FINAL

Work Plan for Radiological Remediation and Final Status Survey of the North Fence Area and Soil Pile Great Lakes Naval Training Center Great Lakes, Illinois

Project USN 2000-003, Phase III, Modification I

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Prepared for:

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GLOSSARY OF ACRONYMS AND ABBREVIATIONS

Acronym or Abbreviation	Definition
AEC	Atomic Energy Commission
AJMC	United States Army Joint Munitions Command
ALARA	As Low As Reasonably Achievable
Bgs	below ground surface
COC	Contaminants of Concern
DCGL	Derived Concentration Guideline Level
DQA	Data Quality Assurance
DQO	Data Quality Objectives
DRMO	Defense Reutilization and Marketing Office
EMC	Elevated Measurement Comparison
EPA	Environmental Protection Agency
FSS	Final Status Survey
GPS	Global Positioning System
GWS	Gamma Walkover Survey
JULIE	Joint Utility Locating Information for Excavators
LBGR	Lower Bound of the Gray Region
MARSSIM	Multi-Agency Radiation Survey and Site Investigation Manual
MDC	Minimum Detectable Concentration
NaI	Sodium Iodide
NFA	North Fence Area
NRC	Nuclear Regulatory Commission
NAVSEADET	Naval Sea Detachment

Acronym or Abbreviation	Definition
PDOP	Positional Dilution of Precision
QA	Quality Assurance
QC	Quality Control
RA	Reference Area
RASO	Radialogical Affairs Support Organization
ROPC	Radionuclides of Potential Concern
RWP	Radiation Work Permit
SP	Soil Pile
SSHP	Site Safety and Health Plan
TCLP	Toxic Characteristic Leachate Procedure
TENORM	Technologically-Enhanced Naturally Occurring Radioactive Material
USCG	United States Coast Guard
WAC	Waste Acceptance Criteria
WCS	Waste Control Specialists
WRS	Wilcoxon Rank Sum (statistical test)

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1.0 INTRODUCTION

The U.S. Army Joint Munitions Command (AJMC) has contracted Cabrera Services, Inc. (CABRERA) to provide a Remediation Work Plan describing the methodology, equipment, instrumentation, sample frequency, and sample analysis for the remediation and final status survey (FSS) of soils located within the boundaries of the Great Lakes Naval Training Center (Site), and to perform that remediation and FSS. This site was formerly used by the Defense Logistics Agency as a storage area for strategic quantities of monazite sands, a thorium-bearing material. The Scope of Work (SOW) is defined by AJMC Basic Ordering Agreement Document DAAA09-00-G-0002, Delivery Order 0036, dated 28 September 2001, and CABRERA proposal 02-129, revision 1, modification I, dated September 27, 2002 to comprise:

- Removal of soil north of the warehouse having activity concentrations of Th-232 greater than 1 pCi/g above background. This area is referred to as the North Fence Area (NFA).

- Design and performance of a post-remediation, MARSSIM-based Final Status Survey (FSS) for unrestricted release of the NFA. Soil activity concentrations of Th-232 greater than 1 pCi/g above background will be disposed of as unimportant quantities of source material (less than 0.05% by weight of mixture and equivalent to 55 pCi/g of soil) as necessary.

- Elimination of the large dirt pile [30.48 m x 15.24 m x 4.88 m (100 ft x 50 ft x 16 ft), approximately 2,267 m^3 (3,000 y^3)] of exhumed soil in the northwest corner of the site. This excavated soil is referenced to as the Soil Pile (SP). The pile contains suspect levels of Th-232 and may additionally have discrete radium instruments and articles (technologically-enhanced naturally occurring radioactive material or TENORM) buried at the base of the pile as necessary.

- Design and performance of a post-remediation, MARSSIM-based Final Status Survey (FSS) for unrestricted release of the SP in one-foot lifts for soil above the lower 1-foot above ground surface. Soil activity concentrations of Th-232 greater than 1 pCi/g above background and Ra-226 greater than 2 pCi/g inclusive of background will be removed and disposed of as low-level radioactive waste quantities of source material (less than 55 pCi/g) and TENORM respectively.

- Performance of a characterization survey on the lower foot of the SP and the ground soil directly beneath the SP.

Characterization surveys performed by CABRERA in 2000 were documented in the Characterization Report (CABRERA 2000). This document forms the baseline on which the project is designed, however, the data contained therein will be supplemented with remedial action control surveys during the field effort. This Remediation Work Plan and associated Site Safety and Health Plan (SSHP) address the defined Scope of Work.

1.1 Project Background

The Site is located in the Naval Training Center Great Lakes, Illinois. The portions of the Site included in this project are shown in Figure 1 (i.e., the Monazite Sand Area). In 1974 the Atomic Energy Commission (AEC) granted a license (license number STE-8179) to Engelhard Minerals & Chemical to package and ship a strategic stockpile of monazite sand from the Great Lakes Naval Training Center and two other sites in Illinois and Ohio. According to records, Engelhard shipped the monazite ore to Holland in 1974. No records have been found indicating that Engelhard or DLA conducted a closeout survey of the area. The monazite sand encompasses approximately 90,000 square yards (300 yards x 300 yards) in the former tank farm area. As stated in the preceding section, in 2000, characterization surveys were performed on the entire 90,000 square yards and documented.

1.2 Radiological History

The U.S. Nuclear Regulatory Commission (NRC) Region III conducted an inspection on January 19, 2000, which revealed several areas of elevated gamma activity on the north side of the former monazite sand storage areas. A one-day scoping survey performed by CABRERA on March 8, 2000 also identified areas of elevated gamma activity and determined that thorium-232 daughter radionuclides were present using sodium iodide (NaI) gamma spectroscopy.

In addition, a buried sound powered phone jack, containing radium was found below ground level near the south east corner of the large soil pile (SP). The device was found by CABRERA in 2000 during the site characterization survey. While no definitive information surrounding the particulars of the discovered radium-containing device is available, it may be surmised that other radium-containing devices could exist at this location. Natural physical processes may have caused the release of radium from the device into the surrounding soil matrix.

1.3 Hazardous Materials

During the characterization survey, six chemical analyses were performed on SP and NFA soil samples to provide information regarding chemical contaminants that could affect disposal options. TCLP analyses for metals, mercury, semi-volatiles, volatiles, chlorinated herbicides, and organochlorine pesticides were performed. The results of TCLP analyses were below 40 CFR Part 261 limits, indicating that no hazardous chemical contamination was identified.

2.0 PROJECT SCOPE AND PURPOSE

The Scope of Work covers the following six tasks associated with two distinct areas at the Site:

North Fence Area:

- Removal of soil north of the warehouse having soil activity concentrations of Th-232 greater than 1 pCi/g above background. Ra-226 is not considered a radionuclide of potential concern (ROPC) in this area. This area is referred to as the North Fence Area (NFA).
- Design and performance of an approved post-remediation, MARSSIM-based FSS for unrestricted release of the NFA.

Soil Pile:

- Elimination of the large SP [30.48 m x 15.24 m x 4.88 m (100 ft x 50 ft x 16 ft), approximately 2,267 m^3 (3,000 y^3)] in the northwest corner of the site using a MARSSIM-based FSS on 0.30 m (1ft) soil lifts with the exception of the lower 0.30 m (1 ft).
- Transport of released SP material to a location on base within 5 miles of the project site.
- Characterization of the lower 0.30 m (1 ft) of the SP and the soil directly beneath the pile.
- Provide for off-site disposal of slightly contaminated soil as identified during MARSSIM surveys of the NFA and SP. Radium contaminated soils potentially found at the SP will be disposed of at a separate facility authorized to receive such material if necessary.

Figure 3 presents the two sites and the proposed sample grid layout.

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3.0 BACKGROUND

The general portion of the Great Lakes Naval Training Center in which this project will take place is shown in Figure 1.

3.1 Historical Site Assessment

Monazite is a rare earth phosphate containing a variety of rare earth oxides particularly cerium and thorium oxide. Thorium has wide industrial applications and has been mined as monazite sand since the 1930's. Monazite typically contains 5-7 % of radioactive thorium and 0.1 to 0.3% of uranium. Isotopes from the thorium series dominate. A major fraction of any identified soil contamination in these areas would therefore be expected to have contamination resulting from the storage of monazite sands.

The former AEC license (license number STE-8179) indicated that 1,826,153 pounds of monazite containing 9.226% of ThO_2 was held at the Great Lakes Site prior to shipping to Holland in 1974. There is limited information on the extent of residual contamination resulting from this operation. During a scoping survey performed by the NRC in January 2000, surface dose rates as high as 80 μR/h were observed along the north fence line of the construction zone. A scoping survey by CABRERA in March 2000 identified several areas of elevated gamma activity and confirmed the presence of Th-232 daughter radionuclides. Gamma radiation levels above the ambient level were identified in the construction zone, along the north fence line, in locations surrounding tanks H, L, and K, and in locations between tanks H, L, and K (see Figure 1). During the scoping survey, six soil samples were collected from areas where elevated gamma radiation levels were observed. These samples were analyzed for Th-232 using gamma spectroscopy. Th-232 concentrations in the samples ranged from 0.93 pCi/g to 64.31 pCi/g, with an average activity concentration of approximately 17 pCi/g.

Samples were also collected in a reference area, in an attempt to characterize natural background concentrations of Ra-226 and Th-232. In that area, the range of combined Ra-226/Th-232 concentrations was 1.6 pCi/g to 5.1 pCi/g, with a mean value of 2.4 pCi/g and a standard deviation of 0.63 pCi/g. It should be noted that, in the reference area, due to the methodology used in quantifying radium, concentrations of Ra-226 may have been slightly underreported.

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4.0 REMEDIATION ACTIVITIES

For the purposes of segregating clean material from contaminated material during this project, the derived concentration guideline level (DGGL) is 1 pCi/g for Th-232 above background for the NFA and the SP. This value corresponds to NUREG/CR-5512 Table 6.91 soil concentration equivalent to 25 mrem/year for Th-232 in equilibrium with progeny at a P_{crit} = 0.05. In addition, the DCGL for the SP has a 2 pCi/g total activity guideline for Ra-226 including background. Ra-226 is not expected to be found in areas being remediated.

4.1 Area Preparation

Excavation and other possible impacted areas will be clearly marked with white paint, or equivalent, prior to commencing work. Notification of Joint Utility Locating Information for Excavators will be coordinated through the installation Environmental Office at least one week before the start of any earthwork, to mark out and identify any conflicting underground utilities.

Prior to beginning work, affected areas will be posted as a "Radioactive Materials Area", "RWP Required for Entry" and "Authorized Personnel Only". Barrier tape or rope will be utilized to define the active work areas. Each posted area will be restricted to a single ingress/egress point, which will be marked by a step-off pad. A frisking station for personnel contamination monitoring will be setup in the area.

4.2 Removal of Soil in Contaminated Areas

Soil removal will generally be accomplished using an excavator, front-end loader, or equivalent, and removed material will be packaged for transportation in end dump trucks, 25-yard roll-off intermodal containers, or B-25 containers. Hand tools may be utilized in size-restricted areas and areas near large stationary features that power machinery cannot readily access.

4.2.1 North Fence Area (NFA)

The NFA Class 1 area is north of the warehouse and is approximately 1,200 m^2 in size (98 m x 12.3 m). The perimeter of the NFA is shown in Figure 1. The majority of the surface of the NFA is bare soil, although some areas are paved or covered with concrete slabs and the southwest portion is grass. A Class 2 area surrounds the Class 1 area. The Class 2 area is approximately 965 m^2 in size (4 m width perimeter around the Class 1 area).

The removal of material in this area is anticipated to encompass only shallow subsurface soils in the uppermost 0.30 m (1 ft), asphalt, or gravel. Thorium-232 surface concentrations as high as 9.5 pCi/g (CABRERA 2000) were noted in this area. The material volume to be removed from this area is not expected to exceed 76.46 m^3 (100 y^3). The removed materials will be placed directly into 25-yard intermodal containers and staged onsite until the job is complete and the waste shipment is scheduled. The intermodal containers will be surveyed prior to transport and disposal at US Ecology TECO facility, Robstown, TX, a licensed disposal site for this waste classification. After loading the container and prior to shipment, on site sample analysis of these soils will be completed. Although unlikely, should Ra-226 concentrations in excess of 30 pCi/g in waste soils be identified, the soils would not be eligible for disposal at TECO due to limitations in the waste stream acceptance criteria to meet State of Texas land disposal requirements. In this event, these wastes would be shipped via exclusive use truck to a U.S. Ecology facility in either Grand View, ID, or Hanford, WA, depending upon activity levels as described in Section 4.2.2.

4.2.2 Soil Pile (SP)

The SP covers an area approximately 30.48 m (100 ft) by 15.24 m (50 ft) and is approximately 4.88 m (16 ft) high. It is located to the west of the warehouse in the former construction zone (Figure 1). The north and west sides of the SP have relatively steep sides, along with small portions of the east side. The south side is graded to allow heavy machinery access to the top of the pile. Some flattening of the pile will occur prior to beginning removal activities to facilitate remediation/removal activities.

The SP will be removed in its entirety down to the last 0.30 m (1ft). This will occur incrementally, with each removal iteration eliminating approximately a one-foot lift of soil from the pile. Total SP volume is expected to be approximately 3,000 cubic yards. Each lift will receive a FSS with 100% coverage of accessible areas with a gross gamma walkover survey (GWS), along with volumetric soil sampling. Prior to removing each lift, evaluation of gamma fluence measurements and laboratory gamma spectroscopy results will be completed. If FSS identifies radioactivity above the DCGL remediation will occur. These evaluations will be transmitted via a standard approval form to the NAVSEADET RASO Project Manager, who will approve the form before lift removal begins.

Material removed from the SP will be disposed in one of two ways, depending on analytical results of samples obtained from each lift. Clean material with less than 1 pCi/g will be placed on a temporary stockpile of soil next to the SP. When sufficient quantities of the clean temporary stockpile have accumulated to permit cost-effective transportation, the temporary stockpile will be loaded into end-dump trucks. The end-dump trucks will deposit the clean soil at a location on base within 5 miles of the SP.

Contaminated volumes of soil, in which the Th-232 concentration exceeds 1 pCi/g above background (and less than 55 pCi/g), or the Ra-226 concentration exceeds 2 pCi/g including background (and less than 30 pCi/g), will be placed directly into 25-yard intermodal containers and staged onsite until the job is complete and the waste shipment is scheduled. No soil is expected to contain Th-232 concentrations exceeding unimportant quantities of source material (55 pCi/g). The intermodal containers will be surveyed prior to transport and disposal at TECO. CABRERA assumes that no more than 140 cubic yards of material in this category will be removed.

4.3 Packaging of Waste Materials

The waste materials exceeding DCGLs will be removed from the NFA and SP areas and placed into 25-yard, hard top roll-off intermodal containers. The intermodal containers provide continuous protection from the elements during storage and transportation. Water absorbing materials will be added as necessary to assure that no freestanding water is present within the container. The loading of the intermodal containers will be controlled to ensure that applicable Department of Transportation (DOT) requirements are met.

Radium is not expected to be encountered during the remediation activities. If Ra-226 is encountered soil with levels exceeding the TECO limit of 30 pCi/g Ra-226 may be packaged in B-25 containers or intermodal containers. Such containers will be staged onsite until job completion and waste shipment has been scheduled.

Prior to shipment, the containers will be surveyed and then loaded on an exclusive-use flatbed truck for transport to either US Ecology Grand View, ID if Ra-226 levels are less than 220 pCi/g or to the US Ecology Hanford site if the Ra-226 is greater than 220 pCi/g, for ultimate disposal. CABRERA assumes that no more than 14 cubic yards of material containing greater than 30 pCi/g Ra-226 will be excavated and shipped to either Grand View or Hanford. Water absorbing materials (e.g., WaterWorks America SP-400 or equivalent) will be added as necessary to assure that no freestanding water is present within the container.

Soil removed from the NFA and SP areas that is determined to be below the DCGL will be removed by excavator, loader, and end-dump truck, and transported, and placed at the pre-identified on-site storage location

4.4 Shipment and Disposal of Waste Materials

Radiological analysis of waste materials to determine their disposition will be performed in the on-site laboratory. While the soils from the SP were chemically characterized during the 2000 characterization survey, additional profiling information to meet TECO waste criteria is likely for both the NFA and the SP due to the time interval between the initial chemical characterizations and the disposal action.

The plan is to ship waste materials compliant with the TECO waste acceptance criteria from the NFA and SP to the disposal facility, shortly after loading. As described above, the 25-yard intermodal containers will be used to transport the containerized contaminated soil via truck for transport and ultimate disposal at TECO US Ecology Robstown, TX Site.

Radium-contaminated soil exceeding TECO acceptance criteria will be packaged in B-25 or intermodal containers and loaded onto an exclusive-use flatbed truck for transport to the US Ecology Grand View, ID or Hanford, WA disposal facility.

CABRERA will use an JMC-approved broker to ship the low-level radioactive waste. CABRERA will provide for exclusive use of vehicles for the shipments. Change out of drivers, trailer, or tractor en route is prohibited. The vehicles will be subject to inspection by the Government. The Government reserves the right to reject any vehicle or driver, which, in the opinion of the Government, does not meet the requirements of the Department of

Transportation. CABRERA will coordinate shipments directly with the approved processor or disposal facility, prior to the containers leaving Great Lakes Naval Training Center property.

The intermodal and B-25 containers used during this remediation removal effort will be inspected for container integrity, surveyed, weighed and required labeling affixed prior to shipment.

The CABRERA JMC-qualified broker will prepare necessary DOT and procedurally required forms (Radioactive Shipment Record, Bill of Lading, etc.). A second quality assurance check on the container labeling shall be performed to ensure compliance. Full, labeled containers should be placed in the designated storage area until shipment. DOT shipping and labeling requirements will be met prior to release of the intermodal and B-25 containers from the site.

4.5 Demobilization Activities

Equipment and materials used on the project within radiological control areas will be surveyed for release and decontaminated as necessary in accordance with CABRERA field operations procedure OP-004 "Unconditional Release of Materials From Radiological Control Areas". Postings and barriers will be removed and materials and support equipment (office facility, equipment, etc.) will be removed from the site.

The radiological criteria for unconditional release of equipment from the site are stated in Section 5.3.

4.6 ALARA Considerations

Dose rates, and the total amount of radioactive materials at the site, indicate that direct external exposure to radiation is of minor consequence during work activities. Measurements of radiation exposure show maximum dose rates in the area are generally well below 40 μR/h at 1 m from the ground surfaces. One hot spot of 90 μR/h was noted by a recent NRC walk down. Personnel exposures are not anticipated to exceed 5 millirem total effective dose equivalent (TEDE) for the job duration.

The potential for internal exposure is slight due to the amounts radioactive material present, the type of material that is mixed with the radioactive materials, and the method utilized for removal of the soils. Continuous sampling, using low volume air samplers, along with breathing zone (BZ) air samples obtained from the workers breathing zone, will be used for evaluation of the hazard.

No environmental releases or exposures to unmonitored personnel are anticipated. Routine monitoring for environmental exposures will be performed using low volume air samples placed in areas of maximum potential exposure. Gamma scan surveys of the areas around the Survey Unit will be performed daily during the remediation to ensure the spread of contamination is minimized. Equipment used for remediation will be surveyed and decontaminated as necessary to minimize the spread of contamination to areas surrounding the Survey Unit.

4.7 Detailed Work Description

4.7.1 Pre-requisites and Precautions

Project personnel will complete and present evidence of having received OSHA 40 hour HAZWOPER training and/or have current 40 hour HAZWOPER refresher training prior to beginning work at the Site. Site personnel shall read and understand the contents of this work plan and the site-specific health and safety plan prior to any physical work on site. Each team member will complete a sign-off sheet indicating his or her understanding of and agreement to the provisions of both plans. These sheets will be filed in the project file.

The immediate work area will be posted as "Radioactive Materials Area", "RWP Required for Entry" and "Authorized Personnel Only". Rope, tape, or an equivalent barrier will be placed around the immediate work area to present a visual barrier and limit access by unauthorized personnel.

Prior to beginning work, a Radiation Work Permit (RWP) will be prepared that will specify the activities to be performed and radiological safety requirements for the work. Personnel assigned to site work will be required to read and understand the requirements prior to beginning work.

Low volume air samplers will be utilized and positioned such that data may be obtained to document and verify that no significant release of radioactive materials from the work activities has occurred. Personnel BZ air samplers should be run long enough to obtain an air sample of sufficient volume to ensure adequate counting instrument sensitivities.

4.7.2 Removal of Contaminated Soils

(A) North fence Area

Areas of the soil identified in the CABRERA 2000 Characterization Report as exceeding the DCGL of 1 pCi/g for Th-232 above background will require removal. The immediate areas of concern are identified on Figure 1. Specific work areas inside the overall controlled area may be prepared in sections of approximately 20 to 40 m^2 at a time for ease of area set up and control of the soil resulting from the removal actions. Larger areas may be needed to accommodate machinery when used.

The Field Lead will ensure that prerequisites are completed. Step off pads, along with clearly delineated radiological postings that indicate the locations of personnel entry and egress from the work area, will be set up. Approved waste transport containers will be staged immediately adjacent to the work area or as close as practically achievable, depending on site-specific conditions, to ensure the movement of soils from the NFA to the intermodal container is minimized.

Soil removal will be commenced using a backhoe loader or equivalent. The contamination has been identified in the upper 6 to 12 inches (approximate). Removal of the top 12 inches of the soil, asphalt and gravel present should be sufficient to effect remediation in the NFA. This may be done in one or two lifts. Hand tools may be used to assist in the removal of small amounts of material near fencing, storm drains, utilities, etc. where machinery may be unwieldy. Soils will be loaded into the appropriate waste container.

Following initial soil removal, a local area gross gamma scan survey will be carried out with a Ludlum Model 44-10 gamma scintillator (2 in. x 2 in. NaI) and Ludlum Model 2221 ratemeter/scaler, or equivalent system, to identify any remaining soil likely to exceed the DCGL. This detection system will be configured to direct its data to a Global Positioning System (GPS) receiver to facilitate precise geo-spatial correlation of the gamma data. If any areas exhibit gamma fluence in excess of background, an additional 0.05 to 0.10 m (2 to 4 in) of the topmost portion of the soil will be removed. The above steps will be repeated as necessary until no gamma count rates in excess of background are observed.

The above methodology will be repeated for subsequent land sections until the entire NFA has been addressed.

Following completion of soil removal actions, equipment used during the effort will undergo release surveys in accordance with approved procedures. Equipment released for unrestricted use shall have the survey results documented specifying the particular equipment and verifying that release criteria have been met.

A MARSSIM-based FSS, as described in Section 5.0, will be performed on the entire NFA after remediation has been completed. This FSS will include 100% gross gamma scans and systematic soil sample collection and analysis to support unrestricted radiological release of the NFA. Additional soil samples will be included at biased sample locations, concentrating on areas of greatest contamination potential (rough cracked surfaces, drainage pathways, fence lines, wind breaks, etc.), as well as areas in which the highest gross gamma count rates are observed. The volume of sampled soil will be well mixed and place into one-liter marinelli type sample containers. Any unused soil will be placed back to the location from which it was taken.

The soil samples will be analyzed with a "field operations laboratory" gamma spectroscopy system and as a minimum will duplicate 10% of the samples by sending them to an independent third party laboratory. The laboratory used to analyze soil samples will be certified by the State of Utah. Section 6.2 provides details of the field operation gamma spectroscopy system.

Following approval from the NAVSEADET RASO Project Manager, the excavated area will be backfilled to rough grade using imported or local clean soil. Soil used for backfill will be sampled and analyzed to ensure that it is free of contamination.

(B) Soil Pile (SP)

The SP was characterized by performing a gamma walkover and collecting and analyzing discrete soil samples (CABRERA 2000). The SP contains suspect levels of Th-232 and potentially has discrete radium instruments and articles at the base of the pile. The SP has dimensions of approximately 30.48 m x 15.24 m (100 ft x 50 ft) and is approximately 4.88 m (16 ft) high (Figure 1). The SP will be removed in its entirety except for the final 0.30 m (1 ft) portion of the SP above the ground surface. Most of the SP is not expected to be contaminated.

The SP will be barricaded off with construction fencing and or caution tape to create a buffer zone to ensure unauthorized personnel do not enter the area when removal operations commence. This buffer zone will also serve as a restricted area and the boundary of the survey area created after removal of the SP. Assuming a 2 m wide buffer zone, it is expected to increase the dimensions of the base ground-level SP survey unit to approximately 34.44 m x 19.20 m (113 ft x 63 ft). Step off pads, along with clearly delineated radiological postings that indicate the locations of personnel entry and egress from the work area, will be set up.

The initial remediation task in the SP area will be to remove radium-contaminated soil at the location where a discrete contaminated object was identified during characterization. During the 2000 survey, at approximate coordinates 626159.4 north, 337824.0 east (see Figure 1), a sound powered phone jack emitting substantially elevated gamma radiation was identified. This sound powered phone jack buried at the base of the SP (ground level) under some debris and soil and was carefully removed and bagged. During this investigation, elevated loose radioactivity was identified on the object. Soils in this area were identified as containing elevated radium concentrations and will be removed.

Prior to any soil removal, some "leveling" of the soil pile will occur. The leveling is required to flatten the soil pile so that the pile can be divided into one-foot lifts to support a MARSSIM survey. The leveling essentially changes the shape of the pile from conical to trapezoidal. Soil removal will be in one-foot lifts with a FSS being performed on each lift as per section 5.0. The lower limit of each individual lift will be marked on the soil pile with surveyor stakes, or other effective marking method, prior to removal of the topmost one-foot layer. As each active lift is being removed it can be checked using these surveyor stakes and string lines to ensure no more than one foot of material is being removed. The surveyor stakes or other marking will then be reset for the next lift. It is expected that no more than 12 lifts will be required. Note that no lift will be removed until approved, as described below, by the NAVSEADET RASO Project Manager.

Prior to any soil removal from the SP, a MARSSIM-based FSS (see Section 5.0) will be performed on each one-foot lift. This will include a 100% scan walkover on the upper surface of the SP lift being addressed, as well as soil sampling and analysis. The scan will be accomplished using Ludlum Model 44-10 gamma scintillator (2 in x 2 in NaI) and a Ludlum Model 2221 scaler/ratemeter, or equivalent detection system, with output directed to a GPS receiver. The GPS will provide precise geospatial correlation of gross gamma data. Areas exhibiting gross gamma count rates exceeding background will be subject to additional remedial effort.

Soil samples will be performed on each lift prior to removal, as specified in Section 5.6. The samples will be located with the GPS to ensure reproducibility of the sample locations. Soil samples will be taken to a depth of one foot to correspond to the soil lift thickness. The volume of collected soil will be well mixed and placed into one-liter marinelli type sample containers. Any unused soil will be placed back into the location from which it was taken.

Soil samples will be analyzed in the on-site gamma spectroscopy laboratory and, as a minimum, 10% of the samples will be sent to an independent third party laboratory as a quality assurance measure. Section 6.2 provides details of the field operation gamma spectroscopy system.

If any areas exceed the Th-232 DCGL of 1 pCi/g above background the soil will be removed and promptly placed in an intermodal container that is staged immediately adjacent to the work area. This will ensure that the contaminated soils are contained without delay and that environmental exposure to exposed suspect soils is minimized. Duplicate samples associated with the suspect soil will be promptly packaged and sent to the independent third party laboratory for verification.

Additionally, in the event that Ra-226 is found in any lift above the 1 foot portion of the SP immediately above ground, operations will immediately cease and RASO will be informed. Any devices containing Ra-226 uncovered during the remediation process will be promptly placed in a polyethylene bag or other containment that will prevent the spread of Ra-226 from the device. The bag or containment system will be dose rated and tagged. The Field Lead will take control of the bagged device and promptly notify the NAVSEADET RASO Project Manager and CABRERA management concerning ultimate disposal.

Upon completion of required remediation and evaluation of gamma fluence measurements and laboratory gamma spectroscopy results, FSS results will be transmitted via a standard approval form to the NAVSEADET RASO Project Manager, who will approve the form before lift removal begins.

Following completion of any contaminated soil removal actions, equipment used during the effort will undergo release surveys in accordance with CABRERA field operations procedure OP-004 "Unconditional Release of Materials From Radiological Control Areas". Should equipment require decontamination, CABRERA field operations procedure OP-018 "Decontamination of Equipment and Tools" will be utilized. Equipment released for unrestricted reuse shall have the survey results documented specifying the particular equipment and verifying that release criteria have been met.

Following approval by the NAVSEADET RASO Project Manager, one-foot soil lifts passing the FSS criteria will be removed and placed on a temporary stockpile of soil next to the SP. The temporary stockpile will be placed in a segregated area such that it is unlikely to become cross-contaminated by subsequent remediation efforts. When sufficient quantities of the clean temporary stockpile have accumulated to permit cost-effective transportation, the temporary stockpile will be loaded into end-dump trucks. The end-dump trucks will place the clean soil at an on-site location within 5 miles from the SP.

5.0 RADIOLOGICAL FINAL STATUS SURVEY

Final Status Surveys will be performed and reviewed with approval by the NAVSEADET RASO Project Manager on every lift of the SP prior to the remediation of that 0.30 m (1 ft) portion of the SP. These surveys are designed to meet the guidance provided in the MARSSIM (NRC 2000). The methods and procedures to be used for the FSS are described in this section.

5.1 Detection Methods

The following radiation detection methods will be used during the radiological surveys:

- Gross gamma fluence (count rate) measurements
- Systematic soil sampling and analysis
- Biased soil sampling and analysis

Field survey methodology, techniques, and terminology are based on guidance contained in the MARSSIM (NRC 2000).

For soil sample data, non-parametric statistical methodologies (Wilcoxon rank sum test), described below, will be utilized to compare the post-remediation site conditions with the naturally occurring background thorium.

5.2 Derived Concentration Guideline Limits

The established site soil DCGL for this work, specified by the AJMC, is 1 pCi/g Th-232 activity above background. Radium is not a radionuclide of potential concern at the NFA or the SP except for the lower 1 foot and ground beneath the SP. Characterization of the lower 0.30 m (1 ft) and the ground beneath the SP will be performed as per section 6.5. The potential for Ra-226 in the lower 0.30 m (1 ft) of the SP and the ground beneath the SP will be determined by the characterization survey.

Details supporting the DCGL derivation are provided in the following paragraphs.

The NRC DandD Code, version 2.1.0, was run twice for DCGL assessments, once for thorium and once for radium. The first DandD run titled, "Great Lakes 1", provides an estimate for Th-232 dose. The code was run for a normalized soil concentration of 1 pCi/g with the setting "nuclide concentrations are NOT distributed among all progeny" and code default settings for the residential scenario. The second run titled, "Great Lakes 2", provides an estimate for Ra-226 dose. The code was run for a normalized soil concentration of 1 pCi/g with the setting "nuclide concentrations are NOT distributed among all progeny" and code default settings for the residential scenario.

The DandD Summary of Results for Th-232 provides for 90% of calculated TEDE values that are less than 23 mrem/year. The Th-232 and progeny 95 % Confidence Interval for the 0.9

quantile value of TEDE is 22.4 to 25.9 mrem/year. This analysis provides a single radionuclide $DCGL_w$ based on 25 mrem/year for Th-232 of approximately 1.08 pCi/g. This value is in agreement with NUREG 5512 Volume 3 Table 6.91 soil concentration equivalent to 25 mrem/year for Th-232+C when adjusted for the soil concentration of 10 pCi/g from the 11 nuclides in the chain (listed as 10.4 pCi/g at a $P_{Crit} = 0.05$).

The DandD Summary of Results for Ra-226 provides for 90% of calculated TEDE values that are less than 41.1 mrem/year. The Ra-226 and progeny 95 % Confidence Interval for the 0.9 quantile value of TEDE is 38.8 to 42.7 mrem/year. This analysis provides a single radionuclide $DCGL_w$ based on Ra-226 of approximately 0.6 pCi/g. This value is in agreement with NUREG 5512 Volume 3 Table 6.91 soil concentration equivalent to 25 mrem/year for Ra-226+C when adjusted for the soil concentration of 9.03 pCi/g from the 10 nuclides in the chain (listed as 5.16 pCi/g at a $P_{Crit} = 0.05$).

5.3 Radionuclides of Potential Concern (ROPCs)

Results from the laboratory gamma spectroscopy of soils analyzed as part of the characterization survey in 2000 reveal confirmation that residual Th-232 in site soils is in secular equilibrium with its daughter radionuclides. There is no evidence of chemical or physical processes that could disturb this equilibrium, but measurements will be performed to confirm the assumption of secular equilibrium in the thorium series chain. Based on the composition of monazite sands described in Section 3.1, uranium series radionuclides are expected to be present but in significantly lower concentrations than thorium series radionuclides and will not be considered during the FSS.

5.4 Representative Reference (Background) Area

The thorium series radionuclides occur naturally and the DCGL is not substantially greater than typical background concentrations, it is necessary to establish background concentrations to identify and evaluate residual contributions from past site operations. Determination of background levels for comparison with Site conditions in specific survey units entails conducting surveys and collecting and analyzing samples from a reference area (RA) to define background radionuclide concentrations.

The RA selected during previous characterization work (CABRERA 2000) is also used to establish the typical background concentrations for this remediation effort. The use of this RA is valid since the RA was sampled recently (calendar year 2000) and no additions of potentially radioactive material have occurred at the NFA or the SP.

The RA was selected from a non-impacted area similar in physical, geological, biological, and natural radiological conditions to the NFA and the SP. Non-impacted in this context should ideally include an area that was not used for, or potentially affected by previous monazite sand operations and has been disturbed from natural conditions similar to the disturbance of the construction zone (reference NUREG-1505). The RA approximates the individual sizes of the NFA and SP Class 1 Survey Units. Figure 2 shows the RA location on the site base map, with the results of the RA gross gamma survey count rate performed during the 2000 characterization survey.

New RA samples shall be taken and analyzed for Th-232 and a percentage shall be sent to an independent laboratory. Sample results for Th-232 from the RA during the 2000 characterization survey are summarized below. The total number of samples taken is 33.

Summary of Reference Area Sample Results

Parameter	***Result (pCi/g Th-232)***
Average	1.1
Standard Deviation	0.3
Maximum	1.7
Minimum	0.6

5.5 Identify Survey Units

The two areas identified with this remediation effort are broken into multiple survey units. The NFA comprises a Class 1 and a Class 2 survey unit, while each lift on the soil pile is an individual survey unit. Since each area has a reasonable likelihood of containing radionuclide concentrations in excess of the DCGL, the areas are considered as either a Class 1 or a Class 2 Impacted area, as defined in the MARSSIM.

