0	0.5	<5	0	0.9	0.4	1.4	0.8	7.9	0.7
3000	2000	0	0.5	<5	0	1.1	0.4	<1	0	2.9	0.5
3000	2200	0	0.5	<7	0	1.6	0.6	2	1	1	0.3
3033	2234	0	0.5	<6	0	0.6	0.4	1	0.8	1.3	0.6
3050	1300	0	0.5	<8	0	1.8	0.5	1.3	0.6	60	3
3050	1350	0	0.5	<4	0	1.1	0.4	2	0.6	4.5	0.7
3050	1400	0	0.5	<6	0	1.4	0.5	2.4	0.8	4.6	0.6
3050	1450	0	1	<7	0	1.3	0.7	1.3	0.8	3.2	1.9
3050	1450	1	2	<15	0	2	0.8	3	1	-a-	-a-
3050	1450	2	3	<7	0	0.8	0.7	2	1	1.3	1.1
3050	1500	0	0.5	12	4	1.7	0.5	2.6	0.9	4.7	0.7
3050	1550	0	0.5	<5	0	1	0.5	2	0.7	2	1
3050	1600	0	0.5	18	4	2.1	0.5	2	0.8	2.4	1.2
3065	1783	0	0.5	<5	0	1.1	0.5	1.8	0.8	2.1	0.7
3080	1843	0	0.5	<9	0	1.1	0.6	1.6	0.7	1.3	0.6
3093	2401	0	1	<11	0	0.9	0.5	3	1	3.1	0.6
3093	2401	4	5	<11	0	1.4	0.6	2	1	1.5	0.4
3093	2401	8	8.5	<7	0	1.5	0.5	3	1	1.2	0.4

Table D.1 (continued)

COORDINATE		DEPTH		URANIUM-238		RADIUM-226		THORIUM-232		THORIUM-230	
EAST	NORTH	START	FINISH	pCi/g	ERROR	pCi/g	ERROR	pCi/g	ERROR	pCi/g	ERROR
3100	1300	0	0.5	<7	0	1.8	0.6	2.1	0.7	14	1
3100	1350	0	1	<14	0	2.6	0.8	5	1	4.2	1
3100	1350	1	2	<8	0	1.7	0.9	1.2	1	-a-	-a-
3100	1350	2	3	<7	0	1.4	0.8	1.2	<1	1	0
3100	1400	0	0.5	<9	0	1.7	0.5	1.7	0.8	1.7	1
3100	1450	0	0.5	<6	0	1.9	0.6	1.9	0.7	8	2
3100	1500	0	0.5	<10	0	1	0.5	4	1	5	1
3100	1550	0	1	<14	0	2.5	0.9	<1	0	1.2	0.9
3100	1550	1	2	<7	0	0.9	0.6	<1	0	-a-	-a-
3100	1550	2	3	<14	0	1.5	0.6	3	1	1.2	0.6
3100	1800	0	0.5	<5	0	1.7	0.5	1.9	0.7	1.8	0.4
3100	2200	0	0.5	<7	0	2.1	0.7	3	1	2	0.4
3112	2000	0	0.5	<9	0	<0.5	0	3	1	1.8	0.4
3119	1771	0	0.5	<8	0	1.2	0.5	3	1	3.4	0.9
3140	1828	0	0.5	<9	0	1.4	0.5	2	0.9	1.7	0.6
3150	1300	0	0.5	<6	0	1.9	0.5	1.1	0.7	10	2
3150	1350	0	0.5	<5	0	0.8	0.4	1.3	0.6	2.5	0.5
3150	1400	0	0.5	<9	0	1.3	0.5	1.9	0.9	4.2	0.5
3150	1450	0	1	<8	0	1.4	0.7	2	1	2.4	1
3150	1450	1	2	<7	0	2	0.7	<1	0	-a-	-a-
3150	1450	2	3	<14	0	2	0.7	3	1	1.1	0.9
3150	1500	0	0.5	<6	0	1.7	0.5	0.9	0.7	7.2	0.9
3150	1550	0	0.5	<5	0	1.7	0.5	1.2	0.8	6.1	0.7
3150	1600	0	0.5	-a-	-a-	-a-	-a-	-a-	-a-	3.3	0.5
3150	1600	0.5	1	-a-	-a-	-a-	-a-	-a-	-a-	1.1	0.3
3150	1650	0	0.5	-a-	-a-	-a-	-a-	-a-	-a-	2.9	0.4
3150	1650	0.5	1	-a-	-a-	-a-	-a-	-a-	-a-	1.4	0.3

Table D.1 (continued)