5.5.1 North Fence Area

The NFA is north of the warehouse and is approximately 1,200 m^2 in size (98 m x 12.3 m). The perimeter of the NFA is shown in Figure 1. The majority of the surface of the NFA is bare soil, although some areas are paved or covered with concrete slabs and the southwest portion is grass.

The MARSSIM provides suggested areas for Class 1 land areas as being up to 2,000 m^2 in size. The NFA will have a Class 1 survey area consistent with the MARSSIM guidance. As a naming convention, this survey unit will be referred to as NFA-SU-1.

A Class 2 area surrounding the NFA Class 1 area has been added. The perimeter of the Class 2 area is shown in Figure 1. The Class 2 area is created by including a surrounding parcel of land 4 m's in width around the entire Class 1 area. This results in the creation of a Class 2 area approximately equal in size to the Class 1 area and is approximately 965 m^2. Class 2 land areas may range in size from 2,000 to 10,000 m^2 as suggested by MARSSIM guidance. This survey unit will be referred to as NFA-SU-2.

5.5.2 Soil Pile

The SP covers an area of approximately 30.48 m x 15.24 m (100 ft x 50 ft) and consists of a mound of soil approximately 4.88 m (16 ft) high. It is located to the west of the warehouse in the former construction zone (Figure 1). The north and west sides of the SP have relatively steep sides, along with small portions of the east side. The south side is graded to allow heavy machinery access to the top of the pile.

A 2 m buffer around the SP, as described in section 4.7.2, will result in a maximum area for the first lift above the 0.30 m (1 ft) lift remaining on the ground level (characterization lift), of approximately 520 m^2 (ellipse with dimensions of 34.5 m x 19.2 m). The MARSSIM provides suggested areas for Class 1 land areas as being up to 2,000 m^2 in size. This area is consistent with the MARSSIM guidance. The upper individual 0.30 m (1 ft) lifts will be smaller in area than the 0.30 m (1 ft) above ground level lift and will therefore also be smaller than the MARSSIM guidance with respect to survey unit size. Each lift will consist of a single survey unit. As a naming convention, the SP survey units will be referred to sequentially as SP-SU-1, SP-SU-2, . . . , SP-SU-N, where N is the total number of soil lifts removed from the soil pile.

5.6 Number of Sample Locations and Survey Coverage

5.6.1 Number of Sample Locations for Each Survey Unit

MARSSIM discusses a method to determine the number of data points required in a given survey unit. A minimum number of measurement locations are required in each survey unit to obtain sufficient statistical confidence that the conclusions drawn from the measurements are correct. For the purpose of this survey, the minimum required number of measurements is based on expected radionuclide concentrations in site areas that may be suitable for release for unrestricted use. The following subsections describe the basis for and derivation of the minimum required measurement locations per survey unit.

(A) Estimation of Relative Shift

The minimum number of measurements required is dependent on the distribution of site residual radionuclide concentrations relative to the DCGL and acceptable decision error limits (α and β) established in Section 5.11.6. The relative shift describes the relationship of site residual radionuclide concentrations to the DCGL and is calculated using the following equation, from Section 8.4.3 of the MARSSIM.

$$\Delta/\sigma = \frac{DCGL_w - LBGR}{\sigma}$$

Where: $DCGL_w$ = the derived concentration guideline level (i.e., release limit)

LBGR = concentration at the lower bound of the gray region. The LBGR is the concentration to which the survey unit must be cleaned in order to have an acceptable probability of passing the statistical tests. The LBGR effectively becomes the survey's action level.

σ = an estimate of the standard deviation of the concentration of residual radioactivity in the survey unit (which includes real spatial variability in the concentration as well as the precision of the measurement system)

(1) DCGL

The soil DCGL for this survey is specified for soil at 1.0 pCi/g for Th-232. This DCGL is assumed to be conservative in nature and is used to calculate the number of samples required in the NFA and SP survey units.

(2) LBGR

The LBGR is typically used as a clean-up guideline (or action level), as discussed above. This application of the LBGR is not directly applicable to the survey design, because remediation (clean-up) has not been performed. As such, the MARSSIM recommendation of setting the LBGR to 0.5 times the DCGL is used to calculate the number of required measurement locations (i.e., the DCGL = 1.0 pCi/g, so the LBGR = 1.0 pCi/g x 0.5 = 0.5 pCi/g).

(3) Sigma (σ)

For the purposes of this survey, the sigma values are drawn from data collected during the 2000 characterization survey. The standard deviation (σ) of Th-232 concentrations in the reference area (CABRERA 2000) from that survey is 0.3 pCi/g. To assure sufficient samples are taken the thorium is assumed to have a standard deviation 50% above the measured standard deviation. For the purposes of this survey, the σ used will be 0.45.

Based on the preceding, the values for relative shift are calculated for each area to be surveyed. The Δ/σ value for the NFA and the SP is 1.1.

(B) Determination of N (Number of Required Measurement Locations)

The Wilcoxon Rank Sum (WRS) statistical test will be used to determine whether portions of the site are suitable for release for unrestricted use, since the contaminants being measured are present in background. The minimum number of systematic measurement locations required in each survey unit for the WRS statistical test is determined using Table 5.3 in the MARSSIM. Using the acceptable α and β errors discussed in Section 5.11.6, the N for the NFA and each SP survey unit is 28. The α and β values associated with the Type I and Type II errors are five percent (5%).

5.6.2 Additional Samples to Meet EMC Criterion

MARSSIM states that in cases where scanning sensitivity is not sufficient to detect small areas of elevated radioactivity, additional samples may be necessary. In such cases, an area factor is used to evaluate the magnitude by which the concentration within a small area of elevated activity can exceed the $DCGL_w$ while maintaining compliance with the release criterion. The following formula is listed in section 5.5.2.4 of the MARSSIM for determining the necessary scan sensitivity when incorporating the area factor:

Scan MDC (required) = ($DCGL_w$) x (Area Factor)

If the actual scan MDC is greater than the required scan MDC, additional samples are required to ensure that the dose-based criterion is satisfied.

In the case of this investigation, the scanning sensitivity has been determined to be 1.8 pCi/g for Th-232. The Area Factor described above may be calculated utilizing the 28 samples taken for each survey unit from the NFA and SP. The average area covered by each sampled area in the NFA survey unit is 43 m^2, and 19 m^2 for the 0.30 m (1 ft) above ground level lift (largest area) of the SP. Utilizing Table 5.6 of MARSSIM and interpolating for area, the calculated area factors for Th-232 is 2.2 and 2.8 for the NFA and SP survey units respectively.

Application of the area factor results in a minimum scan MDC sensitivity not greater than 2.2 pCi/g for Th-232 compared to the MDC of 1.8. Thus scan MDC is adequate.

RESRAD version 6.21 was run in the deterministic mode with default parameters and Th-232 in equilibrium with its daughters. The code was run to include the "unlimited area" (RESRAD 10,000 square meters default), a 43 square meter area and a 19 square meter area. The area factors based on the maximum RESRAD dose (15.06 mrem/y) are: 43 square meters (7.02 mrem/y) resulting in an area factor of 2.1; and 19 square meters (5.736 mrem/y) resulting in an area factor of 2.6. These values are similar to and substantiate the MARSSIM interpolated values of 2.2 and 2.8 respectively. This evaluation verifies the area factors shown in Table 5.6 of MARSSIM for Th-232 for the area size of concern. MARSSIM table 5.6 was developed utilizing RESRAD version 5.6 which has since been refined by version 6.21. This is the likely cause of the minor differences in the derived area factors.

The summary results of the RESRAD code output is included as Attachment C of this Work Plan.

5.6.3 Gamma Walkover Coverage (GWS) in NFA and SP

The NFA and each lift of the SP will be surveyed as MARSSIM Class 1 areas, receiving 100% GWS coverage.

5.6.4 Sampling Coverage in NFA

As discussed previously, 28 systematic soil samples will be obtained in the NFA survey unit. Samples will be obtained at 0 to 0.15 m (0 to 6 in) below ground surface (bgs) after removal action has occurred.

Biased sample results will be compared to the $DCGL_{EMC}$ for evaluation of acceptability. The $DCGL_{EMC}$ has been determined from the area factor for the soil pile, SP, to be $DCGL_{EMC}$ = (area factor) x ($DCGL_W$) = 2.6 x 1 = 2.6 pCi/g Th-232. Likewise, the $DCGL_{EMC}$ for the North Fence Area is $DCGL_{EMC}$ = (area factor) x ($DCGL_W$) = 2.1 x 1 = 2.1 pCi/g Th-232.

Each sample point will be evaluated to determine if it is greater than background by the $DCGL_w$. The average of the reference area data will be considered the site "background" for this determination. When a sample result exceeds background by more than the DCGLw, it will be compared to the applicable $DCGL_{EMC}$. Areas that exceed background by more than the $DCGL_{EMC}$ will be considered unacceptable (i.e., will require remediation).

(A) Biased samples

If areas of elevated radioactivity are identified during the GWS, biased samples will be collected and analyzed to facilitate evaluation of elevated area radionuclide concentrations against MARSSIM elevated measurement comparison (EMC) criteria. In addition, bias measurements may be obtained in areas of rough or cracked surfaces, drainage pathways, fence line, windbreaks etc. At a minimum, one biased soil sample will be collected in the NFA survey unit at the location of the highest gamma walkover reading. Biased samples may also be collected at locations where GWS data Z-scores exceed 3.0 (see Section 5.11.5(E)(2)). Because the GWS has not yet been performed and limited data is available regarding the radiological status of the NFA, it is difficult to estimate the total number of biased samples that will be required. Notwithstanding this, it is assumed that approximately two biased samples will be collected and analyzed as part of the final status survey from each survey unit.

5.6.5 Sampling Coverage in SP

As discussed above, 28 systematic soil samples will be obtained for each 0.30 m (1 ft) soil lift (i.e., SP survey unit). Samples will be obtained at 0 to 0.30 m (0 to 12 in) bgs.

(A) Biased measurements

If areas of elevated radioactivity are identified during the GWS, biased samples will be collected and analyzed to facilitate evaluation of elevated area radionuclide concentrations against MARSSIM elevated measurement comparison (EMC) criteria. At a minimum, one biased soil sample will be collected in each 0.30 m (1 ft) lift of the SP survey units at the location of the highest gamma walkover reading. In addition biased samples may be obtained in the area of the previously identified buried discrete radium source. Biased samples may also be collected at locations where GWS data "Z" Scores exceed 3.0 (see Section 5.11.5(E)(2)). Because the GWS has not yet been performed and limited data is available regarding the radiological status of the SP, it is difficult to estimate the total number of biased samples that will be required. Notwithstanding this, it is assumed that approximately 30 biased samples will be collected and analyzed as part of the final status survey. Figure 3 presents an example of the sample spacing to be used for the survey units. For the purposes of this work plan the number of samples is assumed to be the same for each lift of the SP. In reality, the area will change as the lifts are removed and the sample locations will be spaced accordingly.

5.7 Survey Instrumentation and Survey Techniques

5.7.1 Gamma Walkover Survey

A 100% GWS will be performed over accessible areas in each Class 1 survey unit, as recommended in MARSSIM. The purpose of the GWS is to identify areas of elevated radioactivity. The approximate detection sensitivity of the GWS is 1.8 pCi/gram for Th-232 in secular equilibrium with its radioactive daughter products (see Attachment A). The detection sensitivity is based on surficially deposited 0 to 0.30 m ((0 to 6 in) isotopes. Equipment required for performing the GWS survey includes the following:

- GPS Rover: Trimble Pathfinder Pro - XRS (or equivalent)
- 2 in. by 2 in. NaI detector and associated rate-meter/scaler, equipped with RS-232 download port
- Hardware: IBM-compatible Pentium (minimum) PC, color printer, large capacity data storage device (e.g., zip drive), modem, large format plotter, (note that some hardware may not be site-based).
- Software: Trimble Pathfinder Office, AutoCAD (or equivalent CAD software) with coordinate geometry capability.

The survey will be performed following MARSSIM protocol by walking straight parallel lines over an area while moving the detector in a serpentine motion, 0.05 to 0.10 m (2 to 4 in) above the ground surface. Survey passes will be approximately one m apart. Data from the ratemeter/scaler will be automatically logged into the GPS unit every one second. After completion of the survey, the raw data will be downloaded from the GPS and sent to a data processing specialist for export into a geospatial software program. After completion of data processing, an electronic file with the contoured results of the survey will be returned to the on-site Project Engineer for evaluation.

5.7.2 Soil Sampling

Surface soil samples will be collected in the NFA survey unit NFA-SU-1, NFA-SU-2, SP survey unit SP-SU-N, and in the onsite reference area to enable statistical evaluation of site radionuclide concentrations relative to the DCGL, in accordance with MARSSIM guidance. Soil samples will be collected using hand augers or equivalent equipment and will be collected from 0 to 0.15 m (o to 6 in) in the NFA and 0 to 0.30 m (0 to 12 in) in the SP survey units. The reference area soil samples (CABRERA 2000) were collected at depths of 0.15 to 0.30 m (6 to 12 in) to better approximate NFA sample depths, as approximately the top 0.15 m of the NFA will be remediated. Additional reference area soil samples will be taken in the same reference area as calendar year 2000 as part of this field effort. A total of at least 28 reference area soil samples will be taken. This number is based upon MARSSIM table 5.3 and input as previously described in Section 5.7.1.The following equipment (or equivalent) will be required for this task.

- Hand auger
- Large stainless steel mixing bowl
- Stainless steel utensil for removal of soil core from hand auger after sample is retrieved and for mixing and packaging samples in containers
- Sample containers and chain of custody forms/seals

5.8 Preparation of Survey Units

The NFA and SP survey units may contain debris and equipment, which may obstruct the final status survey. Should such obstructions exist, they will be brought to the attention of the AJMC Site Project Manager and NAVSEADET RASO. The AJMC Project Manager and NAVSEADET RASO will make the decision on removal of the obstruction or of no action. Should the "no action" scenario be adopted the CABRERA Site Manager will record the area and location of the survey exclusion zone and identify its coordinates using the GPS.

5.9 Establish the Survey Reference Coordinate System

To facilitate both survey measurements and data analysis, a survey reference coordinate system will be developed and installed early in the survey process. Coordinates will be referenced to the Illinois State Plane Coordinate System, Zone 1201, Illinois East. The horizontal datum will be the North American Datum of 1983 (NAD 83). At a minimum, the corners of survey units will be identified and clearly marked. Additionally, to facilitate the walkover survey process, intermediate markings may be installed to mark the start and end points of planned survey lines. Use of GPS obviates the need for marking small grid intervals.

5.10 Specify Sampling Locations

Systematic sample locations in NFA and SP survey units will be established and marked using survey flags, paint, or equivalent markings, prior to sample collection. A triangular sampling grid will be established for each survey unit based on its area. Actual survey unit areas will be measured in the field, as it is anticipated that minor deviations from the planned survey unit dimensions will be necessary. This is especially true for the SP which is irregular in shape and has angled perimeter walls resulting in each lift being of slightly larger area than the lift above it. The triangular grid spacing for each survey unit will be determined, based on the measured area of the survey unit, using the following equation (Equation 5-5 from MARSSIM).

$$L = \sqrt{\frac{A}{0.866 \times N}}$$

Where:	L	=	square grid spacing for survey unit
	A	=	area of survey unit

N = number of sample locations

A random start point will be generated and systematic sample locations will be marked in an equilaterial triangular grid using the spacing calculated by the equation shown above.

If the GWS identifies areas of elevated radioactivity, biased samples will be collected to evaluate elevated area radionuclide concentrations against MARSSIM elevated measurement comparison (EMC) criteria. Biased sample locations will be selected based on the results of the GWS, as well as other factors as described in Section 5.6. At a minimum, one biased sample will be collected in each survey unit at the location of the highest gamma walkover measurement.

5.11 Data Quality Objectives for NFA and SP Final Status Surveys

5.11.1 Step 1: State the Problem

(A) Problem Description

The objective of final status survey activities in the NFA and SP is to obtain data of sufficient quality and quantity to support unrestricted release of the areas. The problem is the presence of radioactive material, in the form of monazite sand from former operations and potential for discrete radium sources in the SP. Specific ROPCs present include Th-232 and its radioactive daughter products.

Final Status Survey planning is being performed by a team of CABRERA personnel, with input from the AJMC and NAVSEADET RASO.

(B) Primary Decision Maker

The ultimate decision regarding site disposition will rest with NAVSEADET RASO, in consultation with its regulators. As such, NAVSEADET RASO, in consultation with the AJMC Project Manager, and contractor, will make decisions for the final status survey activities.

(C) Available Resources and Relevant Deadlines

Sufficient resources are available through the combined staff of the AJMC, CABRERA, Naval Training Center, Great Lakes, and NAVSEADET RASO to perform and complete work required achieving final status survey objectives.

5.11.2 Step 2: Identify the Decision

(A) Principal Study Question

Do ROPC concentrations in the NFA and SP survey units exceed background concentrations by more than the DCGL and, if so, what are those concentrations and where in the survey units are they located?

(B) Decision Statement

The following statements assume that ROPC concentrations in Class 1 survey units will be found to exceed background concentrations by more than the DCGL. Decision Statements should be evaluated sequentially, as shown.

(1) Determine whether ROPC concentrations in the survey units exceed background concentrations by more than the DCGL.

(2) Based on sample results, if ROPC concentrations exceed background concentrations by more than the DCGL, perform required remediation.

5.11.3 Step 3: Identify Inputs to the Decision

In order to resolve the decision statements listed in Section 5.12.2 a variety of data is required. This section lists data needs, describes the sources of that data, and discusses the means of obtaining the required data points.

(A) Information Inputs:

The following site characteristics must be determined in order to resolve applicable decision statements:

(1) Concentrations of residual radioactive material in the NFA and the SP:

This information will allow determination as to whether or not the survey units are likely to be suitable for free release. Obtaining this data will facilitate cost effective decision-making about the project's direction and duration.

(B) Information Sources for Above Listed Items:

(1) Concentrations of residual radioactive material in the NFA and SP as determined from onsite lab analyses:

Volumetric sample analysis and gamma walkover survey (GWS) data will provide sufficient information to enable determination of NFA and SP radionuclide concentrations.

5.11.4 Step 4: Define the Study Boundaries

(A) Population of Interest Defining Characteristics:

The population of interest for the NFA is the Th-232 concentrations above background in surface and shallow subsurface soils.

The population of interest for the SP is the Th-232 concentrations above background in the 0.30 m (1 ft) soil lifts with the exception of the lower 0.30 m remaining above the ground that the SP covers.

(B) Spatial Boundaries of the Decision Statement:

The population of interest study is horizontally limited to land areas located in the survey units (see Figure 1). The vertical study area extends from the land surface to the depth of up to 0.15 m (6 in) bgs for the NFA and the SP ground level.

(C) Temporal Boundaries of the Decision Statement

(1) Time frame to which the decision applies:

DCGL values are based on risks to an average member of the Critical Group over a 1000-year period following the study.

(2) Time for data collection:

Data collection and analysis should be performed as soon as practical, as timely completion of the structures and work onsite are contingent upon the results of the final status survey.

(D) Scale of Decision Making:

The NFA Class 1 and 2 area residual radioactivity measurements will be reviewed against the DCGL criteria to assure that no areas exceed the DCGL. Small areas of elevated activity could exist in the Class 1 areas and could require additional sampling points.

All class 2 areas must be below the DCGL. Any Class 2 area greater than the DCGL will be flagged for further investigation/remediation.

Decisions will be made for small areas that may exhibit elevated levels of radioactivity, then for individual survey units regarding whether or not they meet the criteria for unrestricted or restricted release.

(E) Constraints on Data Collection:

Data collection activities can be constrained due to excessive moisture or rain, which can have an adverse effect on field instrumentation and volumetric sample collection. Extremely cold weather can also inhibit data collection, due to its effects on both equipment and project personnel.

5.11.5 Step 5: State the Decision Rules

(A) Parameter of Interest

Parameters of interest are the mean, median, and standard deviation of data collected during the study. Based on the data distribution characteristics resulting from characterization data collection, the preceding parameters may be transformed to equivalent descriptive measures (e.g., logarithms, etc.) to allow more representative statistical testing. By using a graded approach to data testing as discussed below, decisions will be made according to the decision rule stated at the end of this section.

(B) Scale of Decision Making

Decisions are made on two fundamental scales, the survey unit and smaller localized areas of elevated activity. Localized areas of elevated radiation levels are evaluated on an ongoing basis throughout the field effort. In cases where clear indications of elevated measurements are observed, decisions on remediation, survey unit subdivision, etc., may be taken as appropriate. On a larger scale, and as a final determination, data will be evaluated on a survey unit-specific basis.

(C) Action Level

Decisions on a survey unit's acceptability for release are based on comparison of the DCGL to the difference between measured residual radioactivity concentrations in survey units and measured radioactivity in the reference area, subject to applicable statistical analyses specified in MARSSIM. Inputs to this decision will be based on a graded approach to data analysis intended to avoid unnecessary analytical and/or remediation efforts, while also ensuring that project DQOs are met. Graphical and statistical approaches to data analysis are included in the Data Quality Assessment (DQA) process, which is the, "... scientific and statistical evaluation of data to determine if the data are of the right type, quality, and quantity to support their intended use."

For the purposes of this Final Status Survey, the action level used for data comparison is 0.5 pCi/g above background for Th-232, a value corresponding to the Lower Bound of the Gray Region (LBGR). The LBGR concept is discussed in more detail in Section 5.5.1.

(D) Decision Inputs

Geospatial modeling of position-correlated GWS data will provide a graphical view of surface gamma radiation levels and will be updated as the survey progresses. This will serve as the primary decision input during performance of the fieldwork because data will be reduced soon after collection, in comparison to the longer turn around time associated with sample analysis.

Assessment of soil sample data will be as simple as visually inspecting data to identify obvious indicators that the action level has or has not been met. If sample results are below the DCGL, the survey unit will meet the release criteria. If not, the WRS test will be applied to the data.

(1) Spot-Check Gamma Scans During Survey Unit Delineation

Initially, the perimeter of each survey unit will be marked with stakes or survey flags based on the dimensions established in this plan. During this process, the boundary areas will be checked with gross gamma detection instruments to ensure the boundaries surround the areas with observed elevated gamma count rates.

(2) Field Measurements of Survey Unit Dimensions

The dimensions of the survey units will be determined using GPS data, downloaded and interpreted in AutoCad. At a minimum, the corners of the survey units will be logged using the GPS system. The area of each survey unit will then be calculated in units of m^2. This data will be used to determine grid spacing and ensure that survey units do not exceed the maximum size recommended by MARSSIM.

(3) GWS in NFA and SP Survey Units

NFA and SP survey unit GWS data will be reduced and evaluated as follows:

- The measurements will be plotted and color-coded for visual review and evaluation. The average and standard deviation of each survey unit will also be calculated. The location of the highest measurement will be located.

- All data will be evaluated for outliers. CABRERA will plot the measurement data by color-coding in the following ranges: below the scan MDC- light green; between scan MDC and Action Level – dark green; between the action level and the DCGL – orange; and above the DCGL – black.

- The difference between each data point and the average of the survey unit in which it was obtained will be calculated and divided by the standard deviation of the survey unit. This will convert the measurements to multiples of the survey unit standard deviation above or below the average (Z-scores). The color-coding will be based on multiples of the survey unit standard deviation.

- Areas exceeding three standard deviations (3Z) above the survey unit will be identified. The frequency of these occurrences and the maximum measurement in these areas will be compared to the reference area. The geospatial plot will also be visually inspected to identify anomalies in the distribution of measurement data.

(4) Sample Results: Wilcoxon Rank Sum (WRS) Statistical Test

Comparison of RA (background) radionuclide concentrations with survey unit concentrations will be performed using the two-sample WRS statistical test. This test is selected because the ROPCs are present in the natural background. The two-sample WRS test assumes the RA and survey unit data distributions are similar except for a possible shift in the medians. When the data are severely skewed, the value for the mean difference between survey unit measurements and reference measurements may be above the DCGL, while the median difference is below the DCGL. In such cases, the survey unit does not meet the release criterion regardless of the result of the statistical test. On the other hand, if the difference between the largest survey unit measurement and the smallest RA measurement is less than the DCGL, the WRS test will always show that the survey unit meets the release criterion.

In using this test, the hypotheses being tested are:

Null Hypothesis (H_0): The median concentration in the survey unit exceeds that in the RA by more than the DCGL.

versus the alternative:

Alternative Hypothesis (H_a): The median concentration in the survey unit exceeds that in the RA by less than the DCGL.

The WRS will be applied to the Th-232 and Ra-226 concentrations as described in the MARSSIM.

(E) Decision Rules

(1) Field Measurements of Survey Unit Dimensions

If the measured dimensions of a survey unit exceed the 2,000 m^2 maximum recommended by MARSSIM, the AJMC Project Manager and NAVSEADET RASO will be contacted. With their concurrence, the survey unit boundaries will be adjusted accordingly. Significantly larger areas may require setting up additional survey units.

(2) GWS in NFA and SP Survey Units

- A biased soil sample will be collected at the location where the highest GWS data point is observed. Biased samples will not be analyzed by WRS testing.

- If areas exceeding three standard deviations above the RA standard mean are observed, a Z-score plot based on survey unit data will be generated. The Z-score plot is a graphical depiction of survey unit standard deviation values. This plot will be examined to determine areas where additional investigation is warranted. Additional investigations include biased sampling followed by quick laboratory analysis turnaround.

(3) Sample Results: Wilcoxon Rank Sum (WRS) Statistical Test

- If sample results for the survey unit are less than the DCGL, the survey unit is deemed to meet the release criterion.

- If any of the sample results for the survey unit exceeds the DCGL, perform the WRS test. If W_r, the output from the WRS test, for the survey unit is less than the applicable critical value, the median value for residual radioactivity in the survey unit is less than the DCGL to the specified confidence level as indicated by the acceptable decision error specified (see following section). The survey unit meets the release criterion. If W_r for the survey unit is greater than the applicable critical value, the median value for residual radioactivity in the survey unit is greater than the DCGL and the survey unit does not meet the release criterion. Contact the AJMC Project Manager and NAVSEADET RASO for any survey units that do not meet the release criteria (W_r for the survey unit is greater than the applicable critical value). See Section 6.4 for additional discussion of the WRS parameters.

5.11.6 Step 6: Define Acceptable Decision Errors

NRC guidance provides a discussion regarding decision errors. This discussion includes the concept that acceptable error rates, which balance the need to make appropriate decisions with the financial costs of achieving high degrees of certainty, must be specified.

> *Errors can be made when making site remediation decisions. The use of statistical methods allows for controlling the probability of making decision errors. When designing a statistical test, acceptable error rates for incorrectly determining that a site meets or does not meet the applicable decommissioning criteria must be specified. In determining these error rates, consideration should be given to the number of sample data points that are necessary to achieve them. Lower error rates require more measurements, but result in statistical tests of greater power and higher levels of confidence in the decisions. In setting error rates, it is important to balance the consequences of making a decision error against the cost of achieving greater certainty.*

Acceptability decisions are often made based on acceptance criteria. If the mean and median concentrations of a contaminant are less than the associated acceptance criteria, for example, the results can usually be accepted. In cases where data results are not so clear, statistically based decisions are necessary. Statistical acceptability decisions, however, are always subject to error. Two possible error types are associated with such decisions.

The first type of decision error, called a Type I error, occurs when the null hypothesis is rejected when it is actually true. A Type I error is sometimes called a "false positive." The probability of a Type I error is usually denoted by α. Considered in light of H_0 used for this site (discussed above), this error could result in higher potential doses to future site occupants than prescribed by the dose-based criterion.

The second type of decision error, called a Type II error, occurs when the null hypothesis is not rejected when it is actually false. A Type II error is sometimes called a "false negative." The probability of a Type II error is usually denoted by β. The power of a statistical test is defined as the probability of rejecting the null hypotheses when it is false. It is numerically equal to 1-β where β is the Type II error rate. Consequences of Type II errors at the Site include unnecessary remediation expense and project delays.

For the purposes of the NFA and SP final status survey, the acceptable error rate for both Type I and Type II errors is five percent (0.05).

6.0 METHODOLOGY AND APPROACH TO PERFORMING SURVEYS

6.1 Gamma Walkover Survey Utilizing GPS

6.1.1 Estimated Scan Sensitivity

MARSSIM Section 6.7.2.1 describes the methodology used to calculate the Scan Minimum Detectable Concentrations (MDCs) for land areas that are delineated in MARSSIM Table 6.7. The MDC for Th-232 in equilibrium with its progeny in the decay series is 1.8 pCi/g for a 2-inch by 2-inch sodium iodide detector. This methodology is based on a scan speed of 0.5 meters per second and a minimum contaminated area 56 cm in diameter and 15 cm in depth. In a similar fashion, the MDC for Ra-226 in equilibrium with progeny is 2.8 pCi/g for a 2-inch by 2-inch sodium iodide detector. Attachment A entitled *2 in x 2 in NaI MDC Technical Memorandum (Rev. 1)* provides details regarding the calculations used to determine the scan MDC for Th-232.

The gross gamma walkover scan survey in this plan was designed using these parameters. The basic method for performing a GWS is to walk along a path while moving the sodium iodide detector from side to side. A 1-m path width will be used to perform the survey. The total length of travel is approximately 1,200 m for the Class 1 areas and a somewhat smaller distance for the Class 2 area.

6.1.2 GPS Setup

The Global Positioning System (GPS) system will provide high quality, precision geospatial positioning data to support characterization, data verification, and remediation. The rate-meter/scalars used for this work plan will be configured to output directly to the GPS unit. The GPS unit will perform data logging functions.

In order for the GPS unit to achieve sub-meter accuracy, differential position correction is necessary. The units used for this project will achieve realtime differential correction using the Omnistar satellite service. Each technician will carry his/her own rover unit operating both the detector and GPS (making entries into the GPS and checking detector responses).

A survey is performed by walking straight parallel lines over an area while moving the detector in a serpentine motion 0.05 to 0.10 m (2 in to 4-in) above the ground surface. Lines will be approximately one m apart. Once a survey (or series of surveys) is complete, technicians will return the data files to the data processing specialist. The major steps in completing a radiological walkover survey include the following:

1. Technicians arrive at a site designated for a GWS and observe the layout of the area.

2. Significant site features such as buildings, wooded areas, waste piles, or other obstructions are noted on a field map.

3. Technicians, with guidance from the Project Engineer, plan the survey around area features (i.e., decide where survey lines should start and stop, how to survey around obstacles, etc.).

4. Guide markers are positioned accordingly to ensure that the surveyor walks straight lines and achieves complete area coverage (e.g., pin flags are placed at starting and stopping locations).

5. The corners of the designated survey area are located to bound the area.

6. The technician performing the survey records the survey line numbers, the directions each line was walked, deviations around obstructions, etc.

7. The positions of major obstacles (buildings, trailers, etc.) are surveyed by orienting the GPS unit in corners or other distinct locations and collecting position data. These features (called discrete points) are drawn to approximate location and scale in the field notes.

8. The data files (containing the walkover survey data and discrete point measurements) are turned over to the data processing specialist.

Each survey will be designed to optimize the survey data collection procedure, taking into account the area's configuration, buildings, hazards, and other obstructions. Copies of the base map on which structures, roads, or other major features have been located will be available on-site. Technicians will annotate copies of the base map with information relevant to the survey as appropriate.

Each survey pass will be assigned a line number in the GPS unit's data file. The direction of each survey pass will also be noted. Occasionally, non-parallel paths may be required when the surveyor must avoid obstructions such as large bushes, vehicles, or small structures. Significant from a straight path and non-parallel paths may be noted on the field map. Starting at the beginning of a line, the surveyor will begin to collect data and walk straight to a designated endpoint at a constant velocity of approximately 0.25 m per second. The surveyor will stop collecting data once the end point is reached and then position himself at the beginning of the next line. Once in position, the surveyor will again begin to collect data and walk a line parallel to the previous line, stopping at the next designated end point. The survey will continue in this manner until completion. At the discretion of the CABRERA Project Engineer, the preceding methodology may be modified to enable better efficiency in completing the survey. Such modifications will be noted in the project logbook.

Elevated radiation levels detected while surveying the path may be flagged at the time of detection without stopping the path in progress or may be investigated when identified. After the traverse is complete, the surveyors may return to the flagged area and collect supplementary data. These supplemental surveys will be designated in the data dictionary, and annotated on the field map.

Using proper survey technique expedites the survey process and assists post-processing specialists. Additional useful instructions include the following:

- Walk along avoiding tall obstacles, when possible. Walking into an obstacle may result in a path ending without satellite lock. If it becomes necessary to walk toward a tall obstacle, plan the survey to approach the obstacle from the south side, since the majority of satellites are in the south.

- To avoid confusion, lower or remove markers (e.g., pin flags) from paths already surveyed. A surveyor may become confused about which marker is at the next endpoint.

- When recording supplementary data, hold the sensor at approximately the same distance from the ground as during a normal line survey. Consistency in the detection method is important when interpreting survey results.

- Limit individual survey times (i.e., the file size) to one hour or other time specified by the post-processing specialist to minimize the potential for lost data.

- Collect enough discrete points to define structure (or other feature) boundaries.

- When collecting discrete points, hold the GPS antenna directly over the designated feature to optimize position data. If using base maps generated from aerial photography, the discrete point should locate the "drip line" of the corner of the roof, not the corner of the structure.

- Do not round corners to avoid obstacles. Deviate from the imaginary line between markers only when necessary and return to the line as soon as possible.

- When surveying in wooded areas or areas with overhead obstructions, attempt to start and stop at known locations. A "known location" is defined here as a location that can be surveyed by some other means (e.g., measured from a discrete point or at a mapped boundary) or to which survey lines can be extended from areas where satellite lock is achieved.

Although major features such as buildings may appear on base and field maps, position data still should be collected as discrete boundary locations. These discrete points function as mapping control points that facilitate matching and overlaying the GPS positional data collected in the field with the known (previously mapped) locations. Discrete points shall be recorded in the data collector and annotated onto the field map.

6.1.3 Survey Limitations

Although the GPS unit identifies its position using the signals from several satellites, GPS positioning may be affected by overhead obstructions during the course of survey. A loss of satellite signal due to these obstructions may prevent collection of location data, depending on the severity of the loss and the positional filter settings in use in the GPS unit. If this occurs, data collection will not resume until satellite lock is regained (usually by moving past the obstruction) and the positional filter requirements are satisfied. If the signal is lost during a survey, the operator shall continue to walk at constant velocity in a straight line until satellite lock has been reestablished or until a boundary is reached. In such cases, due to positional filter settings in the GPS unit, no gamma logging occurs. In that event, gamma readings must be taken by hand. The surveyor will need to inform the data processing specialist if the gamma count rates between pairs of GPS positional data changes considerably. Such information will be logged in project logs as appropriate. At the discretion of the CABRERA Project Engineer, logging filters may be temporarily overridden to enable gamma logging without GPS lock for brief periods. In such cases, it is especially important to proceed at a constant velocity so that locations for data collected in this manner can be interpolated or extrapolated.

Interpolation and/or extrapolation of gamma data positions beyond good GPS locations require additional post-processing programs or hand editing of data. It is desirable, therefore, to begin and end a survey path with good GPS positions. The survey crew shall extend the beginning or end of a survey path (in a straight line) beyond a designated boundary in order to obtain satellite lock, if necessary. On occasion, it may not be possible to get a good satellite lock because of satellite positions in the sky or technical problems with the satellite system. In this case, a short wait (e.g., one-half hour) is usually sufficient to regain satellite lock. If necessary, survey paths without good satellite locks will be repeated and/or hand surveyed and located.

6.2 Onsite Field Operations Laboratory

6.2.1 General

The Cabrera Services field team will collect soil samples for subsequent on-site analysis utilizing the Field Operations Laboratory (Laboratory) at the Site. The Laboratory analyses will be performed using a gamma spectroscopy system utilizing a high purity germanium (HPGe) coaxial detector, or equivalent. This system will be calibrated with a NIST traceable multiline gamma marinelli standard.

Soil samples will be collected at selected locations in the NFA and SP survey units. Personnel collecting samples will ensure each sample is placed into a clean, unused container. Each sample will be labeled and annotated with, as a minimum, a unique (preferably sequential) sample number, the sampler's name, the sampling date and time, the sample location and any applicable comments. For each single sample or related batch of samples, a sample chain-of-custody form will be filled out. The samples will be either individually listed or batch listed (by chain of custody form number) in the Project Logbook. Samples awaiting shipment to the contract off-site laboratory will be stored in a designated, secure location. Original chain-of-custody forms will remain with the samples to which they apply throughout their life cycle and will be annotated with the shipper's tracking number during times when they are in transit.

Following collection, these samples will be prepared for analysis in accordance with approved procedures by being heated in an oven for moisture removal, ground, and sieved, and subsequently transferred into one-liter marinelli containers prior to gamma spectroscopy analysis. The gamma spectroscopy system will be operated by a trained operator in accordance with standard operating procedures. The operator will perform spectral analysis during each measurement, which will encompass the evaluation of spectra for problems such as peak shift, high dead-time and other potential inconsistencies in spectral structure. A qualified Radiological Engineer will review the integrity of the sample analysis results for each sample. This review will encompass the analysis of sample results for spectral energy shift, agreement between progeny activities assumed to be in secular equilibrium, the presence of potentially unidentified radionuclides, potential source model inconsistencies, as well as other potential inconsistencies.

Count times will be long enough to accomplish sufficient MDCs for each radionuclide to meet applicable Site action levels.

6.2.2 Spectroscopic Energy Lines

The site ROPC is Th-232. This radionuclides may be quantified for activity concentrations directly via gamma decays, or inferred via gamma-emitting progeny, assuming secular equilibrium.

Th-232 activity concentrations will be inferred via progeny activity concentrations of Pb-212 at 238.6 keV, Ac-228 at 911.2 keV and others, assuming secular equilibrium.

Should Ra-226 be encountered, the short-lived equilibrium daughters of radium may be used to determine radium-226 concentrations in the soil. Unfortunately, once the soil is disturbed, these short-lived daughters must be allowed to grow back in. The parent of these daughters, Rn-222, has a moderate half life of 3.8 days, therefore requiring at least two to three weeks of progeny ingrowth to reestablish equilibrium. Since the purpose of establishing the field laboratory is to obtain real time sample results to control excavation activities and enhance remediation decision making, this delay is not practical. Therefore, Ra-226 will be measured directly by detection of its 186.2 keV energy line. It should be noted that U-235 also has a gamma line of similar energy (185.7 keV) that can cause interference with direct Ra-226 detection via the 186.2 keV gamma line. As uranium is not expected to be detected in significant quantities on this project, the only result from this issue may be minor over reporting of Ra-226.

Gamma spectroscopy will also identify other gamma emitting radionuclides that may be present in soils. CABRERA's field laboratory will use a gamma library compiled with data from the National Nuclear Data Center, which lists gamma energy yields for a full range of gamma emitting radionuclides. The data used to compile the library is updated through March 2002.

6.2.3 Quality Assurance

Initial and daily calibrations of the field operation laboratory spectroscopy system will be performed using a mixed-gamma NIST traceable source. System quality assurance will be ensured by tracking peak energy, peak resolution, and net peak area for a high and low energy peak, based on daily source counts. These quality assurance checks will be performed in accordance with applicable CABRERA quality control procedures. The procedures in question are included in CABRERA's Nuclear Materials License and, as such, have been reviewed and found adequate by the NRC. Copies are available for inspection upon request. Instrument control charts will be generated and evaluated and will be included as part of the final status survey report.

6.3 Sample Collection and Analysis

Soil sampling will be achieved using hand-augers or powered augers, as appropriate. Soil samples will be extruded from the augers and transferred into a stainless steel bowl where they will be thoroughly mixed or homogenized. Visually identifiable non-soil components such as stones, twigs, and foreign objects will be manually separated in the field and excluded from the laboratory samples to avoid biasing results low. Samples will not be preserved in the field, as there are no preservation requirements for the radiological analyses. Augers, mixing utensils, and homogenizing bowls will be decontaminated between samples to avoid cross-contamination. Decontamination will be performed by rinsing with water and returning the rinsate to the ground surface in the location where the sample was collected.

Duplicate sample analyses will be performed by a third party laboratory analyzing the original sample as counted by the onsite laboratory. Field duplicate samples will be collected at the frequency specified in Section 7.3.1. Z-score results will be utilized to compare the initial results to the duplicate sample results.

Duplicate samples will be numbered, logged, and transferred, under the CABRERA chain of custody procedures, to the Paragon Analytics, Inc. laboratory in Fort Collins, Colorado for analyses. Paragon Analytics will prepare and provide containers that meet their analytical requirements. The containers will have sufficient capacity to hold the contents of a one-liter marinelli sample container.

Upon receipt at Paragon Analytics the samples will be weighed, dried, and reweighed. The sample will be prepared according to Paragon's internal procedures. Samples being analyzed for radium via gamma spectroscopy will be placed in an airtight container and sealed. The sample will then be stored for approximately 21 days to allow radium equilibrium to be reestablished. Each sample will be analyzed for thorium and uranium series radionuclides using gamma spectroscopy for Uranium-238 (U-238), Radium-226 (Ra-226), Thorium-232 (Th-232) by quantifying their radioactive progeny.

Soil samples will be prepared by drying, sieving and weighing in accordance with Paragon SOP 739, Revision 3, 1999. Analysis by gamma spectroscopy will be performed in accordance with Paragon SOP 713, Revision 5, 2000, which conforms or exceeds the requirements of EPA procedure 901.1.

6.4 Final Status Survey Data Evaluation

Because naturally occurring concentrations of the ROPCs are present in background, hypothesis testing will be performed by the Wilcoxon Rank Sum (WRS) test. In this test, the null hypothesis, H_0, is that the median residual Th-232 concentration in each survey unit being tested exceeds background by more than the DCGL. In the WRS test, reference area (background) measurements are adjusted and, along with survey unit measurements, are ranked, summed, and compared to a critical value. If the sum, or W_r, of the ranks of the ranked reference measurements is greater than the critical value, W_{crit}, H_0 is rejected. The general approach to applying the WRS test is summarized below.

- Obtain the adjusted reference area measurements, Z_i, by adding the DCGLW to each reference area measurement, X_i . $Z_i = X_i + DCGL_W$
- The m adjusted reference sample measurements, Z_i , from the reference area and the n sample measurements, Y_i, from the survey unit are pooled and ranked in order of increasing size from 1 to N, where N = m+n.
- If several measurements are tied (i.e., have the same value), they are all assigned the average rank of that group of tied measurements.
- If there are t "less than" values, they are all given the average of the ranks from 1 to t. Therefore, they are all assigned the rank t(t+1)/(2t) = (t+1)/2, which is the average of the first t integers. If there is more than one detection limit, all observations below the largest detection limit should be treated as "less than" values.
- Sum the ranks of the adjusted measurements from the reference area, W_r.
- Obtain the value of W_{crit} from Table I-4 of the MARSSIM for sample sizes less than 20. Since 32 samples were obtained in the reference area at Great Lakes, calculate the critical value, W_{crit}, from the following:

$$W_{crit} = m(n+m+1)/2 + z\sqrt{nm(n+m+1)/12}$$

Where z is the (1-α) percentile of a standard normal distribution, which can be found in Table-1:

Table 1:

Percentiles of Standard Normal Distribution

α	z
0.001	3.09
0.005	2.575
0.01	2.326
0.025	1.960
0.05	1.645
0.1	1.282

Note that, for this investigation, the value of W_{crit} for the SP soil lift survey units is 390, while the W_{crit} value for the NFA survey unit is 444.

- Compare W_r with the critical value for the appropriate values of n, m, and α. If W_r is greater than W_{crit}, reject the hypothesis that the survey unit exceeds the release criterion.

Additional information on the WRS test is found in Section 8 of the MARSSIM.

6.5 Characterization of Discrete Soil Pile (SP) Layers

A characterization survey will be performed for two soil layers in the SP of one foot depth each. The first soil layer is located from one foot above ground surface to the ground surface (i.e., the last remaining one foot depth of the SP) and the second layer from the ground surface to one foot bgs. These soils will be characterized, instead of performing a FSS due to the potential presence of Ra-226 contaminants in the soil at these discrete depths.

The characterization survey will encompass a 100% GWS on the surface of the remaining SP. The characterization GWS will be performed using the same methods as described for the FSS GWS in Sections 5.7 and 6.1. During the GWS, the coordinates of 3 discrete locations showing the most elevated activity will be recorded using the GPS and used as the locations from which to collect bias soil samples.

The characterization survey will also encompass the collection of a total of 69 soil samples. Soil samples will be collected using the same methods as described for the FSS soil sampling in sections 5.7 and 6.3. The 69 total soil samples include 28 systematic soil samples from 0 to 0.30 m (0 to 12 in) depth and 28 soil samples at the same locations from 0.30 to 0.60 m (12 to 24 in) depth (i.e., representing the bottom 0.30 m (1 ft) SP layer and the ground surface to one foot bgs layer), 10% bias samples (i.e., 6 additional soil samples), and 10% samples for QC comparison (i.e., 7 duplicate samples).

Note: At least four of the seven QC samples should be from bias samples and all of the bias samples will be collected at the locations presenting the most elevated count rates recorded during the GWS.

6.6 Field Records

For surveys of all types, it is essential that significant events be documented and retained for future reference. While some types of project events have specific forms on which they are documented, many events occur on a routine basis during survey field activities that must be documented as they occur. Additionally, project data transactions must also be recorded as they occur. To provide a practical means of capturing this information, project logbooks will be used. At a minimum, the two logbooks described below will be initiated upon project commencement.

6.6.1 Project Data Logbook

Data transactions involving electronic project data shall be recorded in the Project Data Logbook. Electronic project data includes GWS data files, GPS files, hand collected gamma data, etc. Data transactions are defined as any transfer, download, export, differential correction, or other significant manipulation performed on project electronic data records. Project Data Logbook records shall be sufficient to allow data transactions to be reconstructed after the project is completed. The Data Processing Specialist shall be responsible for maintaining the Project Data Logbook. The Project Engineer is responsible to ensure Project Data Logbook entries are made as necessary and appropriate. The Project Engineer will review the Project Data Logbook at least daily and will report significant issues to the Project Manager.

The Project Data Logbook is considered a legal record. Logbooks will be permanently bound and the pages will be pre-numbered. Pages may not be removed from the logbook under any circumstances. Entries shall be legible, factual, detailed, and complete and shall be signed and dated by the individual(s) making the entries. If a mistake is made, the individual making the entry shall place a single line through the erroneous entry and shall initial and date the deletion. Under no circumstances shall any previously entered information be completely obliterated. Use of whiteout in the Project Data Logbook is not permitted for any reason. Only one Project Data Logbook will be maintained. If a Project Data Logbook is completely filled, another volume shall be initiated. In this case, each volume shall be sequentially numbered.

6.6.2 Field Survey Logbooks

These logbooks will be carried by each survey team during project operations. If multiple volumes are needed to support multiple field survey teams, each volume will be clearly identified with a unique designation approved by the Project Engineer. Any survey teams collecting project data shall carry a Field Survey Logbook.

Like the Project Data Logbook, Field Survey Logbooks are considered legal records. Logbooks will be permanently bound and the pages will be pre-numbered. Pages may not be removed from logbooks under any circumstances. Entries shall be legible, factual, detailed, and complete and shall be signed and dated by the individual(s) making the entries. If a mistake is made, the individual making the entry shall place a single line through the erroneous entry and shall initial and date the deletion. Under no circumstances shall any previously entered information be completely obliterated. Use of whiteout in a Field Survey Logbook is not permitted for any reason.

6.6.3 Other logbooks

The Project Engineer may initiate additional logbooks as deemed necessary to ensure project activities are adequately documented. Additional logbooks will be considered legal records and will be subject to the same provisions described above for the Project Data Logbook and Field Survey Logbooks.

6.7 Release Limits for Equipment and Tools

The limits in this section are as defined in: "Termination of Byproduct, Source, and Special Nuclear Materials Licenses," Policy and Guidance Directive FC 83-23 (November 1983).

6.7.1 Limits if radium present above DCGL

a) 100 dpm/100 cm^2, averaged over not more than 1 m^2

b) 300 dpm/100 cm^2, maximum.

c) 20 dpm/100 cm^2 removable.

6.7.2 Limits if radium not present above DCGL

a) 1,000 dpm/100 cm^2, averaged over not more than 1 m^2

b) 3,000 dpm/100 cm^2, maximum.

c) 200 dpm/100 cm^2 removable

6.8 Project Electronic Data

6.8.1 Data Backup

Electronic data collected during the day will be backed-up at the end of the same day on which it was collected (e.g., to CD, zip drive, or equivalent), before processing or editing. This is an archive of the raw data and, once created, it shall not be altered. More than one day's data may go on a single tape or zip disk. Field computer(s) used to store project data will be backed up weekly, as a minimum. Raw archived data will be stored in a different location from weekly backups. Electronic data will be provided daily to data processing specialists and NAVSEADET RASO. The time and date that data files are transmitted will be recorded in the data logbook. File names will be verified by comparison with field notes and corrected if necessary, following approval by the Project Engineer.

6.8.2 Data Processing

Data processing specialists will convert daily GWS/GPS data to state plane coordinates, as necessary, and review the data for errors to fluctuations/interferences in the GPS signal. Data processing specialists will inform the Project Engineer of any identified deficiencies and will make corrections as directed. Conversions, errors, corrections, and/or adjustments to project data shall be documented in the data logbook.

7.0 SURVEY QUALITY ASSURANCE/QUALITY CONTROL (QA/QC)

Activities associated with this work plan shall be performed in accordance with written procedures and/or protocols in order to ensure consistent, repeatable results. Topics covered in project procedures and protocols may include proper use of instrumentation, Quality Control (QC) requirements, equipment limitation, etc. Implementations of Quality Assurance (QA) measures for this work plan are described herein.

7.1 Instrumentation Requirements

(A) Calibration

Equipment and instruments used in the field screening operation will be maintained and calibrated to manufacturer's specifications. A project file will be kept on the equipment used in field screening analysis. Current calibration and or maintenance records for instruments used during the survey will be kept onsite for review and inspection. The records will include, at a minimum, the following:

- Name of the equipment
- Equipment identification (model and serial number)
- Manufacturer
- Data of Calibration
- Calibration Due Date

Instrumentation will be maintained and calibrated to manufacturer's specifications to ensure that required traceability, sensitivity, accuracy and precision of the equipment/instruments are maintained. Instruments will be calibrated at a facility possessing appropriate NRC and/or Agreement State Licenses for performing calibrations using NIST traceable sources.

Instruments will be calibrated at a facility possessing appropriate NRC and/or Agreement State licenses for its calibration sources, which shall be NIST traceable. Field instruments will be source-checked periodically throughout the workday according to the latest calibration record. In addition, the instruments will be checked daily in order to ensure that the calibration is current (i.e., not expired). Written records of daily checks will be maintained and filed in the project file.

(B) Source and Background Checks

Prior to and after daily use, instruments will be quality control (QC) checked by comparing the instrument's response to ambient background and to a designated gamma radiation source. The results of the ambient background and source checks will be recorded in a field logbook.

Instrument response to ambient background will be used to establish a mean background response for each instrument, following the system source check but prior to the commencement of gross gamma survey at the study areas. NaI measurements shall be collected in the selected reference location. Background readings shall be conducted at the beginning of each day prior to collecting data in the field. Results from these surveys will be used to monitor gross fluctuations in background gamma fluence (e.g., from changes due to barometric pressure and other, non-contaminant related causes), and to check detector response. Please note that the background measurements are made solely for the purpose of normalizing each day's survey results and eliminating bias introduced by natural fluctuations in site radiological conditions. Given the qualitative nature of the scanning portion of this study, no attempt will be made to remove naturally occurring radioactivity from survey data to derive net activity.

Source checks will consist of one-minute integrated counts with the designated source position in a reproducible geometry, performed at the designated location. Instrument response to the designated QC check source will be plotted on control charts and evaluated against the average established at the start of the field activities. A performance criterion of +/– 20% of this average will be used as an investigation action level. The Site RSO will investigate results exceeding this criterion and will make appropriate corrections to instrument readings if response is deviated by factors beyond personnel control, such as large humidity or temperature changes. The Site RSO has authority to decide whether or not the instrument is acceptable to use or must be removed from service.

During QC checks, instruments used to obtain radiological data should be inspected for physical damage, current calibration and erroneous readings in accordance with applicable protocols. The individual performing these tasks shall document the results in accordance with the associated instrument protocol. Instrumentation that does not meet the specified requirements of calibration, inspection, or response check will be removed from operation. If the instrument fails the QC response check, any data obtained to that point, but after the last successful QC check will be considered invalid due to faulty instrumentation.

7.2 GPS Requirements and Quality Control

GPS quality control will be accomplished with calibration points, viewing plotted survey data, and keeping detailed field notes. A calibration point is a location with known horizontal and vertical coordinates (e.g., a benchmark) that can be used to check the accuracy of GPS (position) data. Calibration points will ensure that the differential position corrections are calculated properly, and that equipment is performing to specification. GPS calibrations assist the data processor in correcting errors in the survey data and checking the integrity of the GPS system. GPS calibration points shall be set in convenient locations near the areas to be surveyed. Existing unique features such as manholes, fire hydrants, or other permanent features may serve as calibration points. Calibration points shall be set in areas clear of overhead obstructions.

One or more GPS calibration points will be established prior to beginning fieldwork. At each calibrations point, ten initial GPS position readings will be collected, each of a one-minute duration or more. Each set of ten readings will be used to develop the average position of the applicable calibration point. On a daily basis, prior to beginning and following completion of surveys, technicians shall collect position data at the appropriate calibration points. Data may also be collected at a calibration point at any point during a survey if anomalous readings or other indications of potential GPS data quality problems are observed. Additional calibrations may be necessary as determined by the Senior Radiological Engineer in consultation with the Technical Project Manager.

7.2.1 Daily Reviews

Data shall be collected at the calibration point at least two times for each day's survey. Each time calibration point data is collected, the result shall be compared to the calibration benchmark point described previously. Measurements differing from the average by more than one meter will be investigated and corrective measures will be implemented as appropriate.

7.2.2 Quality control of the field survey

Data quality control will be accomplished with mapping control points, viewing plotted survey data, and keeping detailed field notes. Mapping control points (a discrete point at a known location such as in the corner of a base map building) will ensure that the area surveyed will overlay with existing maps. Gamma surveys, when plotted, should exhibit the same configuration as shown in annotated field sketches and field notes. Any anomalies observed by the data processing specialist and/or technicians performing field surveys shall be brought to the attention of the Project Engineer.

7.3 Volumetric Soil Sampling

7.3.1 Duplicate Samples

Volumetric soil sampling will be sent to an independent third party laboratory for gamma spectroscopic analysis. Duplicate samples will be scheduled at a rate of 10% of samples collected. When duplicate analysis is required, the original sample counted by the onsite laboratory will be sent to the third party laboratory. The samples will be numbered using a unique identifier and will be sent to the laboratory for analysis. Additionally, the analytical laboratory should perform duplicate analyses on selected samples as specified in their quality assurance procedures. Duplicate analyses performed by the laboratory will be compared to the initial analytical results by determining a Z-score value for each data set by the following equation:

$$Z = \frac{|S - D|}{\sqrt{\sigma_S^2 + \sigma_D^2}}$$

Where: S, D, ≡ value of (S)ample and (D)uplicate measurements; and,

σ ≡ one sigma error associated with (S)ample and (D)uplicate measurements.

The calculated Z-Score results will be compared to a performance criteria of less than or equal to 2.57. The value of 2.57 corresponds to a 99% confidence level, or, 99% of the Z-Score values will be below 2.57, and only 1% of the values will be above this acceptance criteria, if the sample and the duplicate are truly of the same distribution. Calculated Z-values less than 2.57 will be considered acceptable and values greater than 2.57 will be investigated for possible discrepancies in analytical precision, or for sources of disagreement with the following assumptions of the test:

- the sample measurement and duplicate or replicate measurement are of the same normally distributed population
- the standard deviations, σ_S and σ_D, represent the true standard deviation of the measured population

7.3.2 Laboratory Spike Analyses

Spike analyses may be performed by the laboratory and used to estimate the extent of bias in the analytical measurements. The analytical laboratory adds a known quantity of radioactive material, or analyte, to representative media, and analyzes the spiked media. Bias in the results will be quantified by determining percent difference values for spike analyses data provided by the laboratory. Percent difference values will be determined by the following equation:

$$\%\,\text{Difference} = \frac{(C_S - C_M)}{C_S} * 100$$

Where: C_S ≡ Concentration of spike analyte added to sample

C_M ≡ Measured concentration of analyte in sample

Percent differences will be compared to a performance criteria of 20%. Percent differences greater than 20% will be investigated for possible discrepancies in measurement bias. The error associated with the measured values should be a consideration when evaluating percent differences and qualifying data which do not meet these performance criteria.

7.3.3 Laboratory Blanks

The analytical laboratory performs blank analyses to test analytical accuracy and to estimate the extent of bias in the measurements. Laboratory blanks are also used to demonstrate that laboratory contamination is not the cause of reported analytical results. A blank sample is prepared and analyzed by the analytical laboratory and typically consists of a sample of similar media, free of radiological contamination, which remains with the field sample throughout the entire analytical procedure and analyzed to determine the concentration of the radionuclide of concern. Blank analyses should be performed in accordance with the laboratory's quality assurance procedures. If blank results reported by the laboratory indicate the presence of contamination above the detection limit, or results are not qualified, data should not be used.

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8.0 REFERENCES

(AEC 1974) Application for Source Material License No. AEC-2, Phillip Brothers, NY, dated May 10, 1974.

(CABRERA 2000) Final Report: *Characterization and Final Status Survey of the Monazite Sand Area of the Great Lakes Naval Training Station – Great Lakes, Illinois*, June 2000

(NRC 1998) Draft Regulatory Guide DG-4006, *Demonstrating Compliance with the Radiological Criteria for License Termination,* August, 1998.

(NRC 1998a) NUREG-1505, Rev.1, *A Nonparametric Statistical Methodology for the Design and Analysis of Final Status Decommissioning Surveys*, June, 1998.

(NRC 1999) *Supplemental Information on the Implementation of the Final Rule on Radiological Criteria for License Termination*, Federal Register, Volume 64, Number 234, Tuesday, December 7, 1999, 68396-68396.

(NRC 2000) NUREG-1575, *Multi-Agency Radiation Survey and Site Investigation Manual* (MARSSIM).

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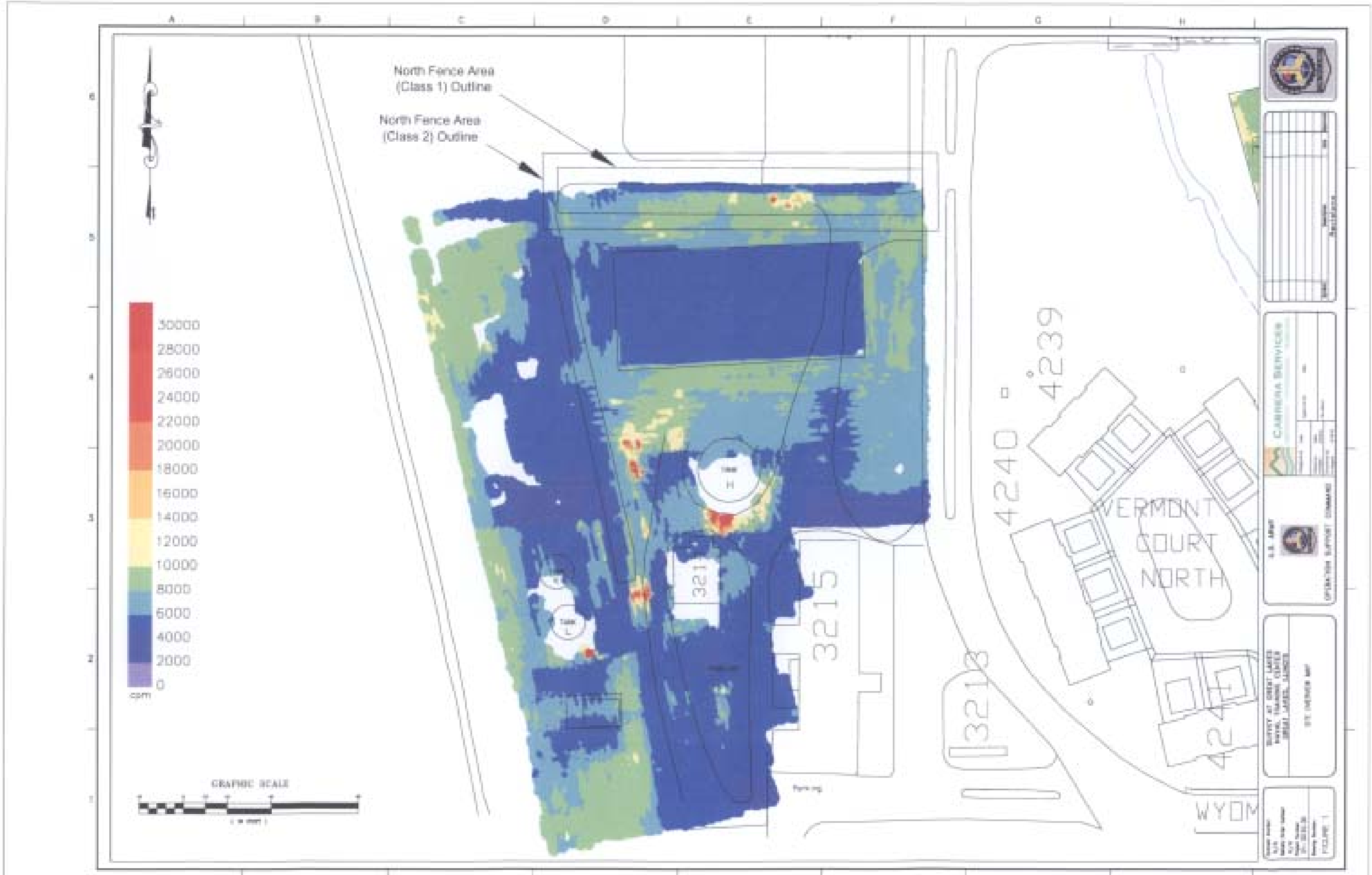
Figures



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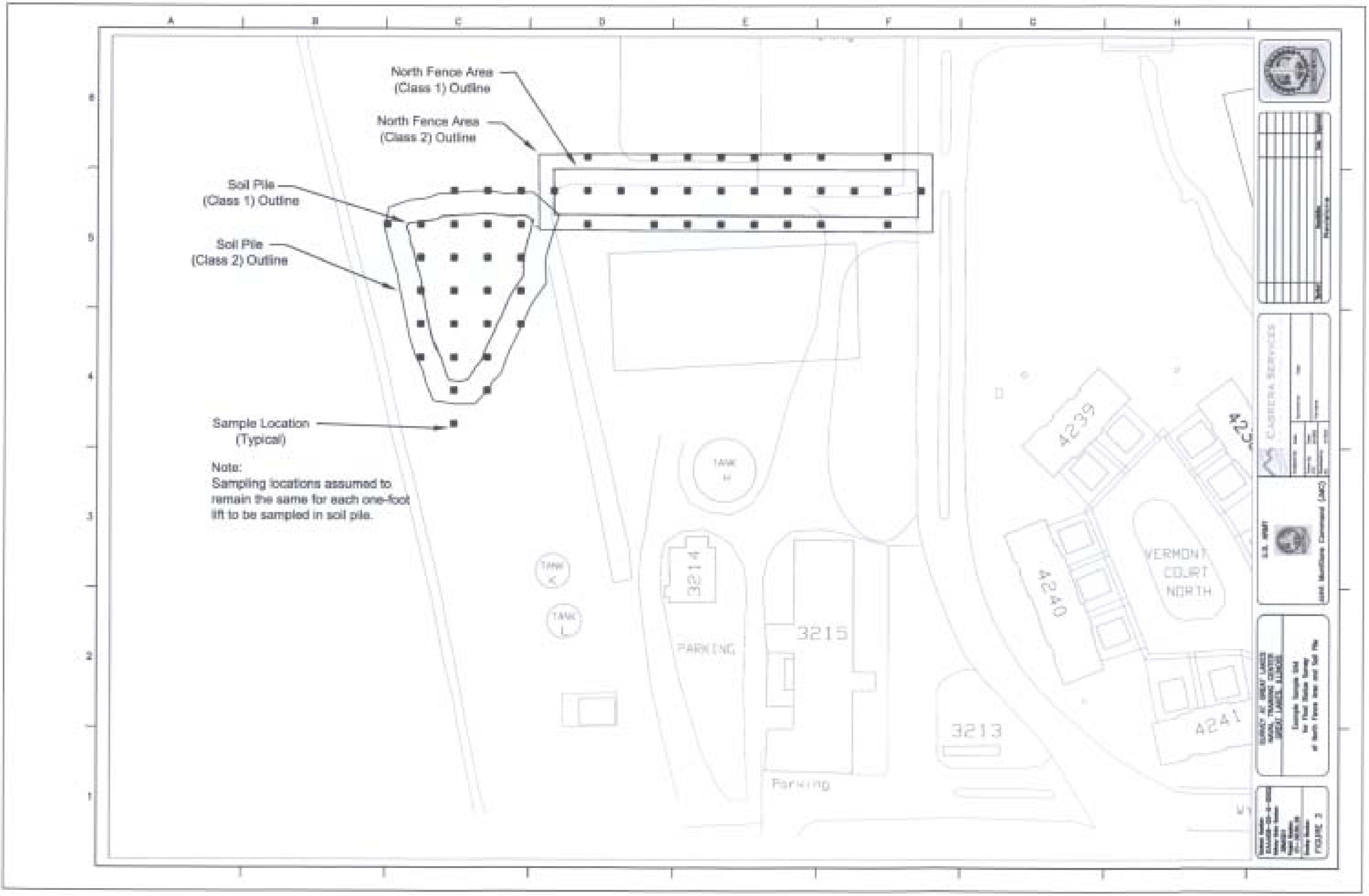

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Attachments

A *2 in. by 2 in. NaI MDC Technical Memorandum (Rev. 1)*

B *Procedures*

C *RESRAD Code Results*

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ATTACHMENT A
2" X 2" NaI MDC TECHNICAL MEMORANDUM (REV 1)

1.0 INTRODUCTION

The U.S. Army Operations Support Command (AOSC) has issued Cabrera Services, Inc. (CABRERA) a delivery order to provide a Remediation Work Plan describing the methodology, equipment, instrumentation, sample frequency, and sample analysis for the remediation of soils located within the boundaries of the Great Lakes Naval Training Center (Site), and to perform that remediation. This site was formerly used by the Defense Logistics Agency as a storage area for strategic quantities of monazite sands, a thorium-bearing material. The Scope of Work (SOW) is defined by AOSC Basic Ordering Agreement Document DAAA09-00-G-0002, Delivery Order 0036, dated 30 September 2001.

Thorium present at the site is assumed to be derived from naturally occurring ^{232}Th in 50-year secular equilibrium with its progeny. The Great Lakes site will be scanned for potential thorium contamination utilizing a Ludlum 44-10 (2"x 2" NaI scintillation detector). Scans of the subject area will be accomplished by a walking speed (1.5 ft/sec) walkover by the surveyor at a detector height of approximately 2-4 inches above the ground surfaces. Results will be tallied by counts per minute (CPM).

1.1 Objectives

The objective of this technical memorandum is to determine the scan sensitivity of the Ludlum 44-10 (2 inch x 2 inch) NaI scintillation detector utilized for the planned gamma walkover survey for thorium. The evaluation considered a 15 cm-thick layer of contaminated soil with a diameter of 56 cm. The scan sensitivity is important for use in interpretation of potential concentrations of thorium in the soil.

2.0 SITE RADIOLOGICAL CONDITIONS

The site area to be surveyed consists of surface soils potentially contaminated with thorium containing sand at various concentrations. Any thorium present will be in equilibrium with its progeny. A 50-year equilibrium has been chosen for the soil containing small amounts of ^{232}Th.

It has been assumed for detection calculations that the contamination is present in a layer on the surface with no cover and that the thorium and progeny contaminants are uniformly mixed with the soil in a volume of soil 56 cm in diameter with a 15 cm thickness.

3.0 SCAN MINIMUM DETECTABLE CONCENTRATION (MDC) CALCULATION AND METHODOLOGY

The methodology used to determine the NaI scintillation detector scan MDC is based on NRC NUREG –1507, titled "Minimum Detectable Concentrations with Typical Radiation Survey Instruments for Various Contaminants and Field Conditions" December 1997. Factors included in this analysis are the surveyor scan efficiency, index of sensitivity, the natural background of the surveyed area, scan rate, detector to source geometry, areal extent of the hot spot, and energy and yield of gamma emissions.