COORDINATE		DEPTH		URANIUM-238		RADIUM-226		THORIUM-232		THORIUM-230	
EAST	NORTH	START	FINISH	pCi/g	ERROR	pCi/g	ERROR	pCi/g	ERROR	pCi/g	ERROR
3150	1700	0	0.5	-a-	-a-	-a-	-a-	-a-	-a-	5.9	0.5
3150	1700	0.5	1	-a-	-a-	-a-	-a-	-a-	-a-	1.2	0.3
3150	1750	0	0.5	-a-	-a-	-a-	-a-	-a-	-a-	1.6	0.3
3150	1750	0.5	1	-a-	-a-	-a-	-a-	-a-	-a-	1.2	0.3
3150	1800	0	0.5	-a-	-a-	-a-	-a-	-a-	-a-	1	0.2
3150	1800	0.5	1	-a-	-a-	-a-	-a-	-a-	-a-	1.6	0.3
3150	1850	0	0.5	-a-	-a-	-a-	-a-	-a-	-a-	1.5	0.3
3150	1850	0.5	1	-a-	-a-	-a-	-a-	-a-	-a-	1.4	0.3
3150	1900	0	0.5	-a-	-a-	-a-	-a-	-a-	-a-	1.9	0.3
3150	1900	0.5	1	-a-	-a-	-a-	-a-	-a-	-a-	1.3	0.3
3150	1950	0	0.5	-a-	-a-	-a-	-a-	-a-	-a-	1.4	0.3
3150	1950	0.5	1	-a-	-a-	-a-	-a-	-a-	-a-	1.1	0.3
3150	2000	0	0.5	-a-	-a-	-a-	-a-	-a-	-a-	2	0.3
3150	2000	0.5	1	-a-	-a-	-a-	-a-	-a-	-a-	1.2	0.2
3150	2050	0	0.5	-a-	-a-	-a-	-a-	-a-	-a-	2.7	0.3
3150	2050	0.5	1	-a-	-a-	-a-	-a-	-a-	-a-	1.5	0.3
3150	2150	0	0.5	-a-	-a-	-a-	-a-	-a-	-a-	1.4	0.3
3150	2150	0.5	1	-a-	-a-	-a-	-a-	-a-	-a-	3.4	0.6
3150	2200	0	0.5	-a-	-a-	-a-	-a-	-a-	-a-	1.1	0.3
3150	2200	0.5	1	-a-	-a-	-a-	-a-	-a-	-a-	1	0.3
3150	2250	0	0.5	-a-	-a-	-a-	-a-	-a-	-a-	1.1	0.3
3150	2250	0.5	1	-a-	-a-	-a-	-a-	-a-	-a-	1.2	0.3
3150	2300	0	0.5	-a-	-a-	-a-	-a-	-a-	-a-	2	0.5
3150	2300	0.5	1	-a-	-a-	-a-	-a-	-a-	-a-	1.2	0.3
3150	2350	0	0.5	-a-	-a-	-a-	-a-	-a-	-a-	2.9	0.4
3150	2350	0.5	1	-a-	-a-	-a-	-a-	-a-	-a-	1.7	0.3
3150	2400	0	0.5	-a-	-a-	-a-	-a-	-a-	-a-	2.7	0.5

Table D.1 (continued)

COORDINATE		DEPTH		URANIUM-238		RADIUM-226		THORIUM-232		THORIUM-230	
EAST	NORTH	START	FINISH	pCi/g	ERROR	pCi/g	ERROR	pCi/g	ERROR	pCi/g	ERROR
3150	2400	0.5	1	-a-	-a-	-a-	-a-	-a-	-a-	1.4	0.5
3150	2450	0	0.5	-a-	-a-	-a-	-a-	-a-	-a-	1.6	0.3
3150	2450	0.5	1	-a-	-a-	-a-	-a-	-a-	-a-	1.9	0.3
3150	2500	0	0.5	-a-	-a-	-a-	-a-	-a-	-a-	1.3	0.3
3150	2500	0.5	1	-a-	-a-	-a-	-a-	-a-	-a-	1	0.3
3150	2550	0	0.5	-a-	-a-	-a-	-a-	-a-	-a-	1.2	0.5
3150	2550	0.5	1	-a-	-a-	-a-	-a-	-a-	-a-	1.1	0.4
3150	2600	0	0.5	-a-	-a-	-a-	-a-	-a-	-a-	1.4	0.3
3150	2600	0.5	1	-a-	-a-	-a-	-a-	-a-	-a-	1.5	0.3
3150	2650	0	0.5	-a-	-a-	-a-	-a-	-a-	-a-	1.4	0.3
3150	2650	0.5	1	-a-	-a-	-a-	-a-	-a-	-a-	1.2	0.3
3150	2700	0	0.5	-a-	-a-	-a-	-a-	-a-	-a-	1.3	0.3
3150	2700	0.5	1	-a-	-a-	-a-	-a-	-a-	-a-	1.5	0.3
3154	2243	0	0.5	<6	0	1.7	0.5	2.2	0.8	1.3	0.5
3199	1414	0	1	<11	0	1.1	0.5	2.3	0.8	2.2	0.9
3199	1414	4	5	<8	0	1.4	0.6	1.1	0.9	1.9	0.7
3199	1414	0	9	<10	0	1.5	0.6	1.8	0.6	1.4	0.4
3200	1250	0	0.5	<10	0	2	0.6	1.7	0.7	49	2
3200	1300	0	0.5	<6	0	1.8	0.5	1.5	0.8	2.7	0.5
3200	1350	0	1	<8	0	1.3	0.7	3	1	3.1	0.9
3200	1350	1	2	<4	0	1.1	0.4	1.9	0.6	-a-	-a-
3200	1350	2	3	<14	0	2.9	0.9	4	1	1.5	0.7
3200	1400	0	0.5	<9	0	0.8	0.5	1.2	0.7	3.4	0.6
3200	1450	0	0.5	<9	0	1.4	0.5	2	1	3.8	0.6
3200	1500	0	0.5	<5	0	1.3	0.5	1.2	0.7	3.9	0.5
3200	1550	0	1	<6	0	1.7	0.7	2	1	8.3	1.5
3200	1550	1	2	<12	0	1.3	0.6	2	1	-a-	-a-