The computer code Microshield was used to model the presence of a normalized 1 pCi/g total thorium with its 50-year decay progeny in soil with the further assumption that the activity is uniformly distributed to a depth of 15 cm and spread over a disk shaped area with a diameter of 56 cm. The uncontaminated soil cover thickness has zero thickness (contamination on the surface) and there is a 0.051 cm aluminum shield simulating the cover of the NaI detector to complete the model source term. This model is consistent with the NUREG-1507 methodology and provides for a count rate to exposure rate ratio (CPM/μR/hr) to be calculated.

The following sections provide tabulated data based upon the NUREG-1507 methodology as applied toward the Ludlum 44-10 2"x2" NaI scintillation detector used in this survey, zero thickness soil cover, and a 56 cm diameter soil uniformly contaminated to a 15 cm thickness. The dose point is centered over the contaminated disk of soil. Additional details and discussion describing the NUREG analysis methodology are described in that publication.

3.1 Fluence Rate to Exposure Rate (FRER, no units)

The fluence rate to exposure rate (FRER) may be approximated by:

$$\text{FRER} \sim (1\ \mu\text{R/hr})/(E_\gamma)(\mu_{en}/\rho)_{air}$$

Wherea,

E_γ = energy of the gamma photon of concern, keV

$(\mu_{en}/\rho)_{air}$ = the mass energy absorption coefficient for air, cm^2/g

And in tabular form:

TABLE 1

Energy$_\gamma$, keV	$(\mu_{en}/\rho)_{air}$, cm^2/g	FRER
40	0.064	0.3906
60	0.0292	0.5708
80	0.0236	0.5297
100	0.0231	0.4329
150	0.0251	0.2656
200	0.0268	0.1866
300	0.0288	0.1157
400	0.0296	0.0845
500	0.0297	0.0673
600	0.0296	0.0563
800	0.0289	0.0433
1,000	0.0280	0.0357
1,500	0.0255	0.0261
2,000	0.0234	0.0214
3,000	0.0205	0.0163

3.2 Probability of Interaction (P) Through Detector End for a Given Energy

The probability, P, of a gamma ray interaction in the NaI scintillation crystal entering through the end of the crystal is given by:

$$\text{Probability (P)} = 1\text{-}e^{-(\mu/\rho)\text{NaI}(X)(\rho\text{NaI})}$$

Where

$(\mu/\rho)_{NaI}$ = the mass attenuation coefficient for NaI

X = the thickness through the bottom edge (end facing the soil) of the Ludlum 44-10 2”x2” NaI crystal, 5.1 cm

ρ = the density of the NaI crystal, 3.67 g/cm^3

And in tabular form:

TABLE 2

Energy$_\gamma$, keV	$(\mu/\rho)_{NaI}$, cm^2/g	P
40	18.3	1.00
60	6.23	1.00
80	2.86	1.00
100	1.58	1.00
150	0.566	1.00
200	0.302	1.00
300	0.153	0.94
400	0.11	0.87
500	0.0904	0.82
600	0.079	0.77
800	0.0657	0.71
1,000	0.0576	0.66
1,500	0.0464	0.58
2,000	0.0412	0.54
3,000	0.0367	0.50

3.3 Relative Detector Response (RDR)

The Relative Detector Response (RDR) by energy is determined by multiplying the relative fluence rate to exposure rate (FRER) by the probability (P) of an interaction and is given by:

RDR = FRER (table 1) x P (table 2)

And in tabular form:

TABLE 3

Energy$_\gamma$, keV	FRER	P	RDR
40	0.3906	1.00	0.3906
60	0.5708	1.00	0.5708
80	0.5297	1.00	0.5297
100	0.4329	1.00	0.4329
150	0.2656	1.00	0.2656
200	0.1866	1.00	0.1859
300	0.1157	0.94	0.1091
400	0.0845	0.87	0.0737
500	0.0673	0.82	0.0549
600	0.0563	0.77	0.0435
800	0.0433	0.71	0.0306
1,000	0.0357	0.66	0.0236
1,500	0.0214	0.58	0.0124
2,000	0.0214	0.54	0.0115
3,000	0.0163	0.50	0.0081

3.4 Determination of CPM per μR/hr as a Function of Energy

The equivalent FRER, P, and finally RDR may be calculated for a NaI Scintillation detector at the cesium-137 energy of 662 keV. Manufacturers of this equipment typically provide an instrument response in terms of CPM and μR/hr at the cesium-137 energy. This point allows one to determine the CPM per μR/hr and ultimately activity concentration and minimum detection sensitivity level in terms of pCi/g.

Based on measured counts in a known field it is estimated that a typical Ludlum 44-10 NaI response is 900 CPM/μR/hr and using the same methodology as shown in the tables above, the FRER, P and RDR are calculated. The mass energy absorption coefficient for air and the mass attenuation coefficient for NaI are interpolated from tables in the Radiological Health Handbook, Revised Edition January 1970, pages 139, and 140.

FRER	$Energy_\gamma$, keV	$(\mu_{en}/\rho)_{air}$, cm^2/g
0.0514	662	0.0294

And

$Energy_\gamma$, keV	$(\mu/\rho)_{NaI}$, cm^2/g	P
662	0.0749	0.75

And Cesium-137 RDR (662 keV) = 0.0387

The detector response (CPM) to another energy is based upon the ratio of the RDR at an energy to the known Cs-137 energy RDR

$$CPM/\mu R/hr,\ E_i = (CPM_{Cs\text{-}137}) \times (RDR_{Ei}) / (RDR_{Cs\text{-}137})$$

$$= (900) \times (RDR_{Ei}) / (RDR_{Cs\text{-}137})$$

and in tabular form:

TABLE 4

Energy$_\gamma$, keV	RDR_{Ei}	Fidler NaI Detector, E_i, cpm per µR/hr
40	0.3906	9078
60	0.5708	13264
80	0.5297	12309
100	0.4329	10060
150	0.2656	6172
200	0.1859	4320
300	0.1091	2536
400	0.0737	1712
500	0.0549	1277
600	0.0435	1010
662	0.0387	900
800	0.0306	711
1,000	0.0236	548
1,500	0.0124	288
2,000	0.0115	267
3,000	0.0081	188

The measured reference area (RA) average count rate (Cabrera 2000) was 9158 CPM using a 2 x 2 NaI scintillation detector. The associated standard deviation for the 9472 measurements gathered during the RA scan was 571 CPM (6.2% of the mean). Based on a the measured RA background CPM and an expected background exposure rate of 5-10 μR/hr, a count rate to exposure rate ratio of 1800 - 900 CPM/μR/hr is calculated. This range agrees with the manufacturer's typical value of 900 CPM/μR/hr for a 2 x 2 NaI response to ^{137}Cs energy.

Finally, the count rate to exposure rate ratio for each of the thorium isotopes and progeny gamma emissions and their contribution to the total exposure rate may be computed using the output of the Microshield runs and the count rate to exposure rate ratios from table 4.

TABLE 5

keV	MicroShield Exposure Rate, μR/hr (with buildup, 1 pCi/g ^{232}Th)	cpm/μR/hr	cpm/μR/hr (weighted)	Percent of NaI detector response
40	3.957E-05	9078	0	0.0%
60	6.309E-05	13264	1	0.1%
80	7.110E-03	12309	91	10.9%
100	1.815E-03	10060	19	2.3%
150	2.134E-03	6172	14	1.6%
200	4.142E-02	4320	187	22.4%
300	3.261E-02	2536	86	10.3%
400	4.042E-03	1712	7	0.9%
500	2.979E-02	1277	40	4.8%
600	8.114E-02	1010	85	10.3%
800	1.058E-01	711	78	9.4%
1000	2.360E-01	548	135	16.2%
1500	7.559E-02	288	23	2.7%
2000	2.136E-03	267	1	0.1%
3000	3.396E-01	188	66	8.0%
Total	9.593E-01		833	100%

3.5 Scan MDC Value

The scan MDC is calculated using the NUREG-1507 methodology where:

The average number of background counts in a one second interval, b_i = CPM/60

For the Ludlum 2 x 2 NaI scintillation detector and the measured RA background count rate of 9158 CPM the calculated background counts in the interval is:

$$b_i = (9158 \text{ CPM}) / 60 = 153 \text{ counts}$$

The minimum detectable count rate, MDCR is

$$\text{MDCR} = (d') \times (b_i)^{0.5} \times (60 \text{ sec/1 min}) \qquad \text{Equation 1}$$

Where d', equal to 1.38 from table 6.1 of NUREG-1507, represents the rate of detections at a 95% true positive proportion with a false positive proportion of 60%, b_i, equals 153 counts, is based on the RA background counts in the interval, and 60 seconds/1 minute is a conversion factor and

$$\text{MDCR} = (1.38) \times 12.37 \times (60 \text{ sec/1 min}) = 1024 \text{ CPM}$$

The Minimum Detectable Count Rate for the surveyor is given as

$$\text{MDCR}_{\text{surveyor}} = \text{MDCR}/(p)^{0.5}$$

Where

p = Surveyor Efficiency, equal to 0.75 to 0.5 as given by NUREG-1507 (0.5 is chosen as a conservative choice) and

$$\text{MDCR}_{\text{surveyor}} = 1024/0.707 = 1448 \text{ CPM}$$

The Minimum Detectable Exposure Rate for the surveyor is obtained from the $\text{MDCR}_{\text{surveyor}}$ divided by the Table 5 weighted count rate to exposure rate value of 833 CPM/μR/hr for thorium and its progeny is

$$(1448 \text{ CPM})/(833 \text{ CPM}/\mu\text{R/hr}) = 1.74 \ \mu\text{R/hr}$$

The scan MDC is then equal to the ratio of the Minimum Detectable Exposure Rate in the field to the exposure rate determined for the normalized 1 pCi/g concentration of total thorium and

Scan MDC = (Normalized $Th_{Total\ Conc}$) x (Exposure $Rate_{Surveyor}$)/(Exposure $Rate_{normalized\ Th\ conc}$)

Scan MDC = (1 pCi/g) x (1.74 μR/hr)/(9.593E-1 μR/hr) = 1.8 pCi/g

4.0 CONCLUSION

The Ludlum 44-10 2"x2" NaI Scintillation scan MDC, for ^{232}Th in 50-year equilibrium with progeny, being uniformly distributed in surface soil with dimensions of 56 cm diameter and 15 cm thick, is estimated to be 1.8 pCi/g.

The value computed is indicative of a sensitive instrument that agrees with scan MDC data presented in NUREG 1507 and MARSSIM Table 6.7 for ^{232}Th in 50-year equilibrium with progeny.

CABRERA SERVICES. INC.

Radiation Safety Procedure

For

Unconditional Release of Material from
Radiological Control Areas

OP-004

Revision 0

Reviewed By: ______________________________ Date: ______
David Watters, Radiological Safety Engineer

Approved By: ______________________________ Date: _______
Steven Masciulli CHP, CSP, Radiation Safety Officer

Approved By: ______________________________ Date: _______
Henry Siegrist CHP, P.E., Corporate Health Physicist

1.0 PURPOSE

The purpose of this procedure is to specify requirements for releasing material from controlled areas and to minimize the potential for unintentionally releasing contaminated items to uncontrolled areas in accordance with the provisions stated in Section 4.0, References. This procedure sets forth the specific requirements for release of materials from controlled areas applicable to Cabrera Services, Inc. (CABRERA) field projects.

2.0 APPLICABILITY

2.1 This procedure provides instructions for CABRERA personnel while performing release surveys of items controlled as contaminated or potentially contaminated with radioactive materials.

2.2 The procedure will be used to ensure by survey that materials released from contaminated or potentially contaminated areas will meet the release criteria applicable to the license conditions, facility requirements, or as specified in regulations or guidance provided by applicable regulatory agencies of the federal or state government.

3.0 PRECAUTIONS, LIMITATIONS AND REQUIREMENTS

3.1 Precautions

3.1.1 Instruments used to perform release surveys shall be operated in accordance with the respective operating procedure.

3.1.2 Large area smears may be used to augment (but not replace) the 100 cm^2 smear survey. Large area wipes may be counted with the Ludlum Model-3 or equivalent. Large area smears are used to obtain immediate information concerning loose contamination for the purpose of radiological protection and to minimize time spent performing disc smears on an item easily identified as contaminated.

3.1.3 A release document package, at a minimum, shall include the following forms:

3.1.3.1 The Health Physics daily log.

3.1.3.2 Material Release Log.

3.1.3.3 Radiation and Contamination Survey or an Unconditional Release of Equipment or Items Survey and/or Sample Calculation Worksheet.

3.1.3.4 Daily Instrument Calibration Log.

3.1.4 The release document shall include the following information:

3.1.4.1 The date of the release survey.

3.1.4.2 The number of the release survey.

3.1.4.3 A description or identification of the item.

3.1.4.4 The identity of the Health Physics Technician performing the release survey.

3.1.4.5 The evaluator of the material for release.

3.1.4.6 The release approval of the RSO or duly authorized representative.

3.1.5 Surveys performed for the release of material shall be documented on a Radiation and Contamination Survey and/or on an Unconditional Release of Equipment or Items Survey.

3.1.6 Radiation/contamination surveys shall be performed in accordance with OP-001.

3.1.7 Items identified as radioactive during the release survey shall be controlled in accordance with OP-019.

3.1.8 Personnel performing release surveys shall be logged in on a Radiation Work Permit in accordance with AP-012 (if applicable).

3.1.9 Audible response instruments must be used during direct scan surveys.

3.1.10 The instruments used for release surveys shall be within current calibration and shall have had a response check performed daily or before use in accordance with the instrument's operating procedure.

3.1.11 Items presented for release shall be direct scanned in an area of low background.

3.2 Limitations

3.2.1 The maximum probe speed during direct scan surveys of surfaces shall be 3 cm/sec.

3.2.2 A response check shall be performed at the completion of the workday for instruments used for direct scan surveys in accordance with the instruments operating procedure.

3.2.3 The probe face shall be held within ¼ inch of the surface being surveyed for alpha radiation, and within ½ inch of the surface being surveyed for beta-gamma radiation.

3.2.4 If an instrument used to perform release surveys fails any operational check, it shall be removed from service. All data collected during the period of instrument failure must be evaluated by the RSO or duly authorized representative.

3.2.5 Posting and access control of controlled areas shall be performed in accordance with OP-019.

3.3 Requirements

None

4.0 REFERENCES

- 10 CFR 20 — Standards for Protection Against Radiation
- AP-001 — Record Retention
- AP-010 — Personnel Protective Equipment
- AP-012 — Radiation Work Permits
- OP-001 — Radiological Surveys
- OP-009 — Use and Control of Radioactive Check Sources
- OP-019 — Radiological Posting
- OP-020 — Operation of Contamination Survey Meters
- OP-021 — Alpha-Beta Counting Instrumentation
- OP-023 — Operation of Micro-R Survey Meters
- NUREG-1556 — Consolidated Guidance About Material Licenses (Vol.11)
- Reg 1.86 — Termination of Operating Licenses for Nuclear Reactors

5.0 DEFINITIONS AND ABBREVIATIONS

5.1 Activity – The rate of disintegration (transformation) or decay of radioactive material. The units of activity for the purpose of this procedure are Becquerel (Bq) or micro-Curies (μCi).

5.2 Contamination – Deposition of radioactive material in any place where it is not desired. Contamination may be due to the presence of alpha particle, beta particle or gamma ray emitting radionuclides.

5.3 Restricted Area – An area to which access is controlled to protect individuals against undue risks from exposure to radiation and radioactive materials.

5.4 Fixed Contamination – Radioactive contamination that is not readily removed from a surface by applying light to moderate pressure when wiping with a paper or cloth disk smear, or masslinn.

5.5 Minimum Detectable Activity (MDA) – For purposes of this procedure, MDA for removable radioactive contamination is defined as the smallest amount of sample activity that will yield a net count with a 95% confidence level based upon the background count rate of the counting instrument used.

5.6 Release for Unconditional Use – A level of radioactive material below which it is acceptable for use without restrictions. Under normal circumstances, authorized limits for residual radioactive material are set equal to, or below, the values specified in Regulatory Guide 1.86, Termination of Operating Licenses for Nuclear Reactors.

5.7 Survey – is defined as an evaluation of the radiological conditions and potential hazards incident to the production, use, transfer, release, disposal, or presence of radioactive material or other sources of radiation.

5.8 Survey Exempt Materials – The contents of sealed containers which remain unopened while in a controlled area are exempt, the outside surfaces are not exempt.

6.0 EQUIPMENT

None

7.0 RESPONSIBILITIES

7.1 Project Manager (PM) – the PM is responsible for ensuring that personnel assigned the task of surveying materials are familiar with this procedure, adequately trained in the use of this procedure, and have access to a copy of this procedure.

7.2 Radiation safety Officer (RSO) – The RSO is responsible for verifying that personnel comply with this procedure and are trained in the use of contamination survey meters described in this procedure.

7.3 Radiological Field Supervisor (RFS) – During field assignments, the RFS is responsible for ensuring that this procedure is implemented. When the RSO is not on site, the RFS will act as the RSO's duly authorized representative for radiological issues.

7.4 Health Physics Technicians (HPT) – The HPT are responsible for performing the surveys described in this procedure.

8.0 INSTRUCTIONS

8.1 Release Limits for Gross Activity (Unknown Isotopes)

EMISSION	**REMOVABLE** dpm/100 cm^2	**TOTAL (Fixed and Removable)** dpm/100 cm^2
Alpha	20	100
Beta-Gamma	200	1000

NOTE: If all of the constituents of the contamination are known and documented on the release documents, the release limits of Table 1 of Regulatory Guide 1.86, Termination of Operating Licenses for Nuclear Reactors applies.

8.2 Inaccessible Surfaces

8.2.1 Items with inaccessible surfaces should be disassembled as completely as possible to facilitate release surveys. Items with inaccessible surfaces will not be unconditionally released unless evaluated by a designated evaluator who authorizes and documents the release.

8.2.2 The following guidance will be used when performing evaluations:

8.2.2.1 A history of the item should be reviewed.

8.2.2.2 The actual release survey shall be reviewed.

8.2.2.3 Determination of the radiological conditions in the area the item has been used or stored shall be reviewed.

8.2.2.4 Use of gamma radiation sensitive detectors such as NaI(Tl) or equivalent should be considered. (These detectors may indicate internal contamination that a beta sensitive detector may not detect due to the beta detector's lack of sensitivity to photon emissions as well as the inability of beta emissions to penetrate through many surfaces).

8.3 Materials considered dangerous, fragile, or not readily smearable due to their physical or chemical nature shall not be unconditionally released unless evaluated on a case by case basis for release in a manner consistent with Section 8.2.2. Evaluation for release shall be performed by a designated evaluator only.

8.4 Survey Exempt Materials

8.4.1 Items such as briefcases, pens, papers, personal clothing, etc., are exempt from the Health Physics release survey requirements of this procedure, unless deemed appropriate by the HPT.

8.4.2 Individuals shall survey the exempt items in the same manner as a whole body frisk when leaving a controlled area or have a Health Physics Technician perform the survey.

8.5 Survey Procedure

8.5.1 Upon receipt of an item presented for release, attempt to determine the history:

8.5.1.1 Purpose of item.

8.5.1.2 The current and past use of the item.

8.5.1.3 The location(s) in which the item was used or stored.

8.5.1.4 If the item was ever used for work with radioactive material or used in an area where radioactive material was used or stored.

NOTE: This knowledge of the item history should provide the surveyor with information helpful in performing the release survey.

8.5.2 Using protective clothing such as gloves, perform large area smears of 100% of the accessible surfaces of the item using large area wipes (e.g. masslinn).

8.5.2.1 Determine if transferable (loose) radioactive material is present by measuring the amount of activity on the surface of the cloth.

8.5.2.2 If the presence of radioactive material is indicated by a count rate above background, the item shall be treated as contaminated until the results of the disc smear survey are obtained and determination is made concerning the actual 100 cm^2 loose contamination levels. The material shall be controlled in accordance with OP-019.

8.5.3 Perform a direct scan of 100% of all accessible areas of the item, in accordance with the instrument's operating procedure, and OP-001.

NOTE: Items presented for release shall be direct scanned in an area of low background. Preferably ≤ 100 CPM. The Health Physics Technician performing the release survey shall determine if the background is acceptable for direct scan of the item.

8.5.4 If the scan indicates radioactive material on the surface of the item is less than the limits of release for total activity, proceed to 8.5.10.

8.5.5 If the scan indicates radioactive material on the surface is greater than regulatory limits for total activity, the item cannot be released.

8.5.6 During the direct scan of the accessible surfaces of the item, a static measurement shall be taken:

8.5.6.1 If an increase in the audible count rate is detected.

8.5.6.2 After each minute of scanning.

8.5.6.3 When the Health Physics Technician determines that an indication of fixed activity in an area less than ten square centimeters may be present.

8.5.6.4 During the static measurement, the meter probe shall be held at the proper distance from the surface being surveyed for the proper response period to allow the meter reading to stabilize, in accordance with the instrument's operating procedure.

8.5.7 Perform disc smears which are representative of 100% of the effective surface area.

8.5.7.1 100% of the effective accessible surface means performing a 100 cm^2 disc smear on all accessible areas of the item suspected of being contaminated.

8.5.8 Count the smears in accordance with reference OP-001 and/or OP-021 as appropriate.

8.5.8.1 Record smear data on the Radiation and Contamination Survey.

8.5.8.2 If the smear results indicate transferable activity below the release limits, proceed to Step 8.5.10

8.5.8.3 If the smear results indicated transferable activity above the release limits, the item cannot be released

8.5.9 If item has internal or inaccessible surfaces, CABRERA personnel will disassemble the item and repeat Steps 8.5.2 through 8.5.5 or have the item evaluated for release by a designated evaluator.

8.5.10 If the item meets the release limits or is evaluated as meeting the unconditional release criteria, complete form OP-004-01. The RSO or duly authorized representative must review the release documents and approve the release before allowing the item to leave the controlled area.

8.5.11 If items are identified as radioactive during the release survey, contact the RSO or duly authorized representative.

8.6 Action level

8.6.1 If direct frisk beta-gamma instrument readings exceed 100 cpm above background (with background less than 200 cpm) or 25 cpm alpha, those areas shall be surveyed as follows:

8.6.1.1 Perform a smearable contamination survey using 100 cm^2 of affected areas, and count the smears for beta-gamma and alpha contamination to determine if contamination is "fixed" or "removable."

8.6.2 Any vehicle with removable contamination exceeding the site limits listed below shall be brought to the attention of the RSO or duly authorized representative and handled appropriately.

8.6.3 Any vehicle with removable contamination exceeding the DOT limits listed below shall be brought to the attention of the RSO or authorized representative for release or acceptance approval.

8.6.3.1 2,200 dpm/100 cm^2 beta-gamma

8.6.3.2 220 dpm/100 cm^2 alpha.

8.6.4 Dose rate surveys, which exceed 0.2 mR/hr, shall be brought to the attention of the RSO or duly authorized representative for release or acceptance approval.

8.7 The results of the survey shall be documented on Radiation and Contamination surveys.

9.0 QUALITY ASSURANCE/RECORDS

9.1 Quality Assurance

9.1.1 Instrumentation used for surveys will be checked with standards each day prior to use and verified to have current valid calibration.

9.1.2 When releasing a large volume of materials, a program may be established under the discretion of the RSO or duly authorized representative to ensure by second check that no radioactive material has been released to the public or the environment.

9.1.3 The health physics technician performing the survey shall review Form OP-004-01 and any other applicable forms for accuracy and completeness.

9.2 Records

9.2.1 Documented information shall be legibly written in ink.

9.2.2 Data shall not be obliterated by erasing, using white-out, or by any other means. Incorrect entries shall be corrected by striking a single line across the entry. The correction shall be entered, initialed, and dated.

9.2.3 The health physics technician performing the survey shall ensure that this procedure is the most current and approved revision.

9.2.4 Entries on Form OP-004-01 and any other pertinent forms must be dated and initialed by the health physics technician performing the survey to be valid.

9.2.5 The RSO or duly authorized representative shall review any applicable completed forms. The review shall be for accuracy and completeness.

10.0 ATTACHMENTS

OP-004-01 Unconditional Release of Equipment or Items Report

OP-004-01
UNCONDITIONAL RELEASE OF EQUIPMENT AND ITEMS LOG

Project Name ______________________________ Project Number ______________

Item/ Equipment Released	Comments	Survey #	Date

Reviewed By: ______________________________ Date: ________

CABRERA SERVICES. INC.

Radiation Safety Procedure

For

Decontamination of Equipment and Tools

OP-018

Revision 0

Reviewed By: ____________________ Date: ______
David Watters, Radiological Safety Engineer

Approved By: ____________________ Date: _______
Steven Masciulli CHP, CSP, Radiation Safety Officer

Approved By: ____________________ Date: _______
Henry Siegrist CHP, P.E., Corporate Health Physicist

1.0 PURPOSE

This procedure establishes the requirements for decontamination of equipment, material, and tools used at Cabrera Services, Inc., (CABRERA) field projects that become contaminated with radioactive material.

2.0 APPLICABILITY

This procedure will be used to identify proper decontamination methods, provide instruction for the decontamination of equipment, material, and tools. Each decontamination operation is unique; thus, this procedure provides general, effective domination techniques and guidelines to be use by CABRERA field personnel. This document applies to all CABRERA PERSONNEL involved in the decontamination process.

3.0 PRECAUTIONS, LIMITATIONS AND REQUIREMENTS

3.1 Precautions

3.1.1 Decontamination of contaminated tools or equipment shall be performed under the direction of a HPT. The HPT shall provide direction in accordance with this procedure, and the Radiation Work Permit (RWP).

3.1.2 Decontamination activities shall be performed within a controlled area established in accordance with the provisions of procedure OP-019.

3.1.3 Controls to contain the spread of loose contamination during the decontamination activity shall be planned and established prior to the decontamination of equipment, material, and tools.

3.2 Limitations

3.2.1 Protective clothing worn by the personnel involved in decontamination activities shall be determined in accordance with the RWP.

3.2.2 Decontamination cleaning solvent/solutions shall only be used in accordance with the directions and limitations listed on the manufacturer supplied MSDS.

3.2.3 Respiratory protection devices required by the RWP for decontamination operations shall be selected and used in accordance with the provisions of AP-006.

3.2.4 A pre-job briefing shall be held to instruct Decontamination Technicians of the conditions of the RWP. All personnel performing work in the decontamination work area shall sign the RWP prior to work.

3.2.5 Every effort should be made by CABRERA personnel to avoid re-contamination of decontaminated materials. Contamination controls shall always be observed throughout a decontamination process.

3.2.6 Radiation and contamination surveys shall be performed in accordance with the provisions of procedure OP-001.

3.2.7 Release of equipment, materials, and tools from the decontamination work area shall be performed in accordance with the provision of procedure OP-004.

3.3 Requirements

None

4.0 REFERENCES

- RSP Radiation Safety Program
- AP-001 Records Retention
- AP-006 Respiratory Protection Program
- AP-012 Radiation Work Permits
- AP-013 Packaging Radioactive Material
- AP-014 Classifying Radioactive Waste
- OP-001 Radiological Surveys
- OP-004 Unconditional Release of Material from Radiological Control Areas
- OP-019 Radiological Posting
- OP-020 Operation of Contamination Survey Meters
- OP-021 Operation of Alpha-Beta Sample Counting Instrumentation
- OP-023 Operation of Micro-R Survey Meters

5.0 DEFINITIONS AND ABBREVIATIONS

5.1 Decontamination - The processes whereby contamination can be safely and effectively removed from equipment, tools and materials, to levels required by Reg. Guide 1.86.

5.2 Herculite - A plastic or polyethylene floor covering and containment material use for decontamination operations. HERCULITE is a brand name.

5.3 MSDS - Material Safety Data Sheet provide safety information and limitations and are issued by the manufacturer of the product.

5.4 Radiation Work Permit (RWP) - A document generated by Health Physics to provide:

- A description and scope of the work to be performed.
- Existing radiological conditions in the work area.
- Limitations placed upon the scope of work.
- Maximum radiological limits allowed.
- Measures to be employed to protect the worker(s).
- Period of time the RWP is valid.
- Special instructions to workers and HP personnel for the work.

6.0 EQUIPMENT

None

7.0 RESPONSIBILITIES

7.1 Project Manager (PM) – The PM is responsible for ensuring that personnel assigned the task of decontamination are familiar with this procedure, adequately trained in the use of this procedure, and have access to a copy of this procedure.

7.2 Radiation Safety Officer (RSO) – The RSO is responsible is responsible for training of personnel in decontamination techniques and performing radiation surveys described in this procedure. The RSO ensures that decontamination technicians are qualified by training and experience to perform the requirements of this procedure.

7.3 Radiological Field Supervisor (RFS) – During field assignments, the RFS is responsible for ensuring that this procedure is implemented. When the RSO is not on site, the RFS will act as the RSO's duly authorized representative for radiological issues.

7.4 Health Physics Technicians (HPT) – The HPT is responsible for performing the surveys of decontaminated items, and ensuring that radioactive material is not released to the public or the environment.

8.0 INSTRUCTIONS

8.1 Pre-Decontamination Preparation

8.1.1 The RFS shall initiate decontamination work instructions.

8.1.2 A radiological survey shall be performed by a HPT on any item or object, which is to be removed from a controlled area.

8.1.3 If radiological survey results indicate that an RWP is required for decontamination, the RSO or duly authorized representative shall write the RWP in accordance with the provisions of procedure AP-012.

8.1.4 If a survey indicates that decontamination is required, the item should be bagged, wrapped, or contained under the direction of health physics. The HPT shall label the item with all pertinent information.

8.1.5 The RFS shall approve or disapprove the decontamination operation based on conditions of the RWP and the cost effectiveness of the operation versus disposal costs.

8.2 Establishment of the Decontamination Work Area

8.2.1 The RSO or duly authorized representative and the RFS shall determine a location for decontamination area.

8.2.2 Once a location has been established, the decontamination area shall be set-up by the HPT under the direction of the RFS.

8.2.3 The decontamination area should consist of the following:

- Covered (or equivalent) floor surfaces. A double layer of Herculite (or equivalent) may be laid on the floor at the direction of Health Physics.
- Covered (Herculite or equivalent) wall surfaces, if applicable.
- Engineering controls (HEPA ventilation, vacuum cleaners, containment tent walls glove bags, etc.), if applicable.
- Engineering controls shall be determined on the basis of the ALARA consideration section of the RWP.

NOTE: All possible engineering controls shall be utilizes when feasible to minimize the need for respiratory protection equipment.

- Safe, sturdy workstations with contamination resistant surfaces. Tables that will support decontamination attempts on heavy pieces of equipment.

- Adequate supply of overhead light, adequate electrical/compressed air supply for the operation of electrical/pneumatic driven decontamination equipment.
- Overhead lifting equipment, if applicable.
- Adequate supply of CABRERA approved cleaning solutions and solvents; adequate supply of decontamination equipment such as:

1. Light duty decontamination equipment such as paper wipes, paper towels, massllin towels, etc.
2. Medium to Heavy-duty decontamination equipment such as scrub pads, wire brushes steel wool, files, sandpaper, etc.
3. Fully stocked hand tool kit for disassemble of contaminated equipment.
4. Power tools, such as drills, saws, electric screwdrivers, etc.
5. Radioactive material storage bags, stickers, etc.
6. Buckets, barrels or drums for the storage of contaminated liquids, sludges, or slurries, if applicable.
7. Blotter paper or sorbent, if applicable.
8. Approved absorbent material such as oil dry, etc., if applicable.

- Storage drums/bags for the storage of contaminated protective clothing under direction of Health Physics.
- Proper surveillance instruments (air monitor/sampler, contamination monitor, friskers, dose rate meter, etc.) in accordance with the RWP.
- Adequate supply of personal protective clothing gloves respiratory equipment, etc.
- Step-Off or Double Step-Off Pad in accordance with the provision of the RWP.
- A designated area within the decontamination area for the segregation of radioactive waste.
- Fire extinguisher(s), if required

8.2.4 Once the decontamination area has been established and stocked for operation, the bagged and/or wrapped contaminated or controlled equipment should be placed in the decontamination work area by the decontamination technician under the direction of the RFS and the HPT. Contaminated or controlled items should always be escorted under the direction of a HPT to the decontamination area.

8.3 Decontamination

8.3.1 After the decontamination area has been posted, and area access controls established, all requirements of the RWP shall be observed.

8.3.2 The preparation for decontamination of a particular tool, material, or piece of equipment shall be performed as follows:

- Position the wrapped item so that the written information on the label/wrapping is visible.

NOTE: Junior Health Physics/Decontamination Technicians may operate survey instruments for decontamination monitoring purpose. HPTs shall oversee Junior Health Physics/Decontamination Technicians when survey instruments are in use.

CAUTION: Survey instruments to be used in a known or suspected contaminated area should be protected (wrapped in plastic, poly, etc.) against possible contamination before use.

- The HPTs shall direct the removal of the item from the wrapping in such a manner (rolling plastic, poly, etc.) to control the spread of contamination.
- An item that is highly contaminated with smearable contamination should be misted with an approved liquid such as demineralized water. The water vapor will wet down the particulate contamination and help prevent the possibility of generating airborne contamination.
- Once the item has been removed from the wrapping and has been properly positioned, discard the wrapping as radioactive waste.

8.3.3 The following decontamination techniques should be considered for the decontamination of equipment, materials, and tools:

- Any equipment with inaccessible areas shall be dismantled so that all surfaces are accessible for decontamination and for survey.
- Decontamination shall be performed in a safe, effective manner.

- The HPT shall be notified immediately if the job conditions change (e.g. suspected asbestos found, presence of mercury in a switch or a light bulb, a fluid leak, or any other special circumstances).

- An HPT (or qualified individual) shall be assigned as a fire watch if any spark creating decontamination techniques (grinding, etc,) are used and there are combustible materials in the area. There shall be a dedicated fire extinguisher located within the decontamination work area.

- In order to secure a safe cleaning surface, the item should be positioned on the worktable (if size and weight permits) and locked into a vise or secured by other approved methods as determined by the RFS.

- The decontamination area shall remain organized and free of debris. The HPT shall enforce the "clean-as-you-go" policy whenever necessary.

- A HEPA vacuum cleaner may be used during the decontamination operation.

8.3.4 Smearable Contamination Removal

When the item is properly positioned for decontamination and the pre-survey has been completed, perform the following:

- Moisten the surface of the item with an approve liquid (e.g. demineralized water).

- Fold a paper or cloth wipe into sections, using one surface of the wipe gently and wipe contamination off in one direction away from the user's body. This should reduce the possibility of personnel contamination.