Table D.1 (continued)

COORDINATE		DEPTH		URANIUM-238		RADIUM-226		THORIUM-232		THORIUM-230	
EAST	NORTH	START	FINISH	pCi/g	ERROR	pCi/g	ERROR	pCi/g	ERROR	pCi/g	ERROR
3200	1550	2	3	<7	0	1.1	0.6	2	1	3.5	1.6
3200	1800	0	0.5	<9	0	1.5	0.5	3	1	2.2	0.4
3200	2000	0	0.5	<12	0	1.9	0.7	2	1	1.8	0.4
3200	2081	0	1	<11	0	1.7	0.6	2	1	1.6	0.7
3200	2081	4	5	<6	0	1.2	0.6	1.1	0.8	1.4	0.3
3200	2200	0	0.5	<6	0	1.2	0.5	1.9	0.8	0.7	0.2
3205	2235	0	0.5	<5	0	1.5	0.5	0.9	0.7	1.2	0.3
3209	2277	0	0.5	<6	0	0.5	0.5	1.3	0.7	1.6	0.4
3240	2231	0	0.5	<6	0	1.3	0.5	2	1	1.8	0.3
3250	1250	0	1	<8	0	1.7	0.4	2.5	0.7	4.7	0.8
3250	1250	1	2	<9	0	2.4	0.5	3	1	-a-	-a-
3250	1250	2	3	<5	0	1	0.4	1.6	0.6	2.5	0.6
3250	1300	0	0.5	<7	0	1	0.4	1.8	0.6	11	1
3250	1350	0	0.5	<5	0	1.2	0.5	1.8	0.7	8	1
3250	1400	0	0.5	<9	0	1.2	0.5	1.3	0.7	7.5	0.7
3250	1450	0	1	<5	0	1.9	0.5	1.6	0.8	7	1
3250	1450	1	2	<9	0	1.3	0.5	2.3	0.9	7	1
3250	1450	2	3	<6	0	0.9	0.6	1	0.8	2.6	0.5
3250	1500	0	0.5	<7	0	1.8	0.6	1.3	0.8	5.7	0.8
3300	1250	0	0.5	<5	0	1.1	0.5	1.9	0.6	6.6	0.8
3300	1300	0	0.5	<8	0	2	0.5	1.6	0.6	10	1
3300	1350	0	1	<9	0	1.7	0.5	2.3	0.9	1.9	0.3
3300	1350	1	2	<7	0	1.1	0.5	1.6	0.8	-a-	-a-
3300	1350	2	3	<5	0	2.7	0.5	1	0.8	1	0.4
3300	1400	0	0.5	<6	0	1.3	0.5	1.3	0.7	5	0.7
3300	1450	0	0.5	<10	0	1	0.6	1.8	0.7	8	1
3300	1500	0	0.5	<8	0	1.6	0.4	2.1	0.7	4	0.8

Table D.1 (continued)

COORDINATE		DEPTH		URANIUM-238		RADIUM-226		THORIUM-232		THORIUM-230	
EAST	NORTH	START	FINISH	pCi/g	ERROR	pCi/g	ERROR	pCi/g	ERROR	pCi/g	ERROR
3400	1800	0	0.5	<5	0	0.8	0.5	1.3	0.6	5.2	0.6
3400	2000	0	0.5	<11	0	2.4	0.7	2	1	3.6	0.6
3400	2200	0	0.5	<7	0	1.5	0.6	2	1	2.6	0.4
3450	1150	0	0.5	<4	0	1.4	0.5	1.4	0.7	16	2
3450	1200	0	0.5	<6	0	1.3	0.5	1.4	0.6	1	0.3
3450	1250	0	1	<5	0	1.5	0.5	<1	0	0.9	0.4
3450	1250	1	2	<8	0	1.2	0.5	1	0.6	-a-	-a-
3450	1250	2	3	<5	0	1	0.4	1.9	0.7	1.9	0.7
3450	1300	0	0.5	<4	0	1.7	0.5	1.9	0.6	1.4	0.5
3450	1350	0	0.5	<8	0	1.2	0.4	1.2	0.7	0.9	0.4
3450	1400	0	0.5	<5	0	1.2	0.4	2.3	0.7	1	0.7
3500	1106	0	0.5	<6	0	1.6	0.6	1.7	0.7	17	2
3500	1150	0	1	<5	0	1.3	0.5	2	0.8	7	1
3500	1150	1	2	<6	0	1.6	0.5	1.6	0.7	-a-	-a-
3500	1150	2	3	<11	0	1.8	0.6	2.2	0.9	3.6	1.3
3500	1200	0	0.5	<11	0	1.6	0.6	2.3	0.9	2.2	0.6
3500	1250	0	0.5	<5	0	1	0.5	1.7	0.7	<0.1	0
3500	1300	0	0.5	<9	0	1.2	0.6	1.6	0.8	8.7	0.9
3500	1350	0	1	<5	0	1.6	0.5	1.7	0.7	0.9	0.4
3500	1350	2	3	<9	0	0.9	0.5	1.9	0.9	5.5	1.6
3500	1400	0	0.5	<12	0	2	0.8	2.6	0.9	0.9	0.5
3500	1500	0	0.5	<11	0	1.9	0.6	3	1	1.5	0.6
3500	1600	0	0.5	<5	0	1.3	0.6	1	0.9	1.8	0.6
3500	1700	0	0.5	<6	0	1.4	0.6	2	1	16	1
3500	1800	0	0.5	<9	0	1.5	0.5	1.7	0.8	3	1
3500	1900	0	0.5	<11	0	2.1	0.6	-a-	-a-	3.9	0.8
3500	2000	0	0.5	<6	0	2.2	0.6	1.3	0.8	1.2	0.6

Table D.1 (continued)

COORDINATE		DEPTH		URANIUM-238		RADIUM-226		THORIUM-232		THORIUM-230	
EAST	NORTH	START	FINISH	pCi/g	ERROR	pCi/g	ERROR	pCi/g	ERROR	pCi/g	ERROR
3300	1699	0	1	<5	0	1.4	0.6	1.6	0.8	5.9	0.7
3300	1699	4	5	<6	0	1.3	0.5	2	1	2.5	0.5
3300	1699	0	8	<4	0	1.2	0.5	1.1	0.6	2.2	0.4
3300	1800	0	0.5	<6	0	1.1	0.5	2.3	0.7	3.4	0.5
3300	2000	0	0.5	<7	0	1.6	0.6	2	1	2.1	0.4
3300	2200	0	0.5	<6	0	1	0.5	1.8	0.9	2.3	0.5
3303	804	0	0.5	2.8	0	1.1	0.1	0.6	0	0.4	0.4
3303	804	2	4	1.2	0.9	1	0.2	1.2	0.4	0.8	0.5
3303	804	10	12	3.1	0	0.8	0.2	1	0.3	0.5	0.4
3350	1200	0	0.5	<8	0	1.1	0.5	1.4	0.6	3.9	0.6
3350	1250	0	1	<9	0	1.6	0.5	2.1	0.8	1.5	0.8
3350	1250	1	2	<5	0	1.4	0.5	1.1	0.8	-a-	-a-
3350	1250	2	3	<9	0	1.6	0.5	4	1	3.6	0.6
3350	1300	0	0.5	<6	0	1.5	0.4	1.1	0.6	1.3	0.4
3350	1350	0	0.5	<4	0	1.5	0.5	1.6	0.7	1.1	0.3
3350	1400	0	0.5	<6	0	1.1	0.4	1.6	0.7	1	0.3
3350	1450	0	1	<5	0	2.1	0.5	1.8	0.8	2.2	0.4
3350	1450	1	2	<7	0	2.8	0.8	1.3	0.7	-a-	-a-
3350	1450	2	3	<8	0	1.3	0.5	1.5	0.8	1.2	0.3
3400	1200	0	0.5	<7	0	1.4	0.5	2	0.7	1.9	0.5
3400	1250	0	0.5	<8	0	1	0.4	1.9	0.7	1.4	0.3
3400	1300	0	0.5	<5	0	1.3	0.5	1.5	0.7	1.1	0.3
3400	1350	0	1	<8	0	1.3	0.5	1.5	0.8	1.2	0.3
3400	1350	1	2	<9	0	1.5	0.5	2.4	0.9	-a-	-a-
3400	1350	2	3	<5	0	1.5	0.5	1.4	0.7	2.3	0.6
3400	1400	0	0.5	<6	0	1.3	0.5	1.5	0.6	1.2	0.3
3400	1450	0	0.5	<7	0	1.3	0.4	1.3	0.6	1.1	0.2

Table D.1 (continued)

COORDINATE		DEPTH		URANIUM-238		RADIUM-226		THORIUM-232		THORIUM-230	
EAST	NORTH	START	FINISH	pCi/g	ERROR	pCi/g	ERROR	pCi/g	ERROR	pCi/g	ERROR
3500	2100	0	0.5	<12	0	1.6	0.6	2	0.9	2.9	0.5
3500	2200	0	0.5	<9	0	1.2	0.6	3	1	2.6	0.4
3500	2300	0	0.5	<12	0	1.5	0.6	<2	0	2.3	0.4
3500	2400	0	0.5	<6	0	1.6	0.6	1.7	0.8	2.5	0.6
3500	2500	0	0.5	<7	0	1.3	0.6	1.4	0.8	1.5	0.6
3500	2600	0	0.5	<13	0	1.7	0.7	<1	0	2.1	0.6
3500	2700	0	0.5	<7	0	1.9	0.6	1.6	0.8	1.8	0.7
3500	2800	0	0.5	<11	0	1.8	0.5	4	1	0.8	0.5
3500	2900	0	0.5	<8	0	1.2	0.4	<1	0	1.8	0.7
3500	3035	0	0.5	<9	0	2	0.6	<1	0	2.8	0.5
3500	3100	0	0.5	<7	0	1.7	0.5	1.7	0.7	1.2	0.3
3530	1211	0	0.5	<3.6	2.7	0.9	0.2	0.9	0	0.5	0.5
3530	1211	4	6	2	1.7	0.9	0.1	1.4	0.4	1	0.6
3530	1211	10	12	10.2	0	1.1	0.1	1.2	0.4	1.3	0.6
3550	1100	0	0.5	<5	0	2.1	0.5	1.1	0.7	29	2
3550	1150	0	0.5	<7	0	1.1	0.5	1.3	0.7	12	1
3550	1200	0	0.5	<10	0	1.7	0.6	2.1	0.8	14	1
3550	1250	0	1	<4	0	1.4	0.4	1.7	0.7	6.2	0.9
3550	1250	1	2	<9	0	1.6	0.5	2.1	0.8	-a-	-a-
3550	1250	2	3	<6	0	1.3	0.5	1.1	0.8	4.5	2.1
3550	1300	0	0.5	<9	0	1	0.5	4	1	1.5	0.3
3550	1350	0	0.5	<4	0	1.5	0.4	1.2	0.6	0.6	0.4
3550	1400	0	0.5	<6	0	1.7	0.4	1.9	0.7	1	0.4
3595	1403	0	1	<11	0	0.9	0.5	3	1	1.3	0.3
3595	1403	4	5	<8	0	1.6	0.6	1.8	0.8	1.5	0.4
3595	1403	0	9	<8	0	1.2	0.5	1.3	0.8	1.7	0.3
3600	1100	0	0.5	<7	0	1.4	0.7	1.2	0.8	-a-	-a-