- Re-fold the paper or cloth wipe so that a clean surface is available (this should prevent cross-contamination) and continue until item is ready for survey.

- For some materials, duct tape will effectively remove smearable contamination. Wrap the duct tape loosely around the gloved hand. Adhesive side out. Roll the tape over the contaminated area. Re-survey.

8.3.5 Fixed Contamination Removal

There are many techniques that can be use to remove fixed contamination. The general idea is to remove the material, which is fixing the activity to the surface, or remove a very thin layer of the surface material. The techniques selected for a particular decontamination operation is at the discretion of the RFS and the HPT. The techniques can be divided into the following categories:

- Light hand decontamination
- Abrasive hand decontamination
- Power tool decontamination
- Machine decontamination (use of abrasive bead blasters, grit blasters, high pressure water wash systems, etc.). The specific implementation of these techniques is not included within the scope of this procedure.
- Cleaning solutions/solvents (use of ultrasonic cleaners, acid baths, electropolishing, etc.). The specific implementation of these techniques is not included within the scope of this procedure.

8.3.6 Light hand decontamination consists of using many of the same techniques as 8.3.4 of this procedure.

8.3.7 Abrasive hand decontamination shall be performed in the following manner:

- Remove as much smearable contamination as possible.
- Moisten the surface of the item(s) to contain contamination.

CAUTION: Abrasive measure should only be applied to surfaces, which are not critical for operation of devices, which must be restored to working condition. Abrasion of machined surfaces should be minimized if the device is intended to provide its designed operation.

- Use an abrasive cleaning tool (e.g. sandpaper, steel wool, steel brush, hand grinder, etc.) to loosen fixed contamination. Clean in one direction only and clean Away from the body to prevent personnel contamination.
- Continue to moisten the surface of the item(s) to contain contamination.
- Remove as much smearable contamination as possible.
- Re-survey.

8.3.8 Power tool decontamination shall be performed in the following manner only under the direction of the HPT.

NOTE: When using power tools, always consider the potential of injury due to the hazards involved. Power tools shall be use cautiously and in accordance with the manufacturer's recommendations.

- Some of the electric power tools that can be use in decontamination operations are:
  - Drills - used to drill out contaminated areas, to disassemble contaminated components and when used with grinding wheels or disks, may be used as an abrasive tool.
  - Saws - used to separate contaminated pieces from clean pieces.
  - Grinders - used to grind fixed contamination form surfaces.
  - Electric screwdrivers - used in the disassembly of component parts

8.3.9 Power tool decontamination shall be performed in the following manner:

- Remove as much smearable contamination as possible as per Section 8.3.4 of this procedure.
- Moisten the surface of the item lightly to contain contamination. Use a spray bottle for moistening.

CAUTION: Do not use electric power tools on a wet working surface. Keep liquids away from electric power tools.

- Whenever feasible the use of containment device (e.g. glove box, etc.) should be used to contain the spread of contamination when using power tools for decontamination operations.
- Use the power tool to remove fixed contamination. Clean in one direction only and clean away from the body to prevent personnel contamination.
- Re-survey.

8.4 Post Decontamination

8.4.1 If the decontamination was successful, the decontamination technician shall notify the HPT who shall perform a release survey in accordance with OP-004.

- If the item satisfies the criteria for release as in OP-004, remove the item to a holding area for disposal and document results. When prepared for disposal, ensure compliance with the provisions of AP-014 and AP-013.

- If the item remains contaminated, attempt a second decontamination.
- If the item remains contaminated, attempt a third decontamination only at the direction of the RSO or duly authorized representative.

8.4.2 If an item cannot be effectively or economically decontaminated, the RFS may direct the CABRERA work crew to volume-reduce (reduce to component parts) the equipment, material, or tools as much as possible. If the item is expendable, the individual parts may be surveyed and released in accordance with step 8.4.1.

8.4.3 If an item is volume-reduced to its component parts and decontamination is not feasible, and the item is not needed, the item parts shall be considered radioactive waste. Radioactive waste is to be segregated into similar material for shipment purposes by the direction of the Project Manager. The RFS shall direct the segregation of radioactive waste into the following categories:

- Steels, hard metals
- Wood
- Fiber products
- Paper
- Rubber
- Cloth (duct tape is considered a cloth)
- Aluminum, soft metals (brass)
- Glass
- Questionable items (e.g. light bulbs pipe with lead solder, electronic component parts) which could be considered mixed or hazardous waste.
- Other categories, if applicable.

8.4.4 After all decontamination operation have been completed a HPT shall perform a release survey of the decontamination area and de-post the area in accordance with procedures OP-001 and OP-019.

9.0 QUALITY ASSURANCE/RECORDS

9.1 Quality Assurance

9.1.1 Instrumentation used in the surveys will be checked with standards daily and verified to have current valid calibration.

9.1.2 Operations conducted using this procedure shall be reviewed for compliance at least annually.

9.2 Records

9.2.1 The records generated by the use of this procedure are documented in accordance with the provisions of referenced CABRERA procedures. No new records are created.

9.2.2 Documented information shall be legible written in ink.

9.2.3 Data shall not be obliterated by erasing or using white-out. Incorrect entries shall be corrected by striking a single line across the entry. The correction shall be entered, initialed, and dated.

10.0 ATTACHMENTS

None

COMPANY CONFIDENTIAL

CABRERA SERVICES

RADIOLOGICAL · ENVIRONMENTAL · REMEDIATION

GAMMA SPECTROSCOPY LABORATORY

OPERATIONAL PROCEDURES

Effective Date

06/04/2002

Revision 2

Prepared By:
CABRERA SERVICES, INC.
East Hartford, CT

Prepared By: ________________________________ Date: ____________
Eric Barbour – ISOCS Manager

Reviewed By: ________________________________ Date: ____________
Henry Siegrist – Health Physicist

Approved By: ________________________________ Date: ____________
David Watters – Senior Health Physicist

Table of Contents

1.0 PURPOSE

The purpose of this procedure is to provide the methods to be used for setup, routine operation and maintenance of a high purity germanium gamma spectroscopy system (gamma system) owned or leased by Cabrera Services, Inc. (CABRERA) in a laboratory setting.

2.0 APPLICABILITY

This procedure describes general measurement and analysis methods to perform gamma emissions analysis of volumetric samples using high resolution intrinsic germanium gamma spectroscopy via the Gamma Acquisition and Analysis (GAA) application within standard, PC based Genie-2000 software. This procedure also encompasses methods of operation and quality assurance procedures for gamma spectroscopy system operation in a mobile laboratory setting. The procedures presented in this document pertain to the use of a gamma spectroscopy system used to generate reportable sample activity results. Algorithms used by Genie-2000 software can be referenced in the Genie-2000 Customization Tools Manual.

3.0 PRECAUTIONS, LIMITATIONS, AND REQUIREMENTS

3.1 Personnel Qualifications

Individuals performing measurements with any gamma spectroscopy system owned or leased by CABRERA shall be familiar with the requirements established in the current and approved version of this procedure. Individuals who operate the system shall have a general knowledge of its principles of operation.

3.2 Quality Assurance

Data collected using the gamma system is considered invalid unless compliance with the quality assurance requirements stated herein is demonstrated and documented.

3.3 Instrument Limitations

3.3.1 The instrument shall not be operated in environments where the ambient temperature exceeds 50° C (122° F) or is less than -10° C (14° F).

3.4 Requirements

3.4.1 Prior to performing any system measurements, detector should be covered with a thin, clear (i.e., see-through) plastic bag.

3.4.2 The instrument is sensitive to temperature changes. Energy calibrations and/or gain adjustments shall be performed when necessary as stated herein to ensure that the accuracy of measurement results is not compromised.

3.4.3 When filling an ISOCS detector (Big Mac) dewar with liquid nitrogen (LN_2), only use LN_2 systems delivering liquid at pressures between 5 psi and 25 psi. An empty, warm Big Mac dewar should not take longer than 45 minutes to fill. Do not attempt

3.4.4 Detector should be allowed to cool for a sufficient time period prior to applying high voltage. This time period will be at least 6 hours for an internal Big Mac dewar and 12 hours for a large dewar with a dip-stick type detector. Guidance sho uld be sought from the ISOCS Manager for ensuring the necessary cooling time.

3.4.5 Authorization and guidance of the ISOCS Manager will be needed prior to warming the germanium detector to room temperature. When allowing a germanium detector to warm, ensure the bias voltage is turned off.

3.4.6 Ensure that the outlet of the tubing connecting the liquid nitrogen (LN_2) cylinder to the detector's dewar is clear of dirt prior to refilling the dewar.

3.4.7 No adjustments should be made to the detector high voltage unless authorized by the ISOCS Manager.

3.5 Safety Precautions

3.5.1 Avoid skin contact with LN_2 to avoid frostbite. Always use proper eye and skin protection, including heavy gloves and eye protection when handling LN_2.

3.5.2 Ensure there is proper ventilation of the area when transferring LN_2 from one dewar (container) to another or when venting LN_2 dewars using pressurized air or gas.

3.5.3 When a cryostat exhibits signs of vacuum failure, such as heavy moisture or ice formation on the surface or extremely high LN_2 loss rate, stop using the unit immediately. Due to explosion hazard, tie a blanket or other large, heavy cloth around the entire unit, including the endcap. Do not allow the unit to warm up. Notify CABRERA Project Manager and contact the ISOCS Manager for further instructions.

3.5.4 Ensure that all sample containers (i.e., Marinelli beakers, etc.), tools, etc. are clean and dry prior to use. Wash all items to remove all traces of any previously contained material. Any items that will not clean adequately should be discarded (as per the Laboratory Manager) to prevent reuse and the possibility of cross-contamination.

3.5.5 Appropriate ALARA measures shall be used to minimize the potential for contamination and unnecessary dose when in the presence of radiological material.

4.0 INITIAL SETUP PROCEDURES

4.1 Initial Setup of Detector

4.1.1 Initial setup shall be performed, or directly supervised, by a qualified Radiological Engineer under the guidance of the ISOCS Manager.

4.1.2 Manufacturers' safety precautions should be reviewed and followed during setup of the system. Refer to Canberra's User Manual, and/or other relevant system manuals for complete instructions.

4.1.3 The germanium system should be in a location that minimizes vibration, electro-magnetic (EM) and radio frequency (RF) interferences. The location shall provide for adequate ventilation and temperature consistency.

4.1.4 When using a large dewar with a dip-stick type detector, note the following procedures: Before attempting to fill the dewar with LN_2, ensure all LN_2 connections are made correctly. An extension of sufficient length should be added to the vent tube to direct cryogenic gases away from personnel and equipment. The vent tube should be directed into an appropriate overflow container. Fill the dewar and allow the detector to cool for at least 12 hours. Monitor the LN_2 level, as there is substantial loss during initial cool down.

4.1.5 When using an internal Big Mac dewar (CABRERA ISOCS system), note the following procedures: Initial filling of the dewar with LN_2 may be performed outside of the collimator as per normal filling procedures. Allow to cool for at least 5 hours, then top off dewar and allow to cool for 1 more hour. Following the source measurement referenced in Section 4.3, place dewar in the collimator in the uplooking position on the supplied dewar stand and ensure proper LN_2 connection is made. Seek guidance from the Laboratory Manager or ISOCS Manager for the proper line to connect with on the back side of the dewar. When disconnecting from the dewar, *ensure that the line to the Big Mac dewar is plugged, otherwise LN_2 leakage will occur.*

4.2 Initial Setup of Spectroscopy System

Prior to setting up Quality Control trends and measurements, the system must be fully calibrated by, or under the direct supervision of, a qualified Radiological Engineer. Contact the ISOCS Manager to ensure that the system has already been properly calibrated and is ready to collect spectra.

The stabilizer should be set up (following system setup) by setting the gain centroid (select MCA, adjust, stab) at the channel equivalent to1460.8 keV. Gain spacing will be approximately 2 channels and gain window will be approximately 4 channels. Contact the ISOCS Manager for guidance, as needed.

Set up (create) the proper file structure folders on the gamma spectroscopy computer system as presented in Section 11.0.

4.3 Initial Quality Control Source Measurement

Long-term detector efficiency trending is being performed on CABRERA ISOCS systems. Therefore, this section only applies to detectors belonging to a CABRERA ISOCS system (i.e., Big Mac dewar).

Long-term efficiency trending will be performed on CABRERA ISOCS detectors using a NIST traceable Eu-152 source, unless otherwise specified by the ISOCS Manager. The ISOCS Manager will provide the method for use of source measurement results.

4.3.1 Prior to setting detector into collimator, perform a ten-minute measurement of the NIST Eu-152 button source. ***Ensure that no other check sources are present in the area around the detector area.*** The source can be taped to a wall and the detector must be center-line to the source and positioned at exactly one-foot from the detector face. Save this file as "Eu-1521ftmmddyy.cnf" (where mmddyy is the current date) into the project "initial measurements" folder, as presented in Section 11.0.

4.3.2 Additionally, remove the source from the wall and perform a ten-minute measurement prior to moving the detector for a background reference. Save this file as "Eu-152bkgdmmddyy.cnf" into the project "initial measurements" folder, as presented in Section 11.0.

4.4 Efficiency Calibration

An efficiency calibration must be performed using a source traceable to the National Institute of Standards and Technology (NIST) as specified by the ISOCS Manager. Detector should be placed in collimator prior to this measurement. See Section 9.0 for general guidance in using Gamma Acquisition and Analysis. If sample measurements are for screening purposes only, then efficiency calibration may not be necessary as per the consent of the ISOCS Manager. ***Ensure that no other check sources are present in the area around the detector area.***

4.4.1 An efficiency calibration will be performed by, or under the direct supervision of, a qualified Radiological Engineer and under the guidance of the ISOCS Manager, as follows:

4.4.2 Place the proper NIST traceable volumetric source onto the detector. Collect source spectra for a thirty-minute time period. Save this file to the project "initial measurements" folder (see Section 11.0) in the following format: "NIST Source mmddyy.cnf". Select **Calibrate**, then **Efficiency**, and then **By Certificate file**. Select the certificate file provided specifically for the project NIST traceable source by the ISOCS Manager.

4.4.3 The Efficiency Calibration box will appear. Perform the efficiency calibration by choosing **Auto**. Evaluate the efficiency curve by choosing **Show**. Choose **OK** when efficiency calibration has been completed.

4.4.4 Save changes using the disk on the tool bar.

4.4.5 Save the efficiency calibration file by selecting **Calibrate, Store** and using the following format: "Project Name Laboratory Efficiency.cal".

4.4.6 Save a copy of the generated efficiency calibration (.cal) file from C:\Genie2k\Calfiles into the project "initial measurements" folder (see Section 11.0).

4.4.7 Reopen the file saved in Section 4.4.2, and load the new calibration file (.cal). Analyze the file and ensure that the source concentration is within tolerance under the guidance of the ISOCS Manager.

5.0 QUALITY CONTROL

5.1 Initial Quality Control Source Measurements

During initial system setup procedures and following the efficiency calibration, twenty initial Quality Control (QC) source measurements must be performed, using a source jig containing a Co-60 and Cd-109 source, or as otherwise specifically specified by the ISOCS Manager, to setup baseline data for daily QC trending. The Cd-109 and Co-60 sources in this source jig (referred to hereafter as Co-Cd source) should not be removed from the source jig and should be kept stable, so as to allow for a reproducible geometry during future source measurements. These source measurements will be analyzed and then transferred into the QA Editor for establishing baseline trend data. Follow the steps in Section 5.3, except the name of each saved measurement will be "qc01.cnf", "qc02.cnf", through "qc20.cnf". These files will be saved into the project "initial measurements" folder as presented in Section 11.0.

Between measurements, stabilize using No-Salt (see Section 7.1), as needed. Also, remove and replace the source jig between each initial source measurement.

Following these twenty measurements, collect one additional source measurement for the current day's QC (if samples are to be analyzed that day), as per Section 5.2.

5.2 Daily Quality Control Source Measurements

A Daily QC Source check is performed using the Co-Cd source at the start of each day on which field measurements will be performed. Source measurements will be performed using the same source and geometry as used for the initial QC measurements. Specific instructions for the performance of Daily QC measurements are presented in Section 5.3. The specific QC parameters evaluated and the acceptable ranges of results are summarized as follows:

QC Calibration Parameter Description	Acceptable Range of Results
Low energy photopeak centroid channel	Within fixed channel limits#
High energy photopeak centroid channel	Within fixed channel limits#
Low energy photopeak FWHM**	Mean ± 2 std. deviations*
High energy photopeak FWHM	Mean ± 2 std. deviations*
Low energy photopeak net counts/second	Mean ± 2 std. deviations*
High energy photopeak net counts/second	Mean ± 2 std. deviations*

* : The mean and standard deviation values for these QC parameters are established by performing a set of 10 initial counts. Subsequent count results are then compared to the established "investigation level" range of [mean ± 2 std. dev.] and "action level" range of [mean ± 3 std. dev.]. The mean and standard deviation shall be updated every 10 counts.
** : FWHM stands for Full Width at Half Maximum. It is the width of the energy peak, in keV, at one half of the peak amplitude, or height.
# : Observed peak centroids should typically be within ± 1.0 keV of theoretical (approx. ± 3 channel limits)

5.3 Specific Instructions for Daily Source QC Measurements

1) Perform QC source measurement using the appropriate count time and source

2) Save and re-open the QC file ("qaddmmyy.cnf")

3) Analyze spectra using the "ISOCS QA and BKGD" analysis sequence then save and close file.

4) Transfer the file into the QA Editor by opening the QA Editor, then opening the project ".QAF" file, and choosing **Results, Transfer**. Choose current qcmmddyy.cnf file.

5) Choose **Results, Report Last Measurement** and check mark "screen" and "printer". If "page one" is check marked, then uncheck "page one" and check mark "new file".

6) In the QC report generated from the previous step, ensure that the "Measurement Date" is correct. Then, if none of the analysis results under the deviation/flags section show "IN" or "AC", then select **File, Save** and QC is complete.

7) If one or more of the analysis results under the deviation/flags section show "IN", then perform an additional measurement (save that measurement as "qcmmddyyb.cnf") and transfer to QA Editor by following the previous steps. Then, go to step 9.

8) If one or more of the analysis results under the deviation/flags section show "AC", then shut down the system and contact the ISOCS Manager for evaluation.

9) If none of the QC results which failed in step 7 show "IN" in the current last measurement report, then go to the next step. Otherwise, if any of the QC result(s) fail again which previously failed in step 7 (i.e., show "IN" or "AC"), then shut down the system and call the ISOCS Manager for evaluation.

10) Reject the second count for any QC results that PASSED the first count using **Results, Edit Values**. The QC results that initially failed in step 7 should **NOT** be rejected.

11) Perform necessary signing and posting of QC data results as presented in the following paragraphs:

QC parameter results from these daily QC Calibration Check counts are stored in a QC file and can be tabulated and plotted for long-term trending. Daily QC data results will be printed each day, as instructed in step 5 above. These daily reports will be initialed and dated by the Laboratory Manager each day and then faxed to the ISOCS Manager. Trend plots will be printed at the end of each week of work, initialed and dated by the Laboratory Manager and faxed to the ISOCS Manager. Trend plots are generated by choosing **Results, Show Chart, Connect Data Points**, and then selecting each of the 6 trends and selecting print under each resulting graph. Printed reports and trend plots will also be retained in a readily accessible folder for review. The Laboratory Manager and/or ISOCS Manager shall review the trend data weekly for biased results. These printouts are intended to provide a record of stable system performance, or alert the user to possible system problems.

In the steps above "IN" signifies the need for an investigation, and "AC" signifies the need for an action.

6.0 SAMPLE RECEIVING

Soil samples will be received by the gamma laboratory in pre-selected containers (e.g., 1–liter Marinelli beakers) and on each container will be printed a unique, pre-determined lab sample number. If no naming convention is specified in the site Work Plan, see the CABRERA Project Manager for the proper naming convention to be used. Soil samples will be stored in the soil sample storage area in preparation for screening measurements. Perform the following sample receiving tasks:

- Weigh each sample as per relevant operating procedures and record the weight of each sample into the logbook and also into the information box in the Gamma and Acquisition Program as per Section *9.10*.

- Use a thin plastic bag to hold the sample prior to placing the sample container over the detector.

7.0 DAILY MEASUREMENT PROCEDURES

Once the system has passed Daily Quality Control measurements as presented in Section 5.0, the following sections will be used to perform proper sample measurement procedures.

7.1 Spectral Stabilization

The No-Salt measurement from the previous evening should be stopped, then select save, then clear, and a five-minute No-Salt measurement should be performed.

The measurement of potassium chloride (No-Salt) will be performed throughout the day and night, as needed, so that the stabilizer can use the 1460.8 keV peak of K-40 for purposes of spectral stabilization.

When energy drift occurs beyond the 0.5 keV tolerance, No-Salt should be measured until the K-40 peak is between 1460.5 keV and 1461.1 keV. Select ctrl L and ctrl R to put markers around the peak and then see Marker Info for peak information.

7.2 Blank Measurement

Following QC analysis on the first day of each week, a weekly blank measurement shall be performed using a laboratory sugar blank. This blank will be a container filled with sugar and water, or equivalent matrix as per the Laboratory Manager, and will have a sample weight equivalent to the average weight of the project samples to be analyzed.

7.2.1 Perform a measurement on the blank using a 30-minute measurement time, or other measurement time specified by the ISOCS Manager. ***Ensure that no check sources are present in the area around the detector area.***

7.2.2 Save the week's blank file as "SugarBKGD.cnf" into the project "Daily Blanks" folder (see Section 11.0).

7.2.3 Re-open the file and analyze this file using the "ISOCS QA and BKGD" analysis sequence. Select **File, Save**. Then select **File, Save As**, and save the file as "SugarBKGDwklymmddyy.cnf" into the same file folder as above, and then close the file.

7.3 Sample Measurements

7.3.1 See Section 6.0 for instructions for proper receipt of soil samples.

7.3.2 Perform measurements for each sample using Section 9.0 for guidance. ***Ensure that no check sources are present in the area around the detector area.***

7.3.3 When performing measurements, *make sure to record all necessary information into the information box as per Section 9.10.*

7.3.4 Ensure dead time falls into guidelines as presented in Section 9.6.

7.3.5 Ensure that the count time is of significant length to reach applicable minimum detectable concentrations (MDCs) as per the guidance of the ISOCS Manager.

7.3.6 Save file using the proper naming convention (see Project Manager) and into the proper file location as per Section 11.0.

7.4 Performing Spectral Analysis

7.4.1 Open the spectral file (.cnf) to be analyzed.

7.4.2 Load the proper calibration file using Section 9.12 for guidance. This calibration file should be created prior to commencement of sample measurement activities either by using the efficiency calibration presented in Section 4.4 or by creating an ISOCS model and generating a mathematical efficiency calibration file. **Do not load any calibration files not specific to the project unless authorized by the ISOCS Manager.**

7.4.3 Perform data analysis using the "ISOCS Subtract BKGD" analysis sequence and guidance from Section 9.13. **No data results shall be reported unless authorized by the CABRERA Project Manager and ISOCS Manager.**

7.5 Energy Drift and Data Recording/Logging

An excel spreadsheet, or equivalent method, should be used to track each sample by recording Sample ID, Weight, Date/Time of sample Measurement, the collector's initials, and result for a specific high energy and low energy peak of known energies (to track peak drift). The high and low energy peaks will be chosen under the guidance of the ISOCS Manager. If the energy of either peak drifts by greater than 0.5 keV from the true peak energy, then stabilization should be performed as presented in Section 7.1. Contact the ISOCS Manager for guidance, as needed.

7.6 Energy Recalibration

Energy recalibrations may be performed only with permission of the ISOCS Manager.

7.6.1 Only a qualified Radiological Engineer may perform energy recalibrations.

7.6.2 Collect a significant number of counts in the spectra (i.e., approximately 1000 counts in each peak used for the calibration).

7.6.3 Select Calibrate, then Energy Recalibration.

7.6.4 Choose the appropriate Certificate file (contact ISOCS Manager). Ensure that all peaks are listed, and select **Auto**.

7.6.5 Save changes using the disk on the toolbar.

7.7 Data Storage (Back-Up)

At the end of each day, back-up (i.e., COPY) the entire project folder and also the Genie2k folder onto an external disk (i.e., PCMCIA or other equivalent method). This disk should be stored separately from the system computer until the next back-up is to be performed. The back-up disk should only contain two folders, the project folder and the Genie2k folder. These two folders will be copied over daily with the most current data.

7.8 No-Salt Measurement

When the stabilizer is in use, stabilization will be performed throughout each night by changing the measurement time sufficient to count No-Salt throughout the night. See Section 7.1 for details.

8.0 PERFORMANCE OF WEEKLY BACKGROUND MEASUREMENT

A background measurement will be performed weekly to identify potential significant deviations in background activity. This measurement should be performed at the end of the day (to avoid interfering with project schedules), if possible.

8.1.1 Remove any radiological check sources from the vicinity of the detector.

8.1.2 Perform a sixty-minute measurement. Save the measurement into the project QA folder; named as "WeeklyBKGDddmmyy.cnf"

8.1.3 Re-open file and analyze using ISOCS QA analysis sequence.

8.1.4 Peaks appearing in the Peak Analysis Report should be evaluated, under the direction of the ISOCS Manager, for the identification of potential radiological contamination of the detector.

9.0 REFERENCE FOR GENERAL GAMMA ACQUISITION OPERATION

The following steps are presented for assistance in operating the Gamma and Acquisition Program (subset program of Canberra Genie-2K Suite).

9.1 Launching GAA

GAA can be opened from the Windows desktop by double-clicking on the GAA Icon or by choosing **Start**, then **Programs**, then **Genie 2000**, then GAA. Before opening the detector, the Inspector must first be switched on. The switch is located on the left side of the Inspector.

9.2 Opening the Detector

Choose **File** (located on the menu bar), then **Open.** Open file type **Detector** and select the specific **ISOCS** detector (e.g. DET01).

9.3 Applying High Voltage to the Detector

Caution: <u>Ensure that the detector has been properly cooled with liquid nitrogen (i.e. for approximately six hours) before performing this step</u>

Choose **MCA** (located on the menu bar), then **Adjust**. A box will appear in the lower portion of the screen. Select the **HVPS** tab. After the **Wait** signal has disappeared, select the **On** button and exit from the **Adjust** box by single-clicking on the **Exit** button.

9.4 Selecting the Appropriate Count Time

Choosing the appropriate count time can be accomplished by using the edit icon located on the shortcut menu bar or by selecting **MCA,** then **Acquire Setup** from the menu bar. Enter the appropriate time where prompted. Count time must be entered as **live time** for the instrument dead time correction to function properly.

9.5 Starting/Stopping Data Acquisition

Pressing the **Start** key under Acquire will cause data acquisition to begin. The **Start** button will no longer be bold face when the acquisition begins. Acquisition can be stopped at any time by pressing the **Stop** button located immediately to the right of the start button. If acquisition is stopped and a preset time is entered (see Section 9.4), pressing the **Start** button will resume acquisition, which will continue until the preset time is reached.

9.6 Dead Time Check

In the **Time Info** section of the GAA display window can be found the **Dead Time**. If the dead time increases to above 5% when no known radiological source (i.e. excluding background) is present or increases above 15% when a known radiological source is being measured, then contact the ISOCS Manager for evaluation.

9.7 Clearing Spectrum Data

Pressing the **Clear** key under the **Start** and **Stop** buttons under Acquire will erase the spectrum data. *Remember to save current detector settings by choosing the save disk icon on the tool bar before clearing data.*

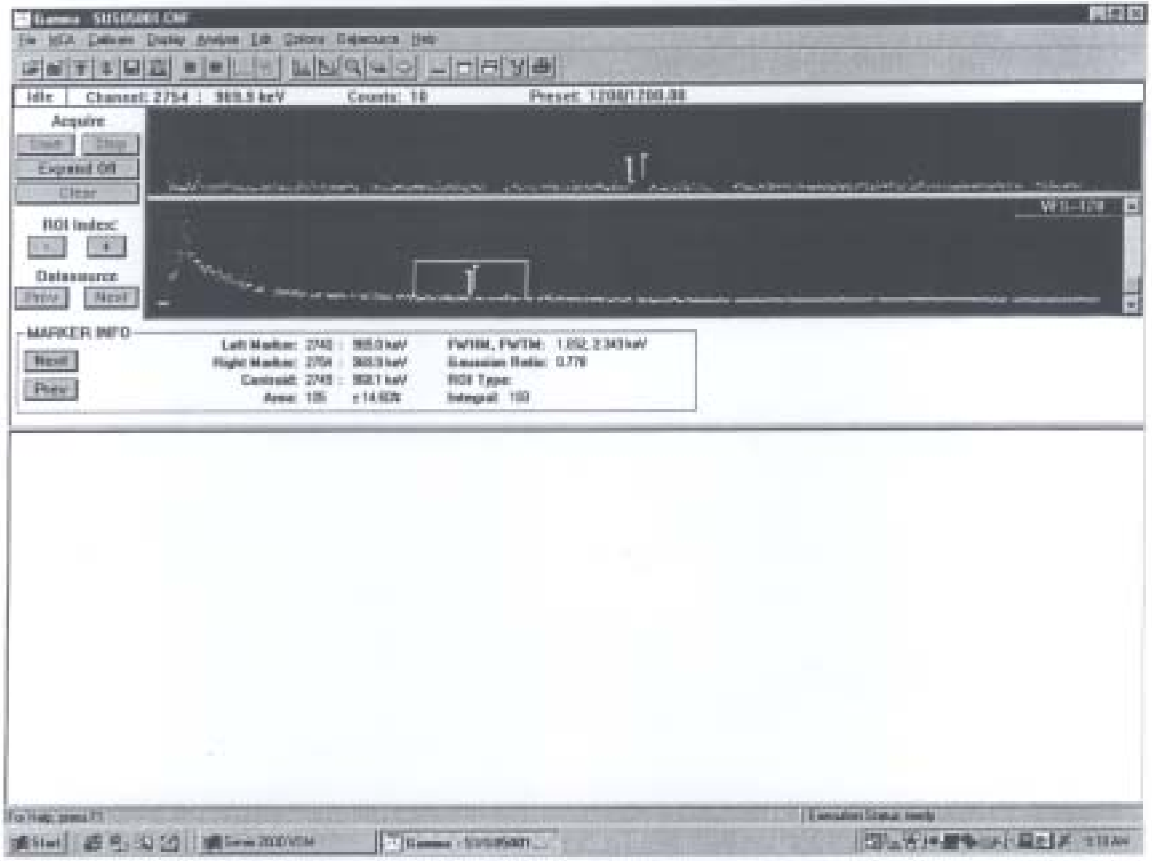
9.8 Information from the Spectrum Display

In the Spectrum Display, the left and right arrow keys will move the spectrum cursor. The information bar above the Spectrum Display, will indicate the energy level (keV) and channel number corresponding to the location of the cursor, as well as the total number of Counts at that energy level, and the Elapsed/Preset time. In Figure 1, the acquisition had been completed, therefore, the elapsed time was 1800 seconds and the preset time was 1800 seconds (1800/1800 is shown in Figure 1). If the instrument had only reached 200 seconds of the preset 1800 seconds, then the display would show 200/1800.

Pressing the left and right arrow keys will move the cursor up and down the energy spectrum. The cursor can also be moved via the mouse by single-clicking in the area of interest.

The spectrum display vertical scale automatically adjusts when counts in any channel exceed the current vertical scale. The initial vertical scale is 64. The spectrum Vertical Full Scale (VFS) display scale can be expanded or contracted by pressing the up and down arrow, respectively.

Figure 2. <u>GAA Screen with Marker Info Displayed</u>



9.9 Adjusting Amplifier Gain and ADC Zero

Prior to the start of each counting session the system alignment should be checked. If the energy gain or ADC zero is beyond acceptable limits, they must be adjusted.

To check and adjust the amplifier gain and ADC zero settings, a suitable check source should be placed near the detector during spectral data acquisition. This check source should emit photons with emission rates sufficient to produce readily detectable photopeaks. A NIST traceable source may be used for this purpose.

The centroid channel and corresponding energy value for each reference photopeak should be compared to the expected values. Observed photopeak centroids should typically be within ± 1.0 keV of the expected energy values. Adjust the vertical full scale of the displayed spectrum and use the **Expand On** button, as appropriate, to view the reference photopeaks.

From the MCA window, click **Acquire ON** and note the position of the photopeaks in the spectrum (specific to the source being used). If necessary, amplifier gain and/or ADC zero settings can be changed by selecting **Adjust** from the MCA menu. This will display the Adjust dialog box.

The scroll bars in the Amp Fine gain, Amp S-fine gain, and ADC Zero sections of this dialog box should then be used to make the appropriate changes. After each change, clear any previous spectral data and start a new acquisition to evaluate the new settings.

When spectral data acquisition using the traceable source indicates that the centroid channel of each reference photopeak is within ± 1.0 keV of the expected energy values, the new settings are deemed acceptable. Select the **Exit** button to exit the Adjust dialog box.

To save the new parameter values, select **File** in the GAA window menu bar, then select **Save** from the **File** menu.

9.10 Identifying Sample Spectra

Descriptive information is entered to uniquely identify each acquired spectrum. This can be done while data acquisition is in progress, or after acquisition has stopped and prior to saving the spectra.

Select **Edit** in the GAA window menu bar, then select **Sample info** from the **Edit** menu. This will display the Edit Sample Information dialog box, which includes descriptive fields for: Sample Title Collector Name, Sample Description, Sample ID, Type, Units, and Sample Geometry.

Editable fields are also provided for Quantity, Uncertainty, Random Error, and Systematic Error. Select the None button in the Buildup Type section, and leave the Sample Date fields blank unless informed otherwise by the ISOCS Manager.

Make sure to enter the following information for every sample analysis in the fields of the Edit Sample Information dialog box:

1) The **Sample Title** should be entered showing the Sample ID and this ID should be *exactly* the same as the file name.
2) **Collector Name**
3) **Sample Description** should present any notes regarding this sample.
4) The detector number, for example "ISOCS 7078", should be entered into the box named **Type**.
5) The **Quantity** box should present the sample weight minus the container tare weight in grams.
6) The **Units** box should have "gram" in it.

Select the **OK** button to save the information and exit this dialog box.

9.11 Saving a Spectral Data File

After spectral acquisition has stopped, the spectral data and related information can be saved in a file. This step is required before analyses of the acquired spectrum can be performed.

Select **File** in the GAA window menu bar, then select **Save as** from the File menu. This will display the Save As dialog box. Enter the desired name, up to eight characters followed by the .CNF extension in the File name field.