Table D.1 (continued)

COORDINATE		DEPTH		URANIUM-238		RADIUM-226		THORIUM-232		THORIUM-230	
EAST	NORTH	START	FINISH	pCi/g	ERROR	pCi/g	ERROR	pCi/g	ERROR	pCi/g	ERROR
3600	1150	0	0.5	<8	0	1.7	0.5	1.5	0.6	36	2
3600	1150	0.5	1	<5	0	1.5	0.5	2.1	0.7	9	2
3600	1150	1	2	<10	0	2.3	0.6	4	1	-a-	-a-
3600	1150	2	3	<6	0	0.8	0.5	0.9	0.7	2.5	0.8
3600	1200	0	0.5	<4	0	1.5	0.5	1.5	0.6	13	2
3600	1250	0	0.5	<6	0	1.2	0.4	1.6	0.6	1.6	0.3
3600	1300	0	0.5	<9	0	0.8	0.5	2	0.7	1.4	0.5
3600	1350	0	1	<4	0	1.5	0.5	1.4	0.6	4.4	0.9
3600	1350	1	2	<8	0	1.5	0.5	1.9	0.8	-a-	-a-
3600	1350	2	3	<5	0	1.8	0.5	1.1	0.7	1.1	0.5
3600	1800	0	0.5	<9	0	1.6	0.5	1.6	0.7	6	1
3600	2000	0	0.5	<7	0	<0.5	0	0.7	0.7	1.7	0.3
3600	2200	0	0.5	<8	0	1.4	0.6	1	1	4.2	0.6
3605	2408	0	1	<4	0	1.3	0.6	1.5	0.8	1.4	0.3
3605	2408	4	5	<10	0	1.1	0.5	3	1	1.1	0.3
3605	2408	8	8.5	<8	0	1.3	0.5	0.9	0.6	1.4	0.3
3609	1100	0	0.5	<11	0	1.4	0.7	2	1	17	2
3617	1674	0	1	<5	0	1	0.5	4	1	10	1
3617	1674	4	5	<6	0	1.4	0.5	1.5	0.7	2	0.6
3617	1674	5.5	5.5	<6	0	1.1	0.5	1.9	0.8	1.4	0.4
3626	1300	0	0.5	<6	0	1.6	0.6	1.3	0.8	14	1
3643	1500	0	0.5	<6	0	1.4	0.7	1.6	0.8	11	1
3660	1700	0	0.5	<10	0	2.1	0.6	1.3	0.8	12	1
3665	1800	0	0.5	<6	0	1.4	0.6	1.3	0.8	15	1
3674	1900	0	0.5	<8	0	2.1	0.8	1.9	0.9	120	10
3676	2000	0	0.5	<9	0	2.4	0.6	1.8	0.8	44	2
3683	2100	0	0.5	<12	0	2.3	0.7	3	1	28	2

Table D.1 (continued)

COORDINATE		DEPTH		URANIUM-238		RADIUM-226		THORIUM-232		THORIUM-230	
EAST	NORTH	START	FINISH	pCi/g	ERROR	pCi/g	ERROR	pCi/g	ERROR	pCi/g	ERROR
3691	2200	0	0.5	<9	0	1.6	0.7	2.1	0.9	65	2
3697	2300	0	0.5	<11	0	1.4	0.8	2	1	33	1
3709	2500	0	0.5	<10	0	2.1	0.7	3	1	4.5	0.6
3722	2700	0	0.5	<11	0	3.1	0.7	1.8	0.9	3.9	1.1
2800	1500	0	0.5	<9	0	2	0.5	2.4	0.8	15	1
2800	1550	0	1	<6	0	0.9	0.6	1.2	0.9	7	0.9
3729	2850	0	0.5	<11	0	1.5	0.6	2.3	0.9	13	1

a- values not requested

Source: U.S. Department of Energy. *Remedial Investigation Addendum for the St. Louis Site.* DOE/OR/21950-132, Comment Resolution Draft. Oak Ridge, Tennessee: Formerly Utilized Sites Remedial Action Program, September 1994.

Table D.2 RESRAD Input Data for SLAPS

Section	Parameter	Value/Range	Reference	Notes
R011	Contaminated Zone Area [m^2]	Area of SLAPS, 8.8 hectacres-88,000 m^2 Area of Ballfields, 32.4 hectacres-324,000 m^2. Total of 412,000 m^2.	p. 1 Site Suitability Study (Feb 94).	Treat SLAPS and Ballfield as one site
	Contaminated Zone Thickness [m]	0.05 to 5.5 meters avg. 1.2 to 2.4 meters use. 1.2 meters	p. 2-10 B.R.A. (Nov.93)	Tab 5 Remedial Investigation Report (Sep 94)
	Length Parallel to Aquifer Flow [m]	approx 455 meters	p. 2-83 F.S., Fig. 2-23	shows groundwater flow gradient toward Coldwater Creek, distance est. from dwg.
	Basic Radiation Dose Limit [mR/yr]	100 mRem/yr	p. 3-10 F.S. Table 3-1 p. 2-3 B.R.A. (Nov 93)	per DOE Order 5400.5
	Time Since Material Placement	29 - 49 years Use 49 years	p. 1 Site Suitability Study (Feb 94)	MED acquired the site in 1946 and stored residures at the site until 1966.
R012	Initial U-238 Soil Concentration	0 to 1600 pCi/g Use 9.83 pCi/g	p. 2-11 and 2-33 B.R.A., Table 2.3 (Nov. 93)	MDA 5 pCi/g calculated weighted avg
	Initial Ra-226 Soil Concentration	<0.3 to 5620 pCi/g Use 4.85 pCi/g	p. 2-11 and 2-33 B.R.A.Table 2.3 (Nov. 93)	MDA 0.5 pCi/g calculated weighted avg

Table D.2 (continued)

Section	Parameter	Value/Range	Reference	Notes
	Initial Th-230 Soil Concentration	0.0 to 15000 pCi/g Use 13.41 pCi/g	p. 2-11 and 2-33 B.R.A.Table 2.3 (Nov. 93)	MDA 0.5 pCi/g calculated weighted avg
	Initial Th-232 Soil Concentration	<0.4 to 63 pCi/g Use 1.05 pCi/g	p. 2-11 and 2-33 B.R.A.Table 2.3 (Nov. 93)	MDA 0.5 pCi/g calculated weighted avg
	Initial Total Uranium Concentration in Groundwater [pCi/liter]	<3 to 8700 Use 1 pCi/liter	p. 2-38 Table 2.5 B.R.A. (Nov 93)	
	Initial Ra-226 Concentration in Groundwate0r [pCi/liter]	<0.1 to 4.0 Use 1 pCi/liter	p. 2-38 Table 2.5 B.R.A. (Nov 93)	
	Initial Th-230 Concentration in Groundwater [pCi/liter]	<0.1 to 130 Use 1 pCi/liter	p. 2-38 Table 2.5 B.R.A. (Nov 93)	
R013	Cover Depth [m]	0.0 - 4.3 use 0:0 meters	p. 2-24 F.S.	p. 2-25 F.S. Figure 2-10 shows soil geology for SLAPS area.
	Density of Cover Material [g/cm3]	1.8	Standard Value	
	Cover Erosion Rate [m/yr]	0.0		p. 71 RESRAD manual
	Contaminated Zone Density [g/cm^3]	1.8	Standard Value	

Table D.2 (continued)

Section	Parameter	Value/Range	Reference	Notes
	Contaminated Zone Erosion Rate [m/yr]	0.001 Use 0.0	RESRAD Default	p. 71 RESRAD manual
	Contaminated Zone Total Porosity	0.43	RESRAD manual Table E.7	Silt 0.45, range (0.34 - 0.51) Clay 0.42, range (0.34 - 0.57)
	Contaminated Zone Effective Porosity	0.10	RESRAD manual Table E.7	Silt 0.20 range (0.01 - 0.39) Clay 0.06 range (0.01 - 0.18)
	Contaminated Zone Hydraulic Conductivity[m/yr]	53.6	RESRAD manual Appendix E, Table E.2	Used Silty Clay Loam
	Contaminated Zone B Parameter	7.75	RESRAD manual, Appendix E, Table E.2	Used Silty Clay Loam
	Evapotranspiration Coefficient	0.75	p. 101 Site Suitability Study (Feb 94)	RESRAD manual, Appendix E.
	Precipitation [m/yr]	avg. 0.955 m/yr 0.5559 to 1.397 m/yr	p. 100 Site Suitability Study (Feb 94)	using records over 27 year period (1964-90)
	Runoff Coefficient	0.4	RESRAD manual, Table E.1.	agric environ, flat land, combo of clay and loam, cultivated land.
	Irrigation [m/yr]	0.0		assumed no irrigation, can't pump groundwater

Table D.2 (continued)