Enter an appropriate supplemental text string (up to 32 characters) in the Description field. Enter text that will be helpful in selecting this file when attempting to identify it at some later time.

Select the **OK** button to save the file and exit the Save As dialog box. The default directory used to store these files is GENE2K\CAMFILES.

To collect additional spectra, clear existing spectral data from the graphics region of the GAA window.

9.12 Loading ISOCS Calibration Parameters

ISOCS Calibration Software must be used to generate an efficiency calibration file appropriate for the object being assayed. The desired ISOCS calibration parameters can be loaded and saved with the spectral data. The spectral data file can then be analyzed to determine nuclide activity concentration.

From the GAA window menu, choose **Calibrate**. Select **Load** from the Calibrate menu. This will display the Load Calibration dialog box. The File Names section in this dialog box will contain a list of all calibration files currently stored in the directory specified by the environment variable CALFILES.

When the Load Calibration dialog box is first displayed, the boxes labeled Energy/Shape and Efficiency will contain a check mark, select the box labeled Energy/Shape to remove the check mark from this box. This will allow new efficiency calibration parameters to be loaded without changing the original energy/shape calibration parameters, which is appropriate for ISOCS measurements.

Use the vertical scroll bar in the File Names section until the desired ISOCS calibration file name is shown then double click on that file name. This will exit the Load Calibration dialog box, and load the efficiency calibration parameters from the selected file into the open CAM file data source.

9.13 Analyzing a Spectral Data File

After opening a CAM file data source and loading the appropriate ISOCS efficiency calibration parameters, spectral data analysis can be performed. The **Analyze** options in the GAA window menu bar can be used to perform these analyses.

Choose **Analyze** in the GAA window menu bar to display the Analyze menu. Next, choose **Execute Sequence** and select the sequence specified by the ISOCS Manager. Usually, only one analysis sequence will be used at each work site.

9.14 Exiting the GAA Application

When all spectral data analyses have been completed, select **File** in the GAA window menu bar. Select **Close** from the File menu. If a data source with unsaved changes was still open in the GAA window, a message screen will be displayed asking whether the latest changes should be saved. Respond appropriately to any such message.

Before completely exiting from GAA, turn off the high voltage to the detector by reversing the steps for applying high voltage in Section 9.3.

10.0 QUALITY ASSURANCE

10.1 Quality Control

Quality Control guidelines are presented in Section 5.0.

10.2 Duplicate Measurements

Duplicate sample measurements will be performed for 10% of gamma system sample measurements, unless otherwise specified by the Project Work Plan or CABRERA Project Manager.

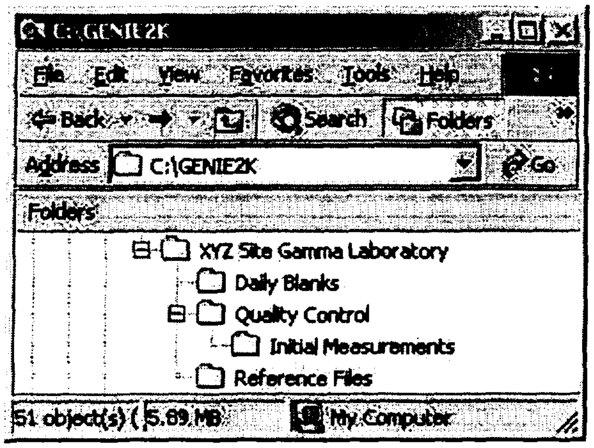
11.0 PROPER WINDOWS FILE STRUCTURE

The proper Windows file structure to be used during CABRERA projects for files related to gamma spectroscopy is as follows:

All files presented below are saved to the **D: drive,** (if drive is partitioned), otherwise use C: drive.

- Folder Level 1 - "XYZ Site Gamma Laboratory" - The first folder will be named as the Project Name and then Gamma Laboratory (example name is provided). Files saved into this folder will be sample measurement (.cnf) files (see Section 7.3). These files will be named as per the naming convention setup for the project. Also in this folder will be another folder as follows:
- Folder Level 2 - "Quality Control" – Files saved into this folder will be 1) The Quality Assurance Editor File for the project (.QAF); and 2) daily QC measurement (.cnf) files (see Section 5.2). The daily QC measurement files will be named "qammddyy.cnf" (for example qa010102.cnf for a QC source measurement performed on Jan 1, 2002). If more than one QC measurement is collected in one day, then suffixes will be used a, b, c, etc. (for example "qa010102a.cnf"). Also in this folder will be another folder as follows:
- Folder Level 3 (inside Quality Control folder)- "Initial Measurements" - Files saved into this folder will be the ten initial source measurement (.cnf) files collected to setup the system QC trending (see Section 5.1).
- Folder Level 2 – "Daily Blanks" – Files saved into this folder will be the daily sugar background blanks as presented in Section 0.
- Folder Level 2 – "Reference Files" – Miscellaneous reference files related to the gamma spectroscopy laboratory may be saved into this file.

The following is an example of the proper file as presented in the steps above:



12.0 ATTACHMENTS

None

Table of Contents

Part I: Mixture Sums and Single Radionuclide Guidelines

Dose Conversion Factor (and Related) Parameter Summary
File: FGR 13 Morbidity

Menu	Parameter	Current Value	Default	Parameter Name
	Dose conversion factors for inhalation, mrem/pCi			
	Ra-228+D	5.080E-03	5.080E-03	DCF2(1)
	Th-228+D	3.450E-01	3.450E-01	DCF2(2)
	Th-232	1.640E+00	1.640E+00	DCF2(3)
	Dose conversion factors for ingestion, mrem/pCi			
	Ra-228+D	1.440E-03	1.440E-03	DCF3(1)
	Th-228+D	8.080E-04	8.080E-04	DCF3(2)
	Th-232	2.730E-03	2.730E-03	DCF3(3)
D-34	Food transfer factors:			
D-34	Ra-228+D , plant/soil concentration ratio, dimensionless	4.000E-02	4.000E-02	RTF(1,1)
D-34	Ra-228+D , beef/livestock-intake ratio, (pCi/kg)/(pCi/d)	1.000E-03	1.000E-03	RTF(1,2)
D-34	Ra-228+D , milk/livestock-intake ratio, (pCi/L)/(pCi/d)	1.000E-03	1.000E-03	RTF(1,3)
D-34				
D-34	Th-228+D , plant/soil concentration ratio, dimensionless	1.000E-03	1.000E-03	RTF(2,1)
D-34	Th-228+D , beef/livestock-intake ratio, (pCi/kg)/(pCi/d)	1.000E-04	1.000E-04	RTF(2,2)
D-34	Th-228+D , milk/livestock-intake ratio, (pCi/L)/(pCi/d)	5.000E-06	5.000E-06	RTF(2,3)
D-34				
D-34	Th-232 , plant/soil concentration ratio, dimensionless	1.000E-03	1.000E-03	RTF(3,1)
D-34	Th-232 , beef/livestock-intake ratio, (pCi/kg)/(pCi/d)	1.000E-04	1.000E-04	RTF(3,2)
D-34	Th-232 , milk/livestock-intake ratio, (pCi/L)/(pCi/d)	5.000E-06	5.000E-06	RTF(3,3)
D-5	Bioaccumulation factors, fresh water, L/kg			
	Ra-228+D , fish	5.000E+01	5.000E+01	BIOFAC(1,1)
	Ra-228+D , crustacea and mollusks	2.500E+02	2.500E+02	BIOFAC(1,2)
D-5	Th-228+D , fish	1.000E+02	1.000E+02	BIOFAC(2,1)
	Th-228+D , crustacea and mollusks	5.000E+02	5.000E+02	BIOFAC(2,2)
	Th-232 , fish	1.000E+02	1.000E+02	BIOFAC(3,1)
D-5	Th-232 , crustacea and mollusks	5.000E+02	5.000E+02	BIOFAC(3,2)

Site-Specific Parameter Summary

Menu	Parameter		User Input	Default	Used by RESRAD (If different from user input)	Parameter Name
R011	Area of contaminated zone (m**2)		1.000E+04	1.000E+04		AREA
R011	Thickness of contaminated zone (m)		2.000E+00	2.000E+00		THICK0
R011	Length parallel to aquifer flow (m)		1.000E+02	1.000E+02		LCZPAQ
R011	Basic radiation dose limit (mrem/yr)		2.500E+01	2.500E+01		BRDL
R011	Time since placement of material (yr)		0.000E+00	0.000E+00		TI
R011	Times for calculations (yr)		1.000E+00	1.000E+00		T(2)
R011	Times for calculations (yr)		3.000E+00	3.000E+00		T(3)
R011	Times for calculations (yr)		1.000E+01	1.000E+01		T(4)
R011	Times for calculations (yr)		3.000E+01	3.000E+01		T(5)
R011	Times for calculations (yr)		1.000E+02	1.000E+02		T(6)
R011	Times for calculations (yr)		3.000E+02	3.000E+02		T(7)
R011	Times for calculations (yr)		1.000E+03	1.000E+03		T(8)
R011	Times for calculations (yr)		not used	0.000E+00		T(9)
R011	Times for calculations (yr)		not used	0.000E+00		T(10)
R012	Initial principal radionuclide (pCi/g)	Ra-228	1.000E+00	0.000E+00		S1(1)
R012	Initial principal radionuclide (pCi/g)	Th-228	1.000E+00	0.000E+00		S1(2)
R012	Initial principal radionuclide (pCi/g)	Th-232	1.000E+00	0.000E+00		S1(3)
R012	Concentration in groundwater (pCi/L)	Ra-228	not used	0.000E+00		W1(1)
R012	Concentration in groundwater (pCi/L)	Th-228	not used	0.000E+00		W1(2)
R012	Concentration in groundwater (pCi/L)	Th-232	not used	0.000E+00		W1(3)
R013	Cover depth (m)		0.000E+00	0.000E+00		COVER0
R013	Density of cover material (g/cm**3)		not used	1.500E+00		DENSCV
R013	Cover depth erosion rate (m/yr)		not used	1.000E-03		VCV
R013	Density of contaminated zone (g/cm**3)		1.500E+00	1.500E+00		DENSCZ
R013	Contaminated zone erosion rate (m/yr)		1.000E-03	1.000E-03		VCZ
R013	Contaminated zone total porosity		4.000E-01	4.000E-01		TPCZ
R013	Contaminated zone field capacity		2.000E-01	2.000E-01		FCCZ
R013	Contaminated zone hydraulic conductivity (m/yr)		1.000E+01	1.000E+01		HCCZ
R013	Contaminated zone b parameter		5.300E+00	5.300E+00		BCZ
R013	Average annual wind speed (m/sec)		2.000E+00	2.000E+00		WIND
R013	Humidity in air (g/m**3)		not used	8.000E+00		HUMID
R013	Evapotranspiration coefficient		5.000E-01	5.000E-01		EVAPTR
R013	Precipitation (m/yr)		1.000E+00	1.000E+00		PRECIP
R013	Irrigation (m/yr)		2.000E-01	2.000E-01		RI
R013	Irrigation mode		overhead	overhead		IDITCH
R013	Runoff coefficient		2.000E-01	2.000E-01		RUNOFF
R013	Watershed area for nearby stream or pond (m**2)		1.000E+06	1.000E+06		WAREA
R013	Accuracy for water/soil computations		1.000E-03	1.000E-03		EPS
R014	Density of saturated zone (g/cm**3)		1.500E+00	1.500E+00		DENSAQ
R014	Saturated zone total porosity		4.000E-01	4.000E-01		TPSZ
R014	Saturated zone effective porosity		2.000E-01	2.000E-01		EPSZ
R014	Saturated zone field capacity		2.000E-01	2.000E-01		FCSZ
R014	Saturated zone hydraulic conductivity (m/yr)		1.000E+02	1.000E+02		HCSZ
R014	Saturated zone hydraulic gradient		2.000E-02	2.000E-02		HGWT
R014	Saturated zone b parameter		5.300E+00	5.300E+00		BSZ
R014	Water table drop rate (m/yr)		1.000E-03	1.000E-03		VWT
R014	Well pump intake depth (m below water table)		1.000E+01	1.000E+01		DWIBWT
R014	Model: Nondispersion (ND) or Mass-Balance (MB)		ND	ND		MODEL

Site-Specific Parameter Summary (continued

Menu	Parameter	User Input	Default	Used by RESRAD (If different from user input	Parameter Name
R014	Well pumping rate (m**3/yr)	2.500E+02	2.500E+02		UW
R015	Number of unsaturated zone strata	1	1		NS
R015	Unsat. zone 1, thickness (m)	4.000E+00	4.000E+00		H(1)
R015	Unsat. zone 1, soil density (g/cm**3)	1.500E+00	1.500E+00		DENSUZ(1)
R015	Unsat. zone 1, total porosity	4.000E-01	4.000E-01		TPUZ(1)
R015	Unsat. zone 1, effective porosity	2.000E-01	2.000E-01		EPUZ(1)
R015	Unsat. zone 1, field capacity	2.000E-01	2.000E-01		FCUZ(1)
R015	Unsat. zone 1, soil-specific b parameter	5.300E+00	5.300E+00		BUZ(1)
R015	Unsat. zone 1, hydraulic conductivity (m/yr)	1.000E+01	1.000E+01		HCUZ(1)
R016	Distribution coefficients for Ra-228				
R016	Contaminated zone (cm**3/g)	7.000E+01	7.000E+01		DCNUCC(1)
R016	Unsaturated zone 1 (cm**3/g)	7.000E+01	7.000E+01	---	DCNUCU(1,
R016	Saturated zone (cm**3/g)	7.000E+01	7.000E+01	---	DCNUCS(1)
R016	Leach rate (/yr)	0.000E+00	0.000E+00	2.374E-03	ALEACH(1)
R016	Solubility constant	0.000E+00	0.000E+00	not used	SOLUBK(1)
R016	Distribution coefficients for Th-228				
R016	Contaminated zone (cm**3/g)	6.000E+04	6.000E+04	---	DCNUCC(2)
R016	Unsaturated zone 1 (cm**3/g)	6.000E+04	6.000E+04	---	DCNUCU(2,
R016	Saturated zone (cm**3/g)	6.000E+04	6.000E+04	---	DCNUCS(2)
R016	Leach rate (/yr)	0.000E+00	0.000E+00	2.778E-06	ALEACH(2)
R016	Solubility constant	0.000E+00	0.000E+00	not used	SOLUBK(2)
R016	Distribution coefficients for Th-232				
R016	Contaminated zone (cm**3/g)	6.000E+04	6.000E+04		DCNUCC(3)
R016	Unsaturated zone 1 (cm**3/g)	6.000E+04	6.000E+04	---	DCNUCU(3,1)
R016	Saturated zone (cm**3/g)	6.000E+04	6.000E+04	---	DCNUCS(3)
R016	Leach rate (/yr)	0.000E+00	0.000E+00	2.778E-06	ALEACH(3)
R016	Solubility constant	0.000E+00	0.000E+00	not used	SOLUBK(3)
	Inhalation rate (m**3/yr)	8.400E+03	8.400E+03		INHALR
R017	Mass loading for inhalation (g/m**3)	1.000E-04	1.000E-04		MLINH
R017	Exposure duration	3.000E+01	3.000E+01		ED
R017	Shielding factor, inhalation	4.000E-01	4.000E-01		SHF3
R017	Shielding factor, external gamma	7.000E-01	7.000E-01		SHF1
R017	Fraction of time spent indoors	5.000E-01	5.000E-01	---	FIND
R017	Fraction of time spent outdoors (on site)	2.500E-01	2.500E-01	---	FOTD
R017	Shape factor flag, external gamma	1.000E+00	1.000E+00	>0 shows circular AREA	FS

Site-Specific Parameter Summary (continued)

Menu	Parameter	User Input	Default	Used by RESRAD (If different from user input)	Parameter Name
R017	Radii of shape factor array (used if FS = -1):				
R017	Outer annular radius (m), ring 1:	not used	5.000E+01		RAD_SHAPE(1)
R017	Outer annular radius (m), ring 2:	not used	7.071E+01		RAD_SHAPE(2)
R017	Outer annular radius (m), ring 3:	not used	0.000E+00		RAD_SHAPE(3)
R017	Outer annular radius (m), ring 4:	not used	0.000E+00		RAD_SHAPE(4)
R017	Outer annular radius (m), ring 5:	not used	0.000E+00		RAD_SHAPE(5)
R017	Outer annular radius (m), ring 6:	not used	0.000E+00		RAD_SHAPE(6)
R017	Outer annular radius (m), ring 7:	not used	0.000E+00		RAD_SHAPE(7)
R017	Outer annular radius (m), ring 8:	not used	0.000E+00		RAD_SHAPE(8)
R017	Outer annular radius (m), ring 9:	not used	0.000E+00		RAD_SHAPE(9)
R017	Outer annular radius (m), ring 10:	not used	0.000E+00		RAD_SHAPE(10)
R017	Outer annular radius (m), ring 11:	not used	0.000E+00		RAD_SHAPE(11)
R017	Outer annular radius (m), ring 12:	not used	0.000E+00		RAD_SHAPE(12)
R017	Fractions of annular areas within AREA:				
R017	Ring 1	not used	1.000E+00		FRACA(1)
R017	Ring 2	not used	2.732E-01		FRACA(2)
R017	Ring 3	not used	0.000E+00		FRACA(3)
R017	Ring 4	not used	0.000E+00	---	FRACA(4)
R017	Ring 5	not used	0.000E+00	---	FRACA(5)
R017	Ring 6	not used	0.000E+00		FRACA(6)
R017	Ring 7	not used	0.000E+00		FRACA(7)
R017	Ring 8	not used	0.000E+00		FRACA(8)
R017	Ring 9	not used	0.000E+00		FRACA(9)
R017	Ring 10	not used	0.000E+00		FRACA(10)
R017	Ring 11	not used	0.000E+00		FRACA(11)
R017	Ring 12	not used	0.000E+00		FRACA(12)
R018	Fruits, vegetables and grain consumption (kg/yr)	1.600E+02	1.600E+02		DIET(1)
R018	Leafy vegetable consumption (kg/yr)	1.400E+01	1.400E+01		DIET(2)
R018	Milk consumption (L/yr)	9.200E+01	9.200E+01		DIET(3)
R018	Meat and poultry consumption (kg/yr)	6.300E+01	6.300E+01		DIET(4)
R018	Fish consumption (kg/yr)	5.400E+00	5.400E+00		DIET(5)
R018	Other seafood consumption (kg/yr)	9.000E-01	9.000E-01		DIET(6)
R018	Soil ingestion rate (g/yr)	3.650E+01	3.650E+01		SOIL
R018	Drinking water intake (L/yr)	5.100E+02	5.100E+02		DWI
R018	Contamination fraction of drinking water	1.000E+00	1.000E+00		FDW
R018	Contamination fraction of household water	not used	1.000E+00		FHHW
R018	Contamination fraction of livestock water	1.000E+00	1.000E+00		FLW
R018	Contamination fraction of irrigation water	1.000E+00	1.000E+00		FIRW
R018	Contamination fraction of aquatic food	5.000E-01	5.000E-01	---	FR9
R018	Contamination fraction of plant food	-1	-1	0.500E+00	FPLANT
R018	Contamination fraction of meat	-1	-1	0.500E+00	FMEAT
R018	Contamination fraction of milk	-1	-1	0.500E+00	FMILK
R019	Livestock fodder intake for meat (kg/day)	6.800E+01	6.800E+01		LFI5
R019	Livestock fodder intake for milk (kg/day)	5.500E+01	5.500E+01		LFI6
R019	Livestock water intake for meat (L/day)	5.000E+01	5.000E+01		LWI5
R019	Livestock water intake for milk (L/day)	1.600E+02	1.600E+02		LWI6
R019	Livestock soil intake (kg/day)	5.000E-01	5.000E-01		LSI
R019	Mass loading for foliar deposition (g/m**3)	1.000E-04	1.000E-04		MLFD

Site-Specific Parameter Summary (continued)

Menu	Parameter	User Input	Default	Used by RESRAD (If different from user input)	Parameter Name
R019	Depth of soil mixing layer (m)	1.500E-01	1.500E-01		DM
R019	Depth of roots (m)	9.000E-01	9.000E-01		DROOT
R019	Drinking water fraction from ground water	1.000E+00	1.000E+00		FGWDW
R019	Household water fraction from ground water	not used	1.000E+00		FGWHH
R019	Livestock water fraction from ground water	1.000E+00	1.000E+00		FGWLW
R019	Irrigation fraction from ground water	1.000E+00	1.000E+00		FGWIR
R19B	Wet weight crop yield for Non-Leafy (kg/m**2)	7.000E-01	7.000E-01		YV(1)
R19B	Wet weight crop yield for Leafy (kg/m**2)	1.500E+00	1.500E+00		YV(2)
R19B	Wet weight crop yield for Fodder (kg/m**2)	1.100E+00	1.100E+00		YV(3)
R19B	Growing Season for Non-Leafy (years)	1.700E-01	1.700E-01		TE(1)
R19B	Growing Season for Leafy (years)	2.500E-01	2.500E-01		TE(2)
R19B	Growing Season for Fodder (years)	8.000E-02	8.000E-02		TE(3)
R19B	Translocation Factor for Non-Leafy	1.000E-01	1.000E-01		TIV(1)
R19B	Translocation Factor for Leafy	1.000E+00	1.000E+00		TIV(2)
R19B	Translocation Factor for Fodder	1.000E+00	1.000E+00		TIV(3)
R19B	Dry Foliar Interception Fraction for Non-Leafy	2.500E-01	2.500E-01		RDRY(1)
R19B	Dry Foliar Interception Fraction for Leafy	2.500E-01	2.500E-01		RDRY(2)
R19B	Dry Foliar Interception Fraction for Fodder	2.500E-01	2.500E-01		RDRY(3)
R19B	Wet Foliar Interception Fraction for Non-Leafy	2.500E-01	2.500E-01		RWET(1)
R19B	Wet Foliar Interception Fraction for Leafy	2.500E-01	2.500E-01		RWET(2)
R19B	Wet Foliar Interception Fraction for Fodder	2.500E-01	2.500E-01		RWET(3)
R19B	Weathering Removal Constant for Vegetation	2.000E+01	2.000E+01		WLAM
C14	C-12 concentration in water (g/cm**3)	not used	2.000E-05		C12WTR
C14	C-12 concentration in contaminated soil (g/g)	not used	3.000E-02		C12CZ
C14	Fraction of vegetation carbon from soil	not used	2.000E-02		CSOIL
C14	Fraction of vegetation carbon from air	not used	9.800E-01		CAIR
C14	C-14 evasion layer thickness in soil (m)	not used	3.000E-01		DMC
C14	C-14 evasion flux rate from soil (1/sec)	not used	7.000E-07		EVSN
C14	C-12 evasion flux rate from soil (1/sec)	not used	1.000E-10		REVSN
C14	Fraction of grain in beef cattle feed	not used	8.000E-01		AVFG4
C14	Fraction of grain in milk cow feed	not used	2.000E-01		AVFG5
C14	DCF correction factor for gaseous forms of C14	not used	8.894E+01		CO2F
STOR	Storage times of contaminated foodstuffs (days)				
STOR	Fruits, non-leafy vegetables, and grain	1.400E+01	1.400E+01		STOR_T(1)
STOR	Leafy vegetables	1.000E+00	1.000E+00		STOR_T(2)
STOR	Milk	1.000E+00	1.000E+00		STOR_T(3)
STOR	Meat and poultry	2.000E+01	2.000E+01		STOR_T(4)
STOR	Fish	7.000E+00	7.000E+00		STOR_T(5)
STOR	Crustacea and mollusks	7.000E+00	7.000E+00		STOR_T(6)
STOR	Well water	1.000E+00	1.000E+00		STOR_T(7)
STOR	Surface water	1.000E+00	1.000E+00		STOR_T(8)
STOR	Livestock fodder	4.500E+01	4.500E+01		STOR_T(9)
R021	Thickness of building foundation (m)	not used	1.500E-01		FLOOR1
R021	Bulk density of building foundation (g/cm**3)	not used	2.400E+00		DENSFL
R021	Total porosity of the cover material	not used	4.000E-01		TPCV
R021	Total porosity of the building foundation	not used	1.000E-01		TPFL
R021	Volumetric water content of the cover material	not used	5.000E-02		PH2OCV

Site-Specific Parameter Summary (continued)

Menu	Parameter	User Input	Default	Used by RESRAD (If different from user input)	Parameter Name
R021	Volumetric water content of the foundation	not used	3.000E-02		PH2OFL
R021	Diffusion coefficient for radon gas (m/sec)				
R021	in cover material	not used	2.000E-06		DIFCV
R021	in foundation material	not used	3.000E-07		DIFFL
R021	in contaminated zone soil	not used	2.000E-06		DIFCZ
R021	Radon vertical dimension of mixing (m)	not used	2.000E+00		HMIX
R021	Average building air exchange rate (1/hr)	not used	5.000E-01		REXG
R021	Height of the building (room) (m)	not used	2.500E+00		HRM
R021	Building interior area factor	not used	0.000E+00		FAI
R021	Building depth below ground surface (m)	not used	-1.000E+00		DMFL
R021	Emanating power of Rn-222 gas	not used	2.500E-01		EMANA(1)
R021	Emanating power of Rn-220 gas	not used	1.500E-01		EMANA(2)
TITL	Number of graphical time points	32			NPTS
TITL	Maximum number of integration points for dose	17			LYMAX
TITL	Maximum number of integration points for risk	257			KYMAX

Summary of Pathway Selections

Pathway	User Selection
1 -- external gamma	active
2 -- inhalation (w/o radon)	active
3 -- plant ingestion	active
4 -- meat ingestion	active
5 -- milk ingestion	active
6 -- aquatic foods	active
7 -- drinking water	active
8 -- soil ingestion	active
9 -- radon	suppressed
Find peak pathway doses	active

Contaminated Zone Dimensions		Initial Soil Concentrations, pCi/g	
Area	10000.00 square meters	Ra-228	1.000E+00
Thickness	2.00 meters	Th-228	1.000E+00
Cover Depth	0.00 meters	Th-232	1.000E+00

Total Dose TDOSE(t), mrem/yr
Basic Radiation Dose Limit = 2.500E+01 mrem/yr
Total Mixture Sum M(t) = Fraction of Basic Dose Limit Received at Time (t)

t (years)	0.000E+00	1.000E+00	3.000E+00	1.000E+01	3.000E+01	1.000E+02	3.000E+02	1.000E+03
TDOSE(t)	1.506E+01	1.504E+01	1.500E+01	1.488E+01	1.480E+01	1.479E+01	1.478E+01	1.475E+01
M(t)	6.025E-01	6.017E-01	5.999E-01	5.953E-01	5.919E-01	5.915E-01	5.912E-01	5.900E-01

Maximum TDOSE(t 1.506E+01 mrem/yr at t = 0.000E+00 years

Total Dose Contributions TDOSE(i,p,t) for Individual Radionuclides (i) and Pathways (p)
As mrem/yr and Fraction of Total Dose At t = 0.000E+00 years

Water Independent Pathways (Inhalation excludes radon)

Radio-	Ground		Inhalation		Radon		Plant		Meat		Milk		Soil	
Nuclide	mrem/yr	fract.	mrem/yr	fract.	mrem/yr	fract.	mrem/yr	fract.	mrem/yr	fract.	mrem/yr	fract.	mrem/yr	fract.
Ra-228	4.071E+00	0.2703	3.718E-03	0.0002	0.000E+00	0.0000	4.755E+00	0.3157	1.392E-01	0.0092	1.685E-01	0.0112	4.051E-02	0.0027
Th-228	4.840E+00	0.3213	1.852E-02	0.0012	0.000E+00	0.0000	5.904E-02	0.0039	1.213E-03	0.0001	8.656E-05	0.0000	1.856E-02	0.0012
Th-232	2.331E-01	0.0155	1.051E-01	0.0070	0.000E+00	0.0000	5.124E-01	0.0340	1.112E-02	0.0007	8.870E-03	0.0006	7.716E-02	0.0051
Total	9.143E+00	0.6070	1.274E-01	0.0085	0.000E+00	0.0000	5.326E+00	0.3536	1.516E-01	0.0101	1.774E-01	0.0118	1.362E-01	0.0090

Total Dose Contributions TDOSE(i,p,t) for Individual Radionuclides (i) and Pathways (p)
As mrem/yr and Fraction of Total Dose At t = 0.000E+00 years

Water Dependent Pathways

Radio-	Water		Fish		Radon		Plant		Meat		Milk		All Pathways*	
Nuclide	mrem/yr	fract.	mrem/yr	fract.	mrem/yr	fract.	mrem/yr	fract.	mrem/yr	fract.	mrem/yr	fract.	mrem/yr	fract.
Ra-228	0.000E+00	0.0000	0.000E+00	0.0000	0.000E+00	0.0000	0.000E+00	0.0000	0.000E+00	0.0000	0.000E+00	0.0000	9.177E+00	0.6093
Th-228	0.000E+00	0.0000	0.000E+00	0.0000	0.000E+00	0.0000	0.000E+00	0.0000	0.000E+00	0.0000	0.000E+00	0.0000	4.937E+00	0.3278
Th-232	0.000E+00	0.0000	0.000E+00	0.0000	0.000E+00	0.0000	0.000E+00	0.0000	0.000E+00	0.0000	0.000E+00	0.0000	9.477E-01	0.0629
Total	0.000E+00	0.0000	0.000E+00	0.0000	0.000E+00	0.0000	0.000E+00	0.0000	0.000E+00	0.0000	0.000E+00	0.0000	1.506E+01	1.0000

*Sum of all water independent and dependent pathways

Total Dose Contributions TDOSE(i,p,t) for Individual Radionuclides (i) and Pathways (p)
As mrem/yr and Fraction of Total Dose At t = 1.000E+00 years

ter Independent Pathways (Inhalation excludes radon)

Radio-Nuclide	Ground mrem/yr	Ground fract.	Inhalation mrem/yr	Inhalation fract.	Radon mrem/yr	Radon fract.	Plant mrem/yr	Plant fract.	Meat mrem/yr	Meat fract.	Milk mrem/yr	Milk fract.	Soil mrem/yr	Soil fract.
Ra-228	4.979E+00	0.3310	8.565E-03	0.0006	0.000E+00	0.0000	4.226E+00	0.2810	1.237E-01	0.0082	1.490E-01	0.0099	4.111E-02	0.0027
Th-228	3.369E+00	0.2240	1.289E-02	0.0009	0.000E+00	0.0000	4.110E-02	0.0027	8.446E-04	0.0001	6.025E-05	0.0000	1.292E-02	0.0009
Th-232	7.850E-01	0.0522	1.059E-01	0.0070	0.000E+00	0.0000	1.050E+00	0.0698	2.657E-02	0.0018	2.767E-02	0.0018	8.210E-02	0.0055
Total	9.132E+00	0.6072	273E-01	0.0085	0.000E+00	0.0000	5.318E+00	0.3535	1.511E-01	0.0100	1.767E-01	0.0118	1.361E-01	0.009

Total Dose Contributions TDOSE(i,p,t) for Individual Radionuclides (i) and Pathways (p)
As mrem/yr and Fraction of Total Dose At t = 1.000E+00 years

Water Dependent Pathways

Radio-Nuclide	Water mrem/yr	Water fract.	mrem/yr	fract.	Radon mrem/yr	Radon fract.	Plant mrem/yr	Plant fract.	Meat mrem/yr	Meat fract.	Milk mrem/yr	Milk fract.	All Pathways* mrem/yr	All Pathways* fract.
Ra-228	0.000E+00	0.0000	0.000E+00	0.0000	0.000E+00	0.0000	0.000E+00	0.0000	0.000E+00	0.0000	0.000E+00	0.0000	9.527E+00	0.6334
Th-228	0.000E+00	0.0000	0.000E+00	0.0000	0.000E+00	0.0000	0.000E+00	0.0000	0.000E+00	0.0000	0.000E+00	0.0000	3.436E+00	0.2285
Th-232	0.000E+00	0.0000	0.000E+00	0.0000	0.000E+00	0.0000	0.000E+00	0.0000	0.000E+00	0.0000	0.000E+00	0.0000	2.078E+00	0.1381
Total	0.000E+00	0.0000	0.000E+00	0.0000	0.000E+00	0.0000	0.000E+00	0.0000	0.000E+00	0.0000	0.000E+00	0.0000	1.504E+01	1.0000

*Sum of all water independent and dependent pathways.

Total Dose Contributions TDOSE(i,p,t) for Individual Radionuclides (i) and Pathways (p)
As mrem/yr and Fraction of Total Dose At t = 3.000E+00 years

ter Independent Pathways (Inhalation excludes radon)

Radio-Nuclide	Ground mrem/yr	Ground fract.	Inhalation mrem/yr	Inhalation fract.	Radon mrem/yr	Radon fract.	Plant mrem/yr	Plant fract.	Meat mrem/yr	Meat fract.	Milk mrem/yr	Milk fract.	Soil mrem/yr	Soil fract.
Ra-228	5.411E+00	0.3608	1.250E-02	0.0008	0.000E+00	0.0000	3.324E+00	0.2216	9.713E-02	0.0065	1.166E-01	0.0078	3.797E-02	0.0025
Th-228	1.632E+00	0.1088	6.246E-03	0.0004	0.000E+00	0.0000	1.991E-02	0.0013	4.092E-04	0.0000	2.919E-05	0.0000	6.25[illegible]E-03	0.0004
Th-232	2.064E+00	0.1377	1.085E-01	0.0072	0.000E+00	0.0000	1.956E+00	0.1304	5.306E-02	0.0035	5.952E-02	0.0040	9.171E-02	0.0061
Total	9.107E+00	0.6073	1.273E-01	0.0085	0.000E+00	0.0000	5.300E+00	0.3534	1.506E-01	0.0100	1.761E-01	0.0117	1.359E-01	0.0091

Total Dose Contributions TDOSE(i,p,t) for Individual Radionuclides (i) and Pathways (p)
As mrem/yr and Fraction of Total Dose At t = 3.000E+00 years

Water Dependent Pathways

Radio-Nuclide	Water mrem/yr	Water fract.	Fish mrem/yr	Fish fract.	Radon mrem/yr	Radon fract.	Plant mrem/yr	Plant fract.	Meat mrem/yr	Meat fract.	Milk mrem/yr	Milk fract.	All Pathways* mrem/yr	All Pathways* fract
Ra-228	0.000E+00	0.0000	0.000E+00	0.0000	0.000E+00	0.0000	0.000E+00	0.0000	0.000E+00	0.0000	0.000E+00	0.0000	8.998E+00	0.6000
Th-228	0.000E+00	0.0000	0.000E+00	0.0000	0.000E+00	0.0000	0.000E+00	0.0000	0.000E+00	0.0000	0.000E+00	0.0000	1.665E+00	0.1110
Th-232	0.000E+00	0.0000	0.000E+00	0.0000	0.000E+00	0.0000	0.000E+00	0.0000	0.000E+00	0.0000	0.000E+00	0.0000	4.334E+00	0.2890
Total	0.000E+00	0.0000	0.000E+00	0.0000	0.000E+00	0.0000	0.000E+00	0.0000	0.000E+00	0.0000	0.000E+00	0.0000	1.500E+01	1.0000

*Sum of all water independent and dependent pathways.