Section	Parameter	Value/Range	Reference	Notes
	Irrigation Mode [overhead or ditch]	no irrigation		
	Watershed Area for Nearby Stream or Pond [m^2]	412,000	p.115 Figure 4-9 Site Suitability Study (Feb 94).	Appears all of the SLAPS and ballfield area is in the watershed area.
	Accuracy for Water/Soil Computations [convergence criterion - only for water dependent pathways]	0.001	RESRAD default	
R014	Density of Saturated Zone [g/cm^3]	1.8	standard default	p. 4-4 F.S. may contain information for this section. also p. 4-26.
	Saturated Zone Total Porosity	0.43	RESRAD manual, Table E.7	Silt 0.45, range (0.34 - 0.51) Clay 0.42, range (0.34 -0.57)
	Saturated Zone Effective Porosity	0.1	RESRAD manual, Table E.7	Silt 0.20, range (0.01 - 0.39) Clay 0.06, range (0.01 -0.18)
	Saturated Zone Hydraulic Conductivity [m/yr]	53.6	RESRAD manual, Appendix E, Table E.2	Silty clay loam check sensitivity
	Saturated Zone Hydraulic Gradient	0.02	RESRAD default	
	Saturated Zone B Parameter	7.75	RESRAD manual, Appendix E, Table E	silty clay loam check sensitivity

Table D.2 (continued)

Section	Parameter	Value/Range	Reference	Notes
	Water Table Drop Rate [m/yr]	0.0	p. 95 Site Suit. Study (Feb94)	upper aquifer varied 2.7 meters over year.
	Well Pump Intake Depth [meters below water table]	5		
	Model for Water Transport Parameters [non dispersion or mass-balance]	0 (non-dispersion model)	p. 71 RESRAD manual	Mass Balance Option only for contaminated zone <1000 m2.
	Well Pumping Rate [m^3/yr]	0.0		assumed can't pump groundwater
R015	Uncontaminated/Unsaturated Strata #1 Thickness [m]	3 to 5 meters use 4 meters	p. 98 Site Suitability Study (Feb 94)	need to decide on value
	Uncontaminated/Unsaturated Strata #1 Soil Density [g/cm^3]	1.8	Standard default	
	Uncontaminated/Unsaturated Strata #1 Total Porosity	range .30 - .45 use 0.43	RESRAD manual, Table E.7	Silt 0.45 Clay 0.42 Limestone 0.30
	Uncontaminated/Unsaturated Strata #1 Effective Porosity	range 0.06 - .20 use 0.10	RESRAD manual, Table E.7	Silt 0.20 Clay 0.06 Limestone .14
	Uncontaminated/Unsaturated Strata #1 Soil Specific B Parameter	7.75	RESRAD manual, Table E.2	Silty Clay Loam

Table D.2 (continued)

Section	Parameter	Value/Range	Reference	Notes
	Uncontaminated/Unsaturated Strata #1 Hydraulic Conductivity [m/yr]	53.6	RESRAD manual, Table E.2	Silty Clay Loam
R016	Distribution Coefficient for U-238 [cm^3/g]	1000	p. 90-91 Table 3-4 Site Suitability Study (Feb. 94) RESRAD manual Table E.5 and E.6	270-67000
	Distribution Coefficient for Ra-226 [cm^3/g]	70	p. 90-91 Table 3-4 Site Suitability Study (Feb. 94) RESRAD manual Table E.3	0-2400
	Distribution Coefficient for Th-230 [cm^3/g]	1000	p. 90-91 Table 3-4 Site Suitability Study (Feb. 94) RESRAD manual Table E.5 and E.6	1.2-400000
	Distribution Coefficient for Th-232 [cm^3/g]	1000	p. 90-91 Table 3-4 Site Suitability Study (Feb. 94) RESRAD manual Table E.5 and E.6	1.2-400000
R017	Inhalation Rate [m^3/yr]	8400	RESRAD default	Recommended by ICRP
	Mass Loading Factor [g/m^3]	0.00004 g/m^3	p. 3-33 B.R.A. (Nov 93)	50% of 0.08 mg/m^3

Table D.2 (continued)

Section	Parameter	Value/Range	Reference	Notes
	Dilution Length for Airborne Dust [m]	0.03 to 250 3 geometric mean	RESRAD suggested range and default value.	
	Exposure Duration [yr]	30	RESRAD default	
	Shielding Factor for Inhalation	0.4	RESRAD default	
	Shielding Factor for External Gamma	0.7	RESRAD default	
	Indoor Time Fraction	0.5	RESRAD default	
	Outdoor Time Fraction	0.25	RESRAD default	
	Shape Factor (External Gamma)	1.0		circular area p.76 RESRAD manual
R018	Fruits, Vegetables, and Grains Consumption [kg/yr]	160	RESRAD default	
	Leafy Vegetables Consumption [kg/yr]	14	RESRAD default	
	Milk Consumption [l/yr]	92	RESRAD default	

Table D.2 (continued)

Section	Parameter	Value/Range	Reference	Notes
	Meat and Poultry Consumption [kg/yr]	63	RESRAD default	
	Fish Consumption [kg/yr]	5.4	RESRAD default	
	Other Seafood Consumption [kg/yr]	0.9	RESRAD default	
	Soil Ingestion [g/yr]	36.5 0.1 g/day	RESRAD default	also p. 3-36 B.R.A. has some soil ingestion rates.
	Drinking Water Intake [l/yr]	510	RESRAD default	
	Contaminated Fraction of Drinking Water	0.0		p. 5-14 F.S. indicates that upper aquifer groundwater is considered poor quality (class IIIA).
	Contaminated Fraction of Household Water	0.0		p. 5-14 F.S. indicates that upper aquifer groundwater is considered poor quality (class IIIA).
	Contaminated Fraction of Livestock Water	0.0		p. 5-14 F.S. indicates that upper aquifer groundwater is considered poor quality (class IIIA).