Total Dose Contributions TDOSE(i,p,t) for Individual Radionuclides (i) and Pathways (p)
As mrem/yr and Fraction of Total Dose At t = 1.000E+01 years

Water Independent Pathways (Inhalation excludes radon)

Radio-Nuclide	Ground mrem/yr	Ground fract.	Inhalation mrem/yr	Inhalation fract.	Radon mrem/yr	Radon fract.	Plant mrem/yr	Plant fract.	Meat mrem/yr	Meat fract.	Milk mrem/yr	Milk fract.	Soil mrem/yr	Soil fract.
Ra-228	3.138E+00	0.2108	8.539E-03	0.0006	0.000E+00	0.0000	1.416E+00	0.0951	4.129E-02	0.0028	4.932E-02	0.0033	1.932E-02	0.0013
Th-228	1.292E-01	0.0087	4.945E-04	0.0000	0.000E+00	0.0000	1.576E-03	0.0001	3.240E-05	0.0000	2.311E-06	0.0000	4.954E-04	0.0000
Th-232	5.767E+00	0.3875	1.181E-01	0.0079	0.000E+00	0.0000	3.845E+00	0.2583	1.082E-01	0.0073	1.255E-01	0.0084	1.157E-01	0.0078
	9.034E+00	0.6070	271E-01	0.0085	0.000E+00	0.0000	5.263E+00	0.3536	1.495E-01	0.0100	1.748E-01	0.0117	1.355E-01	0.009

Total Dose Contributions TDOSE(i,p,t) for Individual Radionuclides (i) and Pathways (p)
As mrem/yr and Fraction of Total Dose At t = 1.000E+01 years

Water Dependent Pathways

Radio-Nuclide	Water mrem/yr	Water fract.	Fish mrem/yr	Fish fract.	Radon mrem/yr	Radon fract.	Plant mrem/yr	Plant fract.	Meat mrem/yr	Meat fract.	Milk mrem/yr	Milk fract.	All Pathways* mrem/yr	All Pathways* fract.
Ra-228	0.000E+00	0.0000	0.000E+00	0.0000	0.000E+00	0.0000	0.000E+00	0.0000	0.000E+00	0.0000	0.000E+00	0.0000	4.672E+00	0.3139
Th-228	0.000E+00	0.0000	0.000E+00	0.0000	0.000E+00	0.0000	0.000E+00	0.0000	0.000E+00	0.0000	0.000E+00	0.0000	1.318E-01	0.0089
Th-232	0.000E+00	0.0000	0.000E+00	0.0000	0.000E+00	0.0000	0.000E+00	0.0000	0.000E+00	0.0000	0.000E+00	0.0000	1.008E+01	0.6772
Total	0.000E+00	0.0000	0.000E+00	0.0000	0.000E+00	0.0000	0.000E+00	0.0000	0.000E+00	0.0000	0.000E+00	0.0000	1.488E+01	1.0000

*Sum of all water independent and dependent pathways

Total Dose Contributions TDOSE(i,p,t) for Individual Radionuclides (i) and Pathways (p)
As mrem/yr and Fraction of Total Dose At t = 3.000E+01 years

ıter Independent Pathways (Inhalation excludes radon)

Radio-	Ground		Inhalation		Radon		Plant		Meat		Milk		Soi:	
Nuclide	mrem/yr	fract.	mrem/yr	fract.	mrem/yr	fract.	mrem/yr	fract.	mrem/yr	fract.	mrem/yr	fract.	mrem/yr	frac
Ra-228	2.851E-01	0.0193	7.942E-04	0.0001	0.000E+00	0.0000	1.214E-01	0.0082	3.538E-03	0.0002	4.220E-03	0.0003	1.716E-03	0.0001
Th-228	9.209E-08	0.0000	3.524E-07	0.0000	0.000E+00	0.0000	1.123E-06	0.0000	2.309E-08	0.0000	1.647E-09	0.0000	3.531E-07	0.0000
Th-232	8.691E+00	0.5873	1.261E-01	0.0085	0.000E+00	0.0000	5.116E+00	0.3457	1.452E-01	0.0098	1.697E-01	0.0115	1.334E-01	0.0090
Total	8.976E+00	0.6066	1.269E-01	0.0086	0.000E+00	0.0000	5.237E+00	0.3539	488E-01	0.010[illegible]	1.739E-01	0.0118	1.351E-01	0.0091

ɔtal Dose Contributions TDOSE(i,p,t) for Individual Radionuclides (i) and Pathways (p)
As mrem/yr and Fraction of Total Dose At t = 3.000E+01 years

Water Dependent Pathways

Radio-	Water		Fish		Radon		Plant		Meat		Milk		All Pathways*	
Nuclide	mrem/yr	fract.	mrem/yr	fract.	mrem/yr	fract.	mrem/yr	fract.	mrem/yr	fract.	mrem/yr	fract.	mrem/yr	fract
Ra-228	0.000E+00	0.0000	0.000E+00	0.0000	0.000E+00	0.0000	0.000E+00	0.0000	0.000E+00	0.0000	0.000E+00	0.0000	4.167E-01	0.0282
Th-228	0.000E+00	0.0000	0.000E+00	0.0000	0.000E+00	0.0000	0.000E+00	0.0000	0.000E+00	0.0000	0.000E+00	0.0000	9.394E-05	0.0000
Th-232	0.000E+00	0.0000	0.000E+00	0.0000	0.000E+00	0.0000	0.000E+00	0.0000	0.000E+00	0.0000	0.000E+00	0.0000	1.438E+01	0.9718
Total	0.000E+00	0.0000	0.000E+00	0.0000	0.000E+00	0.0000	0.000E+00	0.0000	0.000E+00	0.0000	0.000E+00	0.0000	1.480E+01	1.0000

*Sum of all water independent and dependent pathways.

Total Dose Contributions TDOSE(i,p,t) for Individual Radionuclides (i) and Pathways (p)
As mrem/yr and Fraction of Total Dose At t = 1.000E+02 years

ter Independent Pathways (Inhalation excludes radon)

Radio-	Ground		Inhalation		Radon		Plant		Meat		Milk		Soil	
Nuclide	mrem/yr	fract.	mrem/yr	fract.	mrem/yr	fract.	mrem/yr	fract.	mrem/yr	fract.	mrem/yr	fract.	mrem/yr	fract.
Ra-228	5.228E-05	0.0000	1.457E-07	0.0000	0.000E+00	0.0000	2.225E-05	0.0000	6.484E-07	0.0000	7.735E-07	0.0000	3.147E-07	0.0000
Th-228	8.902E-16	0.0000	3.407E-18	0.0000	0.000E+00	0.0000	1.086E-17	0.0000	2.232E-19	0.0000	1.592E-20	0.0000	3.413E-18	0.0000
Th-232	8.969E+00	0.6065	1.269E-01	0.0086	0.000E+00	0.0000	5.234E+00	0.3539	1.487E-01	0.0101	1.738E-01	0.0118	1.350E-01	0.0091
	8.969E+00	0.6065	1.269E-01	0.0086	0.000E+00	0.0000	5.234E+00	0.3539	1.487E-01	0.0101	1.738E-01	0.0118	1.350E-01	0.0091

Total Dose Contributions TDOSE(i,p,t) for Individual Radionuclides (i) and Pathways (p)
As mrem/yr and Fraction of Total Dose At t = 1.000E+02 years

Water Dependent Pathways

Radio-	Water		Fish		Radon		Plant		Meat		Milk		All Pathways*	
Nuclide	mrem/yr	fract.	mrem/yr	fract.	mrem/yr	fract.	mrem/yr	fract.	mrem/yr	fract.	mrem/yr	fract.	mrem/yr	fract
Ra-228	0.000E+00	0.0000	0.000E+00	0.0000	0.000E+00	0.0000	0.000E+00	0.0000	0.000E+00	0.0000	0.000E+00	0.0000	7.641E-05	0.0000
Th-228	0.000E+00	0.0000	0.000E+00	0.0000	0.000E+00	0.0000	0.000E+00	0.0000	0.000E+00	0.0000	0.000E+00	0.0000	9.081E-16	0.0000
Th-232	0.000E+00	0.0000	0.000E+00	0.0000	0.000E+00	0.0000	0.000E+00	0.0000	0.000E+00	0.0000	0.000E+00	0.0000	1.479E+01	1.0000
Total	0.000E+00	0.0000	0.000E+00	0.0000	0.000E+00	0.0000	0.000E+00	0.0000	0.000E+00	0.0000	0.000E+00	0.0000	1.479E+01	1.0000

*Sum of all water independent and dependent pathways

Total Dose Contributions TDOSE(i,p,t) for Individual Radionuclides (i) and Pathways (p)
As mrem/yr and Fraction of Total Dose At t = 3.000E+02 years

Water Independent Pathways (Inhalation excludes radon)

Radio-Nuclide	Ground mrem/yr	Ground fract.	Inhalation mrem/yr	Inhalation fract.	Radon mrem/yr	Radon fract.	Plant mrem/yr	Plant fract.	Meat mrem/yr	Meat fract.	Milk mrem/yr	Milk fract.	Soil mrem/yr	Soil fract
Ra-228	1.100E-15	0.0000	3.066E-18	0.0000	0.000E+00	0.0000	4.683E-16	0.0000	1.365E-17	0.0000	1.628E-17	0.0000	6.624E-18	0.0000
Th-228	0.000E+00	0.0000	0.000E+00	0.0000	0.000E+00	0.0000	0.000E+00	0.0000	0.000E+00	0.0000	0.000E+00	0.0000	0.000E+00	0.0000
Th-232	8.964E+00	0.6065	1.268E-01	0.0086	0.000E+00	0.0000	5.231E+00	0.3539	1.486E-01	0.0101	1.737E-01	0.0118	1.350E-01	0.0091
Total	8.964E+00	0.6065	268E-01	0.0086	0.000E+00	0.0000	5.231E+00	0.3539	1.486E-01	0.0101	1.737E-01	0.0118	1.350E-01	0.0091

Total Dose Contributions TDOSE(i,p,t) for Individual Radionuclides (i) and Pathways (p)
As mrem/yr and Fraction of Total Dose At t = 3.000E+02 years

Water Dependent Pathways

Radio-Nuclide	Water mrem/yr	Water fract.	Fish mrem/yr	Fish fract.	Radon mrem/yr	Radon fract.	Plant mrem/yr	Plant fract.	Meat mrem/yr	Meat fract.	Milk mrem/yr	Milk fract.	All Pathways* mrem/yr	All Pathways* fract
Ra-228	0.000E+00	0.0000	0.000E+00	0.0000	0.000E+00	0.0000	0.000E+00	0.0000	0.000E+00	0.0000	0.000E+00	0.0000	1.608E-15	0.0000
Th-228	0.000E+00	0.0000	0.000E+00	0.0000	0.000E+00	0.0000	0.000E+00	0.0000	0.000E+00	0.0000	0.000E+00	0.0000	0.000E+00	0.0000
Th-232	0.000E+00	0.0000	0.000E+00	0.0000	0.000E+00	0.0000	0.000E+00	0.0000	0.000E+00	0.0000	0.000E+00	0.0000	1.478E+01	1.0000
Total	0.000E+00	0.0000	0.000E+00	0.0000	0.000E+00	0.0000	0.000E+00	0.0000	0.000E+00	0.0000	0.000E+00	0.0000	478E+01	1.0000

*Sum of all water independent and dependent pathways

Total Dose Contributions TDOSE(i,p,t) for Individual Radionuclides (i) and Pathways (p)
As mrem/yr and Fraction of Total Dose At t = 1.000E+03 years

Water Independent Pathways (Inhalation excludes radon)

Ra Nu de	Ground mrem/yr	Ground fract	Inhalation mrem/yr	Inhalation fract	Radon mrem/yr	Radon fract	Plant mrem/yr	Plant fract	Meat mrem/yr	Meat fract	Milk mrem/yr	Milk fract	mrem/yr	
Ra-228	0.000E+00	0.0000	0.000E+00	0.0000	0.000E+00	0.0000	0.000E+00	0.0000	0.000E+00	0.0000	0.000E+00	0.0000	0.000E+00	0.0000
Th-228	0.000E+00	0.0000	0.000E+00	0.0000	0.000E+00	0.0000	0.000E+00	0.0000	0.000E+00	0.0000	0.000E+00	0.0000	0.000E+00	0.0000
Th-232	8.946E+00	0.6065	1.266E-01	0.0086	0.000E+00	0.0000	5.221E+00	0.3539	1.483E-01	0.0101	1.734E-01	0.0118	1.347E-01	0.0091
Total	8.946E+00	0.6065	!66E-01	0.0086	0.000E+00	0.0000	5.221E+00	0.3539	1.483E-01	0.0101	734E-01	0.0118	1.347E-01	0.0091

:al Dose Contributions TDOSE(i,p,t) for Individual Radionuclides (i) and Pathways (p)
As mrem/yr and Fraction of Total Dose At t = 1.000E+03 years

Water Dependent Pathways

Radio-Nuclide	Water mrem/yr	Water fract.	Fish mrem/yr	Fish fract.	Radon mrem/yr	Radon fract.	Plant mrem/yr	Plant fract.	Meat mrem/yr	Meat fract.	Milk mrem/yr	Milk fract.	All Pathways* mrem/yr	All Pathways* fract
Ra-228	0.000E+00	0.0000	0.000E+00	0.0000	0.000E+00	0.0000	0.000E+00	0.0000	0.000E+00	0.0000	0.000E+00	0.0000	0.000E+00	0.0000
Th-228	0.000E+00	0.0000	0.000E+00	0.0000	0.000E+00	0.0000	0.000E+00	0.0000	0.000E+00	0.0000	0.000E+00	0.0000	0.000E+00	0.0000
Th-232	1.206E-30	0.0000	0.000E+00	0.0000	0.000E+00	0.0000	0.000E+00	0.0000	0.000E+00	0.0000	0.000E+00	0.0000	1.475E+01	1.0000
	206E-30	0.0000	0.000E+00	0.0000	0.000E+00	0.0000	0.000E+00	0.0000	0.000E+00	0.0000	000E+00	0.0000	1.475E+01	.0000

*Sum of a: ndependent and dependent pathways

Dose/Source Ratios Summed Over All Pathways
Parent and Progeny Principal Radionuclide Contributions Indicated

Parent (i)	Product (j)	Branch Fraction*	DSR(j,t) (mrem/yr)/(pCi/g) t= 0.000E+00	1.000E+00	3.000E+00	1.000E+01	3.000E+01	1.000E+02	3.000E+02	1.000E+03
Ra-228	Ra-228	.000E+00	8.238E+00	7.285E+00	5.698E+00	2.410E+00	2.062E-01	3.780E-05	7.955E-16	0.000E+00
Ra-228	Th-228	.000E+00	9.390E-01	2.242E+00	3.301E+00	2.262E+00	2.105E-01	3.861E-05	8.127E-16	0.000E+00
Ra-228	∑DSR(j)		9.177E+00	9.527E+00	8.998E+00	4.672E+00	4.167E-01	7.641E-05	1.608E-15	0.000E+00
Th-228	Th-228	1.000E+00	4.937E+00	3.436E+00	1.665E+00	1.318E-01	9.394E-05	9.001E-16	0.000E+00	0.000E+00
Th-232	Th-232	1.000E+00	4.230E-01	4.230E-01	4.230E-01	4.230E-01	4.230E-01	4.229E-01	4.227E-01	4.218E-01
Th-232	Ra-228	1.000E+00	4.848E-01	1.416E+00	2.973E+00	6.197E+00	8.357E+00	8.558E+00	8.553E+00	8.537E+00
Th-232	Th-228	1.000E+00	3.996E-02	2.391E-01	9.379E-01	3.460E+00	5.601E+00	5.806E+00	5.803E+00	5.792E+00
Th-232	∑DSR(j		9.477E-01	2.078E+00	4.334E+00	1.008E+01	1.438E+01	1.479E+01	1.470E+01	1.475E+01

*Branch Fraction is the cumulative factor for the j't principal radionuclide daughter: CUMBRF(j) = BRF(1)*BRF(2)* BRF(j)
The DSR includes contributions from associated (half-life ≤ 0.5 yr) daughters.

Single Radionuclide Soil Guidelines G(i,t) in pCi/g
Basic Radiation Dose Limit = 2.500E+01 mrem/yr

Nuclide (i)	t= 0.000E+00	1.000E+00	3.000E+00	1.000E+01	3.000E+01	1.000E+02	3.000E+02	1.000E+03
Ra-228	2.724E+00	2.624E+00	2.778E+00	5.351E+00	5.999E+01	3.272E+05	*2.726E+14	*2.726E+14
Th-228	5.064E+00	7.275E+00	1.502E+01	1.897E+02	2.661E+05	*8.192E+14	*8.192E+14	*8.192E+14
Th-232	2.638E+01	1.203E+01	5.769E+00	2.480E+00	1.738E+00	1.691E+00	1.692E+00	1.695E+00

*At specific activity limit

Summed Dose/Source Ratios DSR(i,t) in (mrem/yr)/(pCi/g)
and Single Radionuclide Soil Guidelines G(i,t) in pCi/g
at tmin = time of minimum single radionuclide soil guideline
and at tmax = time of maximum total dose = 0.000E+00 years

Nuclide (i)	Initial (pCi/g)	tmin (years)	DSR(i,tmin)	G(i,tmin) (pCi/g)	DSR(i,tmax)	G(i,tmax) (pCi/g)
Ra-228	1.000E+00	1.168 ± 0.002	9.533E+00	2.622E+00	9.177E+00	2.724E+00
Th-228	1.000E+00	0.000E+00	4.937E+00	5.064E+00	4.937E+00	5.064E+00
Th-232	1.000E+00	87.4 ± 0.2	1.479E+01	1.691E+00	9.477E-01	2.638E+01

Individual Nuclide Dose Summed Over All Pathways
Parent Nuclide and Branch Fraction Indicated

Nuclide (j)	Parent (i)	BRF(i)	DOSE(j,t), mrem/yr t= 0.000E+00	1.000E+00	3.000E+00	1.000E+01	3.000E+01	1.000E+02	3.000E+02	1.000E+03
Ra-228	Ra-228	1.000E+00	8.238E+00	7.285E+00	5.698E+00	2.410E+00	2.062E-01	3.780E-05	7.955E-16	0.000E+00
Ra-228	Th-232	1.000E+00	4.848E-01	1.416E+00	2.973E+00	6.197E+00	8.357E+00	8.558E+00	8.553E+00	8.537E+00
Ra-228	∑DOSE(j)		8.723E+00	8.701E+00	8.670E+00	8.607E+00	8.564E+00	8.558E+00	8.553E+00	8.537E+00
Th-228	Ra-228	1.000E+00	9.390E-01	2.242E+00	3.301E+00	2.262E+00	2.105E-01	3.861E-05	8.127E-16	0.000E+00
Th-228	Th-228	1.000E+00	4.937E+00	3.436E+00	1.665E+00	1.318E-01	9.394E-05	9.081E-16	0.000E+00	0.000E+00
Th-228	Th-232	1.000E+00	3.996E-02	2.391E-01	9.379E-01	3.460E+00	5.601E+00	5.806E+00	5.803E+00	5.792E+00
Th-228	∑DOSE(j)		5.916E+00	5.917E+00	5.904E+00	5.854E+00	5.811E+00	5.806E+00	5.803E+00	5.792E+00
Th-232	Th-232	1.000E+00	4.230E-01	4.230E-01	4.230E-01	4.230E-01	4.230E-01	4.229E-01	4.227E-01	4.218E-01

BRF(i) is the branch fraction of the parent nuclide

Individual Nuclide Soil Concentration
Parent Nuclide and Branch Fraction Indicated

Nuclide (j)	Parent (i)	BRF(i)	S(j,t), pCi/g t= 0.000E+00	1.000E+00	3.000E+00	1.000E+01	3.000E+01	1.000E+02	3.000E+02	1.000E+03
Ra-228	Ra-228	1.000E+00	1.000E+00	8.843E-01	6.916E-01	2.925E-01	2.503E-02	4.588E-06	9.657E-17	0.000E+00
Ra-228	Th-232	1.000E+00	0.000E+00	1.134E-01	3.025E-01	6.938E-01	9.561E-01	9.804E-01	9.799E-01	9.780E-01
Ra-228	∑S(j):		1.000E+00	9.978E-01	9.940E-01	9.863E-01	9.811E-01	9.804E-01	9.799E-01	9.780E-01
Th-228	Ra-228	1.000E+00	0.000E+00	2.849E-01	5.363E-01	4.023E-01	3.785E-02	6.943E-06	1.461E-16	0.000E+00
Th-228	Th-228	1.000E+00	1.000E+00	6.961E-01	3.372E-01	2.670E-02	1.903E-05	1.839E-16	0.000E+00	0.000E+00
Th-228	Th-232	1.000E+00	0.000E+00	1.863E-02	1.240E-01	5.599E-01	9.435E-01	9.804E-01	9.799E-01	9.780E-01
Th-228	∑S(j):		1.000E+00	9.996E-01	9.976E-01	9.890E-01	9.814E-01	9.804E-01	9.799E-01	9.780E-01
Th-232	Th-232	1.000E+00	1.000E+00	1.000E+00	1.000E+00	1.000E+00	9.999E-01	9.997E-01	9.992E-01	9.972E-01

BRF(i) is the branch fraction of the parent nuclide.

RESCALC.EXE execution time =   1.35 seconds

Table of Contents

Part I: Mixture Sums and Single Radionuclide Guidelines

Dose Conversion Factor (and Related) Parameter Summary
File: FGR 13 Morbidity

Menu	Parameter	Current Value	Default	Parameter Name
B-1	Dose conversion factors for inhalation, mrem/pCi			
B-1	Ra-228+D	5.080E-03	5.080E-03	DCF2(1)
	Th-228+D	3.450E-01	3.450E-01	DCF2(2)
B-1	Th-232	1.640E+00	1.640E+00	DCF2(3)
D-1	Dose conversion factors for ingestion, mrem/pCi			
D-1	Ra-228+D	1.440E-03	1.440E-03	DCF3(1)
D-1	Th-228+D	8.080E-04	8.080E-04	DCF3(2)
D-1	Th-232	2.730E-03	2.730E-03	DCF3(3)
D-34	Food transfer factors:			
D-34	Ra-228+D , plant/soil concentration ratio, dimensionless	4.000E-02	4.000E-02	RTF(1,1)
D-34	Ra-228+D , beef/livestock-intake ratio, (pCi/kg)/(pCi/d)	1.000E-03	1.000E-03	RTF(1,2)
D-34	Ra-228+D , milk/livestock-intake ratio, (pCi/L)/(pCi/d)	1.000E-03	1.000E-03	RTF(1,3)
D-34				
D-34	Th-228+D , plant/soil concentration ratio, dimensionless	1.000E-03	1.000E-03	RTF(2,1)
D-34	Th-228+D , beef/livestock-intake ratio, (pCi/kg)/(pCi/d)	1.000E-04	1.000E-04	RTF(2,2)
D-34	Th-228+D , milk/livestock-intake ratio, (pCi/L)/(pCi/d)	5.000E-06	5.000E-06	RTF(2,3)
D-34				
D-34	Th-232 , plant/soil concentration ratio, dimensionless	1.000E-03	1.000E-03	RTF(3,1)
D-34	Th-232 , beef/livestock-intake ratio, (pCi/kg)/(pCi/d)	1.000E-04	1.000E-04	RTF(3,2)
D-34	Th-232 , milk/livestock-intake ratio, (pCi/L)/(pCi/d)	5.000E-06	5.000E-06	RTF(3,3)
D-5	Bioaccumulation factors, fresh water, L/kg:			
D-5	Ra-228+D , fish	5.000E+01	5.000E+01	BIOFAC(1,1)
D-5	Ra-228+D , crustacea and mollusks	2.500E+02	2.500E+02	BIOFAC(1,2)
D-5				
D-5	Th-228+D fish	1.000E+02	1.000E+02	BIOFAC(2,1
D-5	Th-228+D crustacea and mollusks	5.000E+02	5.000E+02	BIOFAC(2,2
D-5				
D-5	Th-232 , fish	1.000E+02	1.000E+02	BIOFAC(3,1
D-5	Th-232 , crustacea and mollusks	5.000E+02	5.000E+02	BIOFAC(3,2

Site-Specific Parameter Summary

Menu	Parameter		User Input	Default	Used by RESRAD (If different from user input)	Parameter Name
R011	Area of contaminated zone (m**2)		1.900E+01	1.000E+04		AREA
R011	Thickness of contaminated zone (m)		2.000E+00	2.000E+00		THICK0
R011	Length parallel to aquifer flow (m)		4.360E+00	1.000E+02		LCZPAQ
R011	Basic radiation dose limit (mrem/yr)		2.500E+01	2.500E+01		BRDL
R011	Time since placement of material (yr		0.000E+00	0.000E+00		TI
R011	Times for calculations (yr)		1.000E+00	1.000E+00		T(2)
R011	Times for calculations (yr)		3.000E+00	3.000E+00		T(3)
R011	Times for calculations (yr)		1.000E+01	1.000E+01		T(4)
R011	Times for calculations (yr)		3.000E+01	3.000E+01		T(5)
R011	Times for calculations (yr)		1.000E+02	1.000E+02		T(6)
R011	Times for calculations (yr)		3.000E+02	3.000E+02		T(7)
R011	Times for calculations (yr)		1.000E+03	1.000E+03		T(8)
R011	Times for calculations (yr)		not used	0.000E+00		T(9)
R011	Times for calculations (yr)		not used	0.000E+00		T(10)
R012	Initial principal radionuclide (pCi/g)	Ra-228	1.000E+00	0.000E+00		S1(1)
R012	Initial principal radionuclide (pCi/g)	Th-228	1.000E+00	0.000E+00		S1(2)
R012	Initial principal radionuclide (pCi/g)	Th-232	1.000E+00	0.000E+00		S1(3)
R012	Concentration in groundwater (pCi/L)	Ra-228	not used	0.000E+00		W1(1)
R012	Concentration in groundwater (pCi/L)	Th-228	not used	0.000E+00		W1(2)
R012	Concentration in groundwater (pCi/L)	Th-232	not used	0.000E+00		W1(3)
R013	Cover depth (m)		0.000E+00	0.000E+00		COVER0
R013	Density of cover material (g/cm**3)		not used	1.500E+00		DENSCV
R013	Cover depth erosion rate (m/yr)		not used	1.000E-03		VCV
R013	Density of contaminated zone (g/cm**3)		1.500E+00	1.500E+00		DENSCZ
R013	Contaminated zone erosion rate (m/yr)		1.000E-03	1.000E-03		VCZ
R013	Contaminated zone total porosity		4.000E-01	4.000E-01	---	TPCZ
R013	Contaminated zone field capacity		2.000E-01	2.000E-01	---	FCCZ
R013	Contaminated zone hydraulic conductivity (m/yr)		1.000E+01	1.000E+01		HCCZ
R013	Contaminated zone b parameter		5.300E+00	5.300E+00		BCZ
R013	Average annual wind speed (m/sec)		2.000E+00	2.000E+00		WIND
R013	Humidity in air (g/m**3)		not used	8.000E+00		HUMID
R013	Evapotranspiration coefficient		5.000E-01	5.000E-01		EVAPTR
R013	Precipitation (m/yr)		1.000E+00	1.000E+00		PRECIP
R013	Irrigation (m/yr)		2.000E-01	2.000E-01		RI
R013	Irrigation mode		overhead	overhead		IDITCH
R013	Runoff coefficient		2.000E-01	2.000E-01		RUNOFF
R013	Watershed area for nearby stream or pond (m**2)		1.000E+06	1.000E+06		WAREA
R013	Accuracy for water/soil computations		1.000E-03	1.000E-03		EPS
R014	Density of saturated zone (g/cm**3)		1.500E+00	1.500E+00		DENSAQ
R014	Saturated zone total porosity		4.000E-01	4.000E-01		TPSZ
R014	Saturated zone effective porosity		2.000E-01	2.000E-01		EPSZ
R014	Saturated zone field capacity		2.000E-01	2.000E-01		FCSZ
R014	Saturated zone hydraulic conductivity (m/yr)		1.000E+02	1.000E+02		HCSZ
R014	Saturated zone hydraulic gradient		2.000E-02	2.000E-02		HGWT
R014	Saturated zone b parameter		5.300E+00	5.300E+00		BSZ
R014	Water table drop rate (m/yr)		1.000E-03	1.000E-03		VWT
R014	Well pump intake depth (m below water table)		1.000E+01	1.000E+01		DWIBWT

Site-Specific Parameter Summary (continued)

Menu	Parameter	User Input	Default	Used by RESRAD (If different from user input)	Parameter Name
R014	Model: Nondispersion (ND) or Mass-Balance (MB)	ND	ND		MODEL
R014	Well pumping rate (m**3/yr)	2.500E+02	2.500E+02		UW
R015	Number of unsaturated zone strata	1	1		NS
R015	Unsat. zone 1, thickness (m)	4.000E+00	4.000E+00		H(1)
R015	Unsat. zone 1, soil density (g/cm**3)	1.500E+00	1.500E+00		DENSUZ(
R015	Unsat. zone 1, total porosity	4.000E-01	4.000E-01		TPUZ(1)
R015	Unsat. zone 1, effective porosity	2.000E-01	2.000E-01		EPUZ(1)
R015	Unsat. zone 1, field capacity	2.000E-01	2.000E-01		FCUZ(1)
R015	Unsat. zone 1, soil-specific b parameter	5.300E+00	5.300E+00		BUZ(1)
R015	Unsat. zone 1, hydraulic conductivity (m/yr)	1.000E+01	1.000E+01		HCUZ(1)
R016	Distribution coefficients for Ra-228				
R016	Contaminated zone (cm**3/g)	7.000E+01	7.000E+01		DCNUCC(1)
R016	Unsaturated zone 1 (cm**3/g)	7.000E+01	7.000E+01		DCNUCU(1,1)
R016	Saturated zone (cm**3/g)	7.000E+01	7.000E+01	---	DCNUCS(1)
R016	Leach rate (/yr)	0.000E+00	0.000E+00	2.374E-03	ALEACH(1)
R016	Solubility constant	0.000E+00	0.000E+00	not used	SOLUBK(1)
R016	Distribution coefficients for Th-228				
R016	Contaminated zone (cm**3/g)	6.000E+04	6.000E+04		DCNUCC(2)
R016	Unsaturated zone 1 (cm**3/g)	6.000E+04	6.000E+04	---	DCNUCU(2,1)
R016	Saturated zone (cm**3/g)	6.000E+04	6.000E+04	---	DCNUCS(2)
R016	Leach rate (/yr)	0.000E+00	0.000E+00	2.778E-06	ALEACH(2)
R016	Solubility constant	0.000E+00	0.000E+00	not used	SOLUBK(2)
R016	Distribution coefficients for Th-232				
R016	Contaminated zone (cm**3/g)	6.000E+04	6.000E+04	---	DCNUCC(3)
R016	Unsaturated zone 1 (cm**3/g)	6.000E+04	6.000E+04	---	DCNUCU(3,1)
R016	Saturated zone (cm**3/g)	6.000E+04	6.000E+04	---	DCNUCS(3)
R016	Leach rate (/yr)	0.000E+00	0.000E+00	2.778E-06	ALEACH(3)
R016	Solubility constant	0.000E+00	0.000E+00	not used	SOLUBK(3)
R017	Inhalation rate (m**3/yr)	8.400E+03	8.400E+03		INHALR
R017	Mass loading for inhalation (g/m**3)	1.000E-04	1.000E-04		MLINH
R017	Exposure duration	3.000E+01	3.000E+01		ED
R017	Shielding factor, inhalation	4.000E-01	4.000E-01		SHF3
R017	Shielding factor, external gamma	7.000E-01	7.000E-01		SHF1
R017	Fraction of time spent indoors	5.000E-01	5.000E-01	---	FIND
R017	Fraction of time spent outdoors (on site)	2.500E-01	2.500E-01	---	FOTD
R017	Shape factor flag, external gamma	1.000E+00	1.000E+00	>0 shows circular AREA.	FS

Site-Specific Parameter Summary (continued)