Table D.2 (continued)

Section	Parameter	Value/Range	Reference	Notes
	Contaminated Fraction of Irrigation Water	0.0		p. 5-14 F.S. indicates that upper aquifer groundwater is considered poor quality (class IIIA).
	Contaminated Fraction of Aquatic Food	0.0		No Fish from Coldwater Creek
	Contaminated Fraction of Plant Food	0.5		Family garden
	Contaminated Fraction of Meat	0.0		Not likely to have livestock
	Contaminated Fraction of Milk	0.0		Not likely to have livestock
R019	Livestock Fodder Intake for Meat [kg/day]	68	RESRAD default	
	Livestock Fodder Intake for Milk [kg/day]	55	RESRAD default	
	Livestock Water Intake for Meat [l/day]	50	RESRAD default	
	Livestock Water Intake for Milk [l/day]	160	RESRAD default	

Table D.2 (continued)

Section	Parameter	Value/Range	Reference	Notes
	Livestock Intake for Soil [kg/day]	0.5	RESRAD default	
	Mass Loading for Foliar Deposition [g/m^3]	0.0001	RESRAD default	
	Depth of Soil Mixing Layer [m]	0.15	RESRAD default	
	Depth of Roots [m]	0.9	RESRAD default	
	Storage Time Before Use for Fruits, Non-Leafy Vegetables, and Grains [days]	14	RESRAD default	
	Storage Time Before Use for Leafy Vegetables [days]	1	RESRAD default	
	Storage Time Before Use for Milk [days]	1	RESRAD default	
	Storage Time Before Use for Meat [days]	20	RESRAD default	
	Storage Time Before Use for Fish [days]	7	RESRAD default	

Table D.2 (continued)

Section	Parameter	Value/Range	Reference	Notes
	Storage Time Before Use for Crustacea and Mollusks[days]	7	RESRAD default	
	Storage Time Before Use for Well Water and/or Surface Water [days]	1	RESRAD default	
	Storage Time Before Use for Livestock Fodder [days]	45	RESRAD default	
	Groundwater Fractional Usage of Drinking Water	0.0		assuming can't pump groundwater
	Groundwater Fractional Usage of Livestock Water	0.0		assuming can't pump groundwater
	Groundwater Fractional Usage of Household Usage Water	0.0		assuming can't pump groundwater
	Groundwater Fractional Usage of Irrigation Water	0.0		assuming can't pump groundwater
R021	Building Foundation Thickness [m]	0.15 for Building	RESRAD default	
	Building Foundation Density [g/cm^3]	2.4 for Building	RESRAD default	
	Building Foundation Total Porosity	0.1 for Building	RESRAD default	

Table D.2 (continued)

Section	Parameter	Value/Range	Reference	Notes
	Building Foundation Volumetric Water Content	0.03 for Building	RESRAD default	
	Building Foundation Effective Radon Diffusion Coefficient [m^2/sec]	-1		RESRAD will calculate
	Contaminated Zone Radon Diffusion Coefficient [m^2/sec]	-1		RESRAD will calculate
	Radon Vertical Dimension of Mixing [m]	2	RESRAD default	
	Average Annual Wind Speed [m/sec]	4.17 m/sec (15 km/hr)	p. 3-1 B.R.A. (Nov 93)	Predominantly from the south.
	Building Air Exchange Rate [1/hr]	0.5 to 1.5 0.5	RESRAD range and value default	
	Building Room Height [m]	2.2 to 3.0 2.5	RESRAD range and value default	
	Building Indoor Area Factor	0.0		RESRAD will calculate
	Foundation Depth Below Ground Surface [m]	0.0 to 3.0 1.0	RESRAD range and value defaults	
	Radon Emanation Coefficient Rn-222	0.01 to 1.0 0.25	RESRAD range and value default	

Table D.2 (continued)

Section	Parameter	Value/Range	Reference	Notes
	Radon Emanation Coefficient Rn-220	0.01 to 1.0 0.15	RESRAD range and value default.	

VITA

Duane E. White was born in Arlington, Virginia on October 6, 1971. He attended public schools in the public system of Alexandria, Virginia. He graduated from T. C. Williams High School in June 1989. After graduation, he entered Norfolk State University in Norfolk, Virginia where he received a Bachelor of Science degree in Physics in May of 1993. Right after he left Norfolk State University, he entered the Master's program in Nuclear Engineering with a concentration in Radiation Protection at the University of Tennessee, Knoxville in August of 1993. While at the University of Tennessee, Knoxville he worked for the university's Industrial Engineering Department, Minority Student Affairs Department, and the Radiological Safety Department. As a Graduate Teacher's Assistant working for the Department of Industrial Engineering, Duane assisted in teaching a entry level computer programming course for first year engineering students. The computer programs taught in this course were Microsoft Excel, Microsoft Word, Matlab, and DOS. As a Math Tutor for the Department of Minority Student Affairs. He tutored students in Pre-Algebra, Algebra 1 and 2 and, Engineering and Business Calculus 1 and 2. During his last year of graduate study, Duane was a Graduate Assistant for the Department of Radiological Safety. While at this job, he handled the disposal of radioactive waste produced at the University of Tennessee, Knoxville. Also, he checked and delivered all radioactive packages to their designated departments at the University of Tennessee, Knoxville. His Master's of Science degree in Nuclear Engineering was received in December 1995.