Menu	Parameter	User Input	Default	Used by RESRAD (If different from user input	Parameter Name
R017	Radii of shape factor array (used if FS = -1):				
R017	Outer annular radius (m), ring 1:	not used	5.000E+01		RAD_SHAPE(1)
R017	Outer annular radius (m), ring 2:	not used	7.071E+01		RAD_SHAPE(2)
R017	Outer annular radius (m), ring 3:	not used	0.000E+00		RAD_SHAPE(3)
R017	Outer annular radius (m), ring 4:	not used	0.000E+00		RAD_SHAPE(4)
R017	Outer annular radius (m), ring 5:	not used	0.000E+00		RAD_SHAPE(5)
R017	Outer annular radius (m), ring 6:	not used	0.000E+00		RAD_SHAPE(6)
R017	Outer annular radius (m), ring 7:	not used	0.000E+00		RAD_SHAPE(7)
R017	Outer annular radius (m), ring 8:	not used	0.000E+00		RAD_SHAPE(8)
R017	Outer annular radius (m), ring 9:	not used	0.000E+00	---	RAD_SHAPE(9)
R017	Outer annular radius (m), ring 10:	not used	0.000E+00	---	RAD_SHAPE(10)
R017	Outer annular radius (m), ring 11:	not used	0.000E+00	---	RAD_SHAPE(11)
R017	Outer annular radius (m), ring 12:	not used	0.000E+00	---	RAD_SHAPE(12)
R017	Fractions of annular areas within AREA:				
R017	Ring 1	not used	1.000E+00		FRACA(1)
R017	Ring 2	not used	2.732E-01		FRACA(2)
R017	Ring 3	not used	0.000E+00		FRACA(3)
R017	Ring 4	not used	0.000E+00		FRACA(4)
R017	Ring 5	not used	0.000E+00		FRACA(5)
R017	Ring 6	not used	0.000E+00		FRACA(6)
R017	Ring 7	not used	0.000E+00		FRACA(7)
R017	Ring 8	not used	0.000E+00		FRACA(8)
R017	Ring 9	not used	0.000E+00		FRACA(9)
R017	Ring 10	not used	0.000E+00		FRACA(10)
R017	Ring 11	not used	0.000E+00		FRACA(11)
R017	Ring 12	not used	0.000E+00		FRACA(12)
R018	Fruits, vegetables and grain consumption (kg/yr)	1.600E+02	1.600E+02		DIET(1)
R018	Leafy vegetable consumption (kg/yr)	1.400E+01	1.400E+01		DIET(2)
R018	Milk consumption (L/yr)	9.200E+01	9.200E+01		DIET(3)
R018	Meat and poultry consumption (kg/yr)	6.300E+01	6.300E+01		DIET(4)
R018	Fish consumption (kg/yr)	5.400E+00	5.400E+00		DIET(5)
R018	Other seafood consumption (kg/yr)	9.000E-01	9.000E-01		DIET(6)
R018	Soil ingestion rate (g/yr)	3.650E+01	3.650E+01		SOIL
R018	Drinking water intake (L/yr)	5.100E+02	5.100E+02		DWI
R018	Contamination fraction of drinking water	1.000E+00	1.000E+00		FDW
R018	Contamination fraction of household water	not used	1.000E+00		FHHW
R018	Contamination fraction of livestock water	1.000E+00	1.000E+00	---	FLW
R018	Contamination fraction of irrigation water	1.000E+00	1.000E+00	---	FIRW
R018	Contamination fraction of aquatic food	5.000E-01	5.000E-01	---	FR9
R018	Contamination fraction of plant food	-1	-1	0.950E-02	FPLANT
R018	Contamination fraction of meat	-1	-1	0.950E-03	FMEAT
R018	Contamination fraction of milk	-1	-1	0.950E-03	FMILK
R019	Livestock fodder intake for meat (kg/day)	6.800E+01	6.800E+01		LFI5
R019	Livestock fodder intake for milk (kg/day)	5.500E+01	5.500E+01		LFI6
R019	Livestock water intake for meat (L/day)	5.000E+01	5.000E+01		LWI5
R019	Livestock water intake for milk (L/day)	1.600E+02	1.600E+02		LWI6
R019	Livestock soil intake (kg/day)	5.000E-01	5.000E-01		LSI

Site-Specific Parameter Summary (continued)

Menu	Parameter	User Input	Default	Used by RESRAD (If different from user input)	Parameter Name
R019	Mass loading for foliar deposition (g/m**3)	1.000E-04	1.000E-04		MLFD
R019	Depth of soil mixing layer (m)	1.500E-01	1.500E-01		DM
R019	Depth of roots (m)	9.000E-01	9.000E-01		DROOT
R019	Drinking water fraction from ground water	1.000E+00	1.000E+00		FGWDW
R019	Household water fraction from ground water	not used	1.000E+00		FGWHH
R019	Livestock water fraction from ground water	1.000E+00	1.000E+00		FGWLW
R019	Irrigation fraction from ground water	1.000E+00	1.000E+00		FGWIR
R19B	Wet weight crop yield for Non-Leafy (kg/m**2)	7.000E-01	7.000E-01		YV(1)
R19B	Wet weight crop yield for Leafy (kg/m**2)	1.500E+00	1.500E+00		YV(2)
R19B	Wet weight crop yield for Fodder (kg/m**2)	1.100E+00	1.100E+00		YV(3)
R19B	Growing Season for Non-Leafy (years)	1.700E-01	1.700E-01		TE(1)
R19B	Growing Season for Leafy (years)	2.500E-01	2.500E-01		TE(2)
R19B	Growing Season for Fodder (years)	8.000E-02	8.000E-02		TE(3)
R19B	Translocation Factor for Non-Leafy	1.000E-01	1.000E-01		TIV(1)
R19B	Translocation Factor for Leafy	1.000E+00	1.000E+00		TIV(2)
R19B	Translocation Factor for Fodder	1.000E+00	1.000E+00		TIV(3)
R19B	Dry Foliar Interception Fraction for Non-Leafy	2.500E-01	2.500E-01		RDRY(1)
R19B	Dry Foliar Interception Fraction for Leafy	2.500E-01	2.500E-01		RDRY(2)
R19B	Dry Foliar Interception Fraction for Fodder	2.500E-01	2.500E-01		RDRY(3)
R19B	Wet Foliar Interception Fraction for Non-Leafy	2.500E-01	2.500E-01		RWET(1)
R19B	Wet Foliar Interception Fraction for Leafy	2.500E-01	2.500E-01		RWET(2)
R19B	Wet Foliar Interception Fraction for Fodder	2.500E-01	2.500E-01		RWET(3)
R19B	Weathering Removal Constant for Vegetation	2.000E+01	2.000E+01		WLAM
C14	C-12 concentration in water (g/cm**3)	not used	2.000E-05		C12WTR
C14	C-12 concentration in contaminated soil (g/g)	not used	3.000E-02		C12CZ
C14	Fraction of vegetation carbon from soil	not used	2.000E-02		CSOIL
C14	Fraction of vegetation carbon from air	not used	9.800E-01		CAIR
C14	C-14 evasion layer thickness in soil (m)	not used	3.000E-01		DMC
C14	C-14 evasion flux rate from soil (1/sec)	not used	7.000E-07		EVSN
C14	C-12 evasion flux rate from soil (1/sec)	not used	1.000E-10		REVSN
C14	Fraction of grain in beef cattle feed	not used	8.000E-01		AVFG4
C14	Fraction of grain in milk cow feed	not used	2.000E-01		AVFG5
C14	DCF correction factor for gaseous forms of C14	not used	8.894E+01		CO2F
STOR	Storage times of contaminated foodstuffs (days)				
STOR	Fruits, non-leafy vegetables, and grain	1.400E+01	1.400E+01		STOR_T(1)
STOR	Leafy vegetables	1.000E+00	1.000E+00		STOR_T(2)
STOR	Milk	1.000E+00	1.000E+00		STOR_T(3)
STOR	Meat and poultry	2.000E+01	2.000E+01		STOR_T(4)
STOR	Fish	7.000E+00	7.000E+00		STOR_T(5)
STOR	Crustacea and mollusks	7.000E+00	7.000E+00		STOR_T(6)
STOR	Well water	1.000E+00	1.000E+00		STOR_T(7)
STOR	Surface water	1.000E+00	1.000E+00		STOR_T(8)
STOR	Livestock fodder	4.500E+01	4.500E+01		STOR_T(9)
R021	Thickness of building foundation (m)	not used	1.500E-01		FLOOR1
R021	Bulk density of building foundation (g/cm**3)	not used	2.400E+00		DENSFL
R021	Total porosity of the cover material	not used	4.000E-01		TPCV

Site-Specific Parameter Summary (continued)

Menu	Parameter	User Input	Default	Used by RESRAD (If different from user input)	Paramet Name
R021	Total porosity of the building foundation	not used	1.000E-01		TPFL
R021	Volumetric water content of the cover material	not used	5.000E-02		PH2OCV
R021	Volumetric water content of the foundation	not used	3.000E-02		PH2OFL
R021	Diffusion coefficient for radon gas (m/sec):				
R021	in cover material	not used	2.000E-06		DIFCV
R021	in foundation material	not used	3.000E-07		DIFFL
R021	in contaminated zone soil	not used	2.000E-06		DIFCZ
R021	Radon vertical dimension of mixing (m)	not used	2.000E+00		HMIX
R021	Average building air exchange rate (1/hr)	not used	5.000E-01		REXG
R021	Height of the building (room) (m)	not used	2.500E+00		HRM
R021	Building interior area factor	not used	0.000E+00		FAI
R021	Building depth below ground surface (m)	not used	-1.000E+00		DMFL
R021	Emanating power of Rn-222 gas	not used	2.500E-01		EMANA(1)
R021	Emanating power of Rn-220 gas	not used	1.500E-01		EMANA(2)
TITL	Number of graphical time points	32			NPTS
TITL	Maximum number of integration points for dose	17			LYMAX
TITL	Maximum number of integration points for risk	257			KYMAX

Summary of Pathway Selections

Pathway	User Selection
1 -- external gamma	active
2 -- inhalation (w/o radon)	active
3 -- plant ingestion	active
4 -- meat ingestion	active
5 -- milk ingestion	active
6 -- aquatic foods	active
7 -- drinking water	active
8 -- soil ingestion	active
9 -- radon	suppressed
Find peak pathway doses	active

Summary : Great Lakes 19 sq meter area RESRAD Default Parameters for Th322
File : GreatL2.RAD

Contaminated Zone Dimensions		Initial Soil Concentrations, pCi/g	
Area	19.00 square meters	Ra-228	1.000E+00
Thickness	2.00 meters	Th-228	1.000E+00
Cover Depth	0.00 meters	Th-232	1.000E+00

Total Dose TDOSE(t), mrem/yr
Basic Radiation Dose Limit = 2.500E+01 mrem/yr
Total Mixture Sum M(t) = Fraction of Basic Dose Limit Received at Time (t

t (years)	0.000E+00	1.000E+00	3.000E+00	1.000E+01	3.000E+01	1.000E+02	3.000E+02	1.000E+03
TDOSE(t)	5.736E+00	5.730E+00	5.714E+00	5.669E+00	5.633E+00	5.628E+00	5.625E+00	5.614E+00
M(t)	2.295E-01	2.292E-01	2.286E-01	2.267E-01	2.253E-01	2.251E-01	2.250E-01	2.246E-01

Maximum TDOSE(t) 5.736E+00 mrem/yr at t = 0.000E+00 years

RESRAD, Version 6.21 T½ Limit = 0.5 year 06/02/2003 12:17 Page

Summary : Great Lakes 19 sq meter area RESRAD Default Parameters for Th322

File : GreatL2.RAD

Total Dose Contributions TDOSE(i,p,t) for Individual Radionuclides (i) and Pathways (p)
As mrem/yr and Fraction of Total Dose At t = 0.000E+00 years

Water Independent Pathways (Inhalation excludes radon)

Radio-	Ground		Inhalation		Radon		Plant		Meat		Milk		Soil	
Nuclide	mrem/yr	fract.	mrem/yr	fract.	mrem/yr	fract.	mrem/yr	fract.	mrem/yr	fract.	mrem/yr	fract.	mrem/yr	fract
Ra-228	2.492E+00	0.4344	1.920E-03	0.0003	0.000E+00	0.0000	9.034E-02	0.0157	2.645E-04	0.0000	3.200E-04	0.0001	7.697E-04	0.0001
Th-228	2.931E+00	0.5110	9.563E-03	0.0017	0.000E+00	0.0000	1.121E-03	0.0002	2.305E-06	0.0000	1.644E-07	0.0000	3.525E-04	0.0001
Th-232	1.428E-01	0.0249	5.428E-02	0.0095	0.000E+00	0.0000	9.732E-03	0.0017	2.112E-05	0.0000	1.685E-05	0.0000	1.466E-03	0.0003
Total	5.566E+00	0.9703	6.576E-02	0.0115	0.000E+00	0.0000	1.012E-01	0.0176	2.879E-04	0.000[illegible]	3.371E-04	0.0001	2.588E-03	0.0005

Total Dose Contributions TDOSE(i,p,t) for Individual Radionuclides (i) and Pathways (p)
As mrem/yr and Fraction of Total Dose At t = 0.000E+00 years

Water Dependent Pathways

Radio-	Water		Fish		Radon		Plant		Meat		Milk		All Pathways*	
Nuclide	mrem/yr	fract	mrem/yr	fract	mrem/yr	fract	mrem/yr	fract.			mrem/yr	fract	mrem/yr	fract.
Ra-228	0.000E+00	0.0000	0.000E+00	0.0000	0.000E+00	0.0000	0.000E+00	0.0000	0.000E+00	0.0000	0.000E+00	0.0000	2.586E+00	0.4507
Th-228	0.000E+00	0.0000	0.000E+00	0.0000	0.000E+00	0.0000	0.000E+00	0.0000	0.000E+00	0.0000	0.000E+00	0.0000	2.942E+00	0.5129
Th-232	0.000E+00	0.0000	0.000E+00	0.0000	0.000E+00	0.0000	0.000E+00	0.0000	0.000E+00	0.0000	0.000E+00	0.0000	2.083E-01	0.0363
Total	0.000E+00	0.0000	0.000E+00	0.0000	0.000E+00	0.0000	0.000E+00	0.0000	0.000E+00	0.0000	0.000E+00	0.0000	5.736E+00	1.0000

*Sum of all water independent and dependent pathways

Total Dose Contributions TDOSE(i,p,t) for Individual Radionuclides (i) and Pathways (p)
As mrem/yr and Fraction of Total Dose At t = 1.000E+00 years

Water Independent Pathways (Inhalation excludes radon)

Radio-	Ground		Inhalation		Radon		Plant		Meat		Milk		Soil	
Nuclide	mrem/yr	fract.	mrem/yr	fract.	mrem/yr	fract.	mrem/yr	fract.	mrem/yr	fract.	mrem/yr	fract.	mrem/yr	fract
Ra-228	3.039E+00	0.5304	4.423E-03	0.0008	0.000E+00	0.0000	8.030E-02	0.0140	2.350E-04	0.0000	2.831E-04	0.0000	7.811E-04	0.0001
Th-228	2.040E+00	0.3561	6.657E-03	0.0012	0.000E+00	0.0000	7.804E-04	0.0001	1.604E-06	0.0000	1.145E-07	0.0000	2.454E-04	0.0000
Th-232	4.801E-01	0.0838	5.467E-02	0.0095	0.000E+00	0.0000	1.995E-02	0.0035	5.047E-05	0.0000	5.257E-05	0.0000	1.560E-03	0.0003
Total	5.560E+00	0.9703	6.575E-02	0.0115	0.000E+00	0.0000	1.010E-01	0.0176	2.871E-04	0.0001	3.358E-04	0.0001	2.586E-03	0.0005

Total Dose Contributions TDOSE(i,p,t) for Individual Radionuclides (i) and Pathways (p)
As mrem/yr and Fraction of Total Dose At t = 1.000E+00 years

Water Dependent Pathways

Radio-	Water		Fish		Radon		Plant		Meat		Milk		All Pathways*	
Nuclide	mrem/yr	fract.	mrem/yr	fract.	mrem/yr	fract.	mrem/yr	fract.	mrem/yr	fract.	mrem/yr	fract.	mrem/yr	fract
Ra-228	0.000E+00	0.0000	0.000E+00	0.0000	0.000E+00	0.0000	0.000E+00	0.0000	0.000E+00	0.0000	0.000E+00	0.0000	3.125E+00	0.5454
Th-228	0.000E+00	0.0000	0.000E+00	0.0000	0.000E+00	0.0000	0.000E+00	0.0000	0.000E+00	0.0000	0.000E+00	0.0000	2.048E+00	0.3575
Th-232	0.000E+00	0.0000	0.000E+00	0.0000	0.000E+00	0.0000	0.000E+00	0.0000	0.000E+00	0.0000	0.000E+00	0.0000	5.564E-01	0.0971
Total	0.000E+00	0.0000	0.000E+00	0.0000	0.000E+00	0.0000	0.000E+00	0.0000	0.000E+00	0.0000	0.000E+00	0.0000	5.730E+00	1.0000

*Sum of all water independent and dependent pathways

Total Dose Contributions TDOSE(i,p,t) for Individual Radionuclides (i) and Pathways (p)
As mrem/yr and Fraction of Total Dose At t = 3.000E+00 years

Water Independent Pathways (Inhalation excludes radon)

Radio-	Ground		Inhalation		Radon		Plant		Meat		Milk		Soil	
Nuclide	mrem/yr	fract.	mrem/yr	fract.	mrem/yr	fract.	mrem/yr	fract.	mrem/yr	fract.	mrem/yr	fract.	mrem/yr	fract.
Ra-228	3.295E+00	0.5768	6.456E-03	0.0011	0.000E+00	0.0000	6.315E-02	0.0111	1.845E-04	0.0000	2.215E-04	0.0000	7.214E-04	0.0001
Th-228	9.886E-01	0.1730	3.225E-03	0.0006	0.000E+00	0.0000	3.781E-04	0.0001	7.773E-07	0.0000	5.545E-08	0.0000	1.189E-04	0.0000
Th-232	1.260E+00	0.2205	5.604E-02	0.0098	0.000E+00	0.0000	3.717E-02	0.0065	1.008E-04	0.0000	1.131E-04	0.0000	1.743E-03	0.0003
Total	5.544E+00	0.9703	6.572E-02	0.0115	0.000E+00	0.0000	1.007E-01	0.0176	2.861E-04	0.0001	3.346E-04	0.0001	2.583E-03	0.0005

Total Dose Contributions TDOSE(i,p,t) for Individual Radionuclides (i) and Pathways (p)
As mrem/yr and Fraction of Total Dose At t = 3.000E+00 years

Water Dependent Pathways

Radio-	Water		Fish		Radon		Plant		Meat		Milk		All Pathways*	
Nuclide	mrem/yr	fract.	mrem/yr	fract.	mrem/yr	fract.	mrem/yr	fract.	mrem/yr	fract.	mrem/yr	fract.	mrem/yr	fract
Ra-228	0.000E+00	0.0000	0.000E+00	0.0000	0.000E+00	0.0000	0.000E+00	0.0000	0.000E+00	0.0000	0.000E+00	0.0000	3.366E+00	0.5891
Th-228	0.000E+00	0.0000	0.000E+00	0.0000	0.000E+00	0.0000	0.000E+00	0.0000	0.000E+00	0.0000	0.000E+00	0.0000	9.923E-01	0.1737
Th-232	0.000E+00	0.0000	0.000E+00	0.0000	0.000E+00	0.0000	0.000E+00	0.0000	0.000E+00	0.0000	0.000E+00	0.0000	1.355E+00	0.2372
Total	0.000E+00	0.0000	0.000E+00	0.0000	0.000E+00	0.0000	0.000E+00	0.0000	0.000E+00	0.0000	0.000E+00	0.0000	5.714E+00	1.0000

*Sum of all water independent and dependent pathways

Total Dose Contributions TDOSE(i,p,t) for Individual Radionuclides (i) and Pathways (p)
As mrem/yr and Fraction of Total Dose At t = 1.000E+01 years

Water Independent Pathways (Inhalation excludes radon)

Radio-	Ground		Inhalation		Radon		Plant		Meat		Milk		Soil	
Nuclide	mrem/yr	fract.	mrem/yr	fract.	mrem/yr	fract.	mrem/yr	fract.	mrem/yr	fract.	mrem/yr	fract.	mrem/yr	fract.
Ra-228	1.908E+00	0.3366	4.409E-03	0.0008	0.000E+00	0.0000	2.691E-02	0.0047	7.846E-05	0.0000	9.370E-05	0.0000	3.670E-04	0.0001
Th-228	7.826E-02	0.0138	2.553E-04	0.0000	0.000E+00	0.0000	2.993E-05	0.0000	6.153E-08	0.0000	4.390E-09	0.0000	9.412E-06	0.0000
Th-232	3.513E+00	0.6198	6.096E-02	0.0108	0.000E+00	0.0000	7.305E-02	0.0129	2.055E-04	0.0000	2.384E-04	0.0000	2.197E-03	0.0004
Total	5.500E+00	0.9702	6.563E-02	0.0116	0.000E+00	0.0000	9.998E-02	0.0176	2.841E-04	0.0001	3.321E-04	0.0001	2.574E-03	0.0005

Total Dose Contributions TDOSE(i,p,t) for Individual Radionuclides (i) and Pathways (p)
As mrem/yr and Fraction of Total Dose At t = 1.000E+01 years

Water Dependent Pathways

Radio-	Water				Radon		Plant		Meat		Milk		All Pathways*	
Nuclide	mrem/yr	fract.	mrem/yr	fract.	mrem/yr	fract.	mrem/yr	fract.	mrem/yr	fract.	mrem/yr	fract.	mrem/yr	fract
Ra-228	0.000E+00	0.0000	0.000E+00	0.0000	0.000E+00	0.0000	0.000E+00	0.0000	0.000E+00	0.0000	0.000E+00	0.0000	1.940E+00	0.3423
Th-228	0.000E+00	0.0000	0.000E+00	0.0000	0.000E+00	0.0000	0.000E+00	0.0000	0.000E+00	0.0000	0.000E+00	0.0000	7.856E-02	0.0139
Th-232	0.000E+00	0.0000	0.000E+00	0.0000	0.000E+00	0.0000	0.000E+00	0.0000	0.000E+00	0.0000	0.000E+00	0.0000	3.650E+00	0.6439
Total	0.000E+00	0.0000	0.000E+00	0.0000	0.000E+00	0.0000	0.000E+00	0.0000	0.000E+00	0.0000	0.000E+00	0.0000	5.669E+00	1.0000

*Sum of all water independent and dependent pathways

Total Dose Contributions TDOSE(i,p,t) for Individual Radionuclides (i) and Pathways (p)
As mrem/yr and Fraction of Total Dose At t = 3.000E+01 years

Water Independent Pathways (Inhalation excludes radon

Radio-	Ground		Inhalation		Radon		Plant		Meat		Milk		Soil	
Nuclide	mrem/yr	fract.	mrem/yr	fract.	mrem/yr	fract.	mrem/yr	fract.	mrem/yr	fract.	mrem/yr	fract.	mrem/yr	fract.
Ra-228	1.733E-01	0.0308	4.101E-04	0.0001	0.000E+00	0.0000	2.306E-03	0.0004	6.721E-06	0.0000	8.018E-06	0.0000	3.261E-05	0.0000
Th-228	5.578E-05	0.0000	1.820E-07	0.0000	0.000E+00	0.0000	2.133E-08	0.0000	4.386E-11	0.0000	3.129E-12	0.0000	6.708E-09	0.0000
Th-232	5.291E+00	0.9394	6.513E-02	0.0116	0.000E+00	0.0000	9.720E-02	0.0173	2.759E-04	0.0000	3.224E-04	0.0001	2.534E-03	0.0004
Tota	5.464E+00	0.9701	6.554E-02	0116	0.000E+00	0.0000	9.950E-02	0.0177	2.827E-04	0.000	3.305E-04	0.0001	2.567E-03	0.0005

Total Dose Contributions TDOSE(i,p,t) for Individual Radionuclides (i) and Pathways (p)
As mrem/yr and Fraction of Total Dose At t = 3.000E+01 years

Water Dependent Pathways

Radio-	Water				Radon		Plant				Milk		All Pathways*	
Nuclide	mrem/yr	fract.	mrem/yr	fract.	mrem/yr	fract.	mrem/yr	fract.	mrem/yr	fract.	mrem/yr	fract.	mrem/yr	fract.
Ra-228	0.000E+00	0.0000	0.000E+00	0.0000	0.000E+00	0.0000	0.000E+00	0.0000	0.000E+00	0.0000	0.000E+00	0.0000	1.761E-01	0.0313
Th-228	0.000E+00	0.0000	0.000E+00	0.0000	0.000E+00	0.0000	0.000E+00	0.0000	0.000E+00	0.0000	0.000E+00	0.0000	5.599E-05	0.0000
Th-232	0.000E+00	0.0000	0.000E+00	0.0000	0.000E+00	0.0000	0.000E+00	0.0000	0.000E+00	0.0000	0.000E+00	0.0000	5.457E+00	0.9687
Total	0.000E+00	0.0000	0.000E+00	0.0000	0.000E+00	0.0000	0.000E+00	0.0000	0.000E+00	0.0000	0.000E+00	0.0000	5.633E+00	1.0000

*Sum of all water independent and dependent pathways

otal Dose Contributions TDOSE(i,p,t) for Individual Radionuclides (i) and Pathways (p)
As mrem/yr and Fraction of Total Dose At t = 1.000E+02 years

Water Independent Pathways (Inhalation excludes radon)

Radio-Nuclide	Ground mrem/yr	Ground fract.	Inhalation mrem/yr	Inhalation fract.	Radon mrem/yr	Radon fract.	Plant mrem/yr	Plant fract.	Meat mrem/yr	Meat fract.	Milk mrem/yr	Milk fract.	Soil mrem/yr	Soil fract.
Ra-228	3.179E-05	0.0000	7.521E-08	0.0000	0.000E+00	0.0000	4.227E-07	0.0000	1.232E-09	0.0000	1.470E-09	0.0000	5.979E-09	0.0000
Th-228	5.392E-16	0.0000	1.759E-18	0.0000	0.000E+00	0.0000	2.062E-19	0.0000	4.240E-22	0.0000	3.025E-23	0.0000	6.485E-20	0.0000
Th-232	5.460E+00	0.9701	6.552E-02	0.0116	0.000E+00	0.0000	9.944E-02	0.0177	2.825E-04	0.0001	3.302E-04	0.0001	2.566E-03	0.0005
Total	5.460E+00	0.9701	6.552E-02	0.0116	0.000E+00	0.0000	9.944E-02	0.0177	2.825E-04	0.0001	3.302E-04	0.0001	2.566E-03	0.0005

Total Dose Contributions TDOSE(i,p,t) for Individual Radionuclides (i) and Pathways (p)
As mrem/yr and Fraction of Total Dose At t = 1.000E+02 years

Water Dependent Pathways

Radio-Nuclide	Water mrem/yr	Water fract.	Fish mrem/yr	Fish fract.	Radon mrem/yr	Radon fract.	Plant mrem/yr	Plant fract.	Meat mrem/yr	Meat fract.	Milk mrem/yr	Milk fract.	All Pathways* mrem/yr	All Pathways* fract.
Ra-228	0.000E+00	0.0000	0.000E+00	0.0000	0.000E+00	0.0000	0.000E+00	0.0000	0.000E+00	0.0000	0.000E+00	0.0000	3.229E-05	0.0000
Th-228	0.000E+00	0.0000	0.000E+00	0.0000	0.000E+00	0.0000	0.000E+00	0.0000	0.000E+00	0.0000	0.000E+00	0.0000	5.412E-16	0.0000
Th-232	0.000E+00	0.0000	0.000E+00	0.0000	0.000E+00	0.0000	0.000E+00	0.0000	0.000E+00	0.0000	0.000E+00	0.0000	5.628E+00	1.0000
otal	0.000E+00	0.0000	0.000E+00	0.0000	0.000E+00	0.0000	0.000E+00	0.0000	0.000E+00	0.0000	0.000E+00	0.0000	5.628E+00	1.0000

*Sum of all water independent and dependent pathways

RESRAD, 'ersion 6.21   T½ Limit = 0.5 year   '/02/2003 12:17 Page
Summary : Great Lakes 19 sq meter area RESRJ Defa Parameters for Th322
File : GreatL2.RAD

Total Dose Contributions TDOSE(i,p,t) for Individual Radionuclides (i) and Pathways (p)
As mrem/yr and Fraction of Total Dose At t = 3.000E+02 years

Water Independent Pathways :nhala excludes rad

Radio-	'round		Inhalation		Radon				Meat					
Nuclide	mrem/yr	fract.	mrem/yr	fract.	mrem/yr	fract.	mrem/yr	fract.	mrem/yr	fract.	mrem/yr	fract.	mrem/yr	fract.
Ra :8	6.691E-16	0.0000	1.583E-18	0.0000	0.000E+00	0.0000	8.897E-18	0.0000	2.593E-20	0.0000	3.093E-20	0.0000	1.259E-19	
Th :8	0.000E+00	0.0000	0.000E+00	0.0000	0.000E+00	0.0000	0.000E+00	0.0000	0.000E+00	0.0000	0.000E+00	0.0000	0.000E+00	.0000
Th :2	5.457E+00	0.9701	6.548E-02	0.0116	0.000E+00	0.0000	9.938E-02	0.0177	2.823E-04	0.0001	3.301E-04	0.0001	2.564E-03	.0005
Total	5.457E+00	0.9701	6.548E-02	0.0116	0.000E+00	0.0000	9.938E-02	0.0177	.823E-04	0.000	3.301E-04	0.0001	2.564E-03	0005

Total Dose Contributions TDOSE(i,p t) for Individual Radionuclides (i) and Pathways (p
As mrem/yr and Fracti m of Total Dose At t = 3.000E+02 years

Water Dependent Pathways

Radio-	Water				Radon						Milk		Pathways*	
Nuclide	mrem/yr	fract.	mrem/yr	fract.	mrem/yr	fract.	mrem/yr	fract.	mrem/yr	fract.	mrem/yr	fract.	mrem/yr	fract
Ra :8	0.000E+00	0.0000	0.000E+00	0.0000	0.000E+00	0.0000	0.000E+0	).0000	(.000E+00	.0000	.000E+00	.0000	6.797E-16	0.0000
Th :8	0.000E+00	0.0000	0.000E+00	0.0000	0.000E+00	0.0000	0.000E+0	).0000	(.000E+00	.0000	.000E+00		0.000E+00	0.0000
Th :2	0.000E+00	0.0000	0.000E+00	0.0000	0.000E+00	0.0000	0.000E+0	).0000	(.000E+00	).0000	.000E+00		5.625E+00	1.0000
Total	.000E+0		0.000E+00	0.0000	0.000E+00	0.0000	0.000E+00	0.0000	0.000E+00	0.0000	0.000E+00	0.0000	5.625E+00	1.00

*Sum of all water ndependent and dependent pathways

Total Dose Contributions TDOSE(i,p,t) for Individual Radionuclides (i) and Pathways (p)
As mrem/yr and Fraction of Total Dose At t = 1.000E+03 years

Water Independent Pathways (Inhalation excludes radon)

Radio-Nuclide	Ground mrem/yr	Ground fract.	Inhalation mrem/yr	Inhalation fract.	Radon mrem/yr	Radon fract.	Plant mrem/yr	Plant fract.	Meat mrem/yr	Meat fract.	Milk mrem/yr	Milk fract.	Soil mrem/yr	Soil fract.
Ra-228	0.000E+00	0.0000	0.000E+00	0.0000	0.000E+00	0.0000	0.000E+00	0.0000	0.000E+00	0.0000	0.000E+00	0.0000	0.000E+00	0.0000
Th-228	0.000E+00	0.0000	0.000E+00	0.0000	0.000E+00	0.0000	0.000E+00	0.0000	0.000E+00	0.0000	0.000E+00	0.0000	0.000E+00	0.0000
Th-232	5.446E+00	0.9701	6.536E-02	0.0116	0.000E+00	0.0000	9.919E-02	0.0177	2.818E-04	0.0001	3.294E-04	0.0001	2.560E-03	0.0005
Total	5.446E+00	0.9701	6.536E-02	0.0116	0.000E+00	0.0000	9.919E-02	0.0177	2.818E-04	0.0001	3.294E-04	0.0001	2.560E-03	0.0005

Total Dose Contributions TDOSE(i,p,t) for Individual Radionuclides (i) and Pathways (p)
As mrem/yr and Fraction of Total Dose At t = 1.000E+03 years

Water Dependent Pathways

Radio-Nuclide	Water mrem/yr	Water fract.	Fish mrem/yr	Fish fract.	Radon mrem/yr	Radon fract.	Plant mrem/yr	Plant fract.	Meat mrem/yr	Meat fract.	Milk mrem/yr	Milk fract.	All Pathways* mrem/yr	All Pathways* fract.
Ra-228	0.000E+00	0.0000	0.000E+00	0.0000	0.000E+00	0.0000	0.000E+00	0.0000	0.000E+00	0.0000	0.000E+00	0.0000	0.000E+00	0.0000
Th-228	0.000E+00	0.0000	0.000E+00	0.0000	0.000E+00	0.0000	0.000E+00	0.0000	0.000E+00	0.0000	0.000E+00	0.0000	0.000E+00	0.0000
Th-232	0.000E+00	0.0000	0.000E+00	0.0000	0.000E+00	0.0000	0.000E+00	0.0000	0.000E+00	0.0000	0.000E+00	0.0000	5.614E+00	1.0000
Total	0.000E+00	0.0000	0.000E+00	0.0000	0.000E+00	0.0000	0.000E+00	0.0000	0.000E+00	0.0000	0.000E+00	0.0000	5.614E+00	1.0000

*Sum of all water independent and dependent pathways

Dose/Source Ratios Summed Over All Pathways
Parent and Progeny Principal Radionuclide Contributions Indicated

Parent (i)	Product (j)	Branch Fraction*	t= 0.000E+00	1.000E+00	3.000E+00	1.000E+01	3.000E+01	1.000E+02	3.000E+02	1.000E+03
			DSR(j,t) (mrem/yr)/(pCi/g)							
Ra-228	I }	1.000E+00	2.043E+00	1.807E+00	1.413E+00	5.976E-01	5.114E-02	9.373E-06	1.973E-16	0.000E+00
Ra-228	7 }	1.000E+00	5.426E-01	1.318E+00	1.953E+00	1.343E+00	1.250E-01	2.292E-05	4.824E-16	0.000E+00
Ra-228	}))		2.586E+00	3.125E+00	3.366E+00	1.940E+00	1.761E-01	3.229E-05	6.797E-16	0.000E+00
Th-228	Th-228	1.000E+00	2.942E+00	2.048E+00	9.923E-01	1.956E-02	5.599E-05	5.412E-16	0.000E+00	0.000E+00
Th-2:	Th-23	1.000E+00	6.034E-02	6.034E-02	6.034E-02	6.033E-02	6.033E-02	6.032E-02	6.029E-02	6.017E-02
Th-2:	Ra-22	1.000E+00	1.253E-01	3.570E-01	7.432E-01	1.543E+00	2.078E+00	2.120E+00	2.127E+00	2.123E+00
Th-2:	Th-22	1.000E+00	2.270E-02	1.391E-01	5.518E-01	2.047E+00	3.318E+00	3.440E+00	3.438E+00	3.431E+00
Th-2:	∑DSR(		2.083E-01	5.564E-01	1.355E+00	3.650E+00	5.457E+00	5.628E+00	5.625E+00	5.614E+00

*Branch Fraction is the cumulative factor for the j't principal radionuclide daughter CUMBRF(j) = BRF(1)*BRF(2)* BRF(j)
The DSR includes contributions from associated (half-life ≤ 0.5 yr) daughters.

Single Radionuclide Soil Guidelines G(i,t) in pCi/g
Basic Radiation Dose Limit = 2.500E+01 mrem/yr

Nuclide	0.000E+00	1.000E+00	3.000E+00	1.000E+01	3.000E+01	1.000E+02	3.000E+02	1.000E+03
Ra-228	9.669E+00		7.427E+00		1.420E+02	7.742E-05	*2.726E+14	*2.726E+14
Th-228	8.496E+00		2.519E+01		4.465E+05	*8.192E+14	*8.192E+14	*8.192E+14
Th-232	1.200E+02		1.845E+01		4.582E+00	4.442E+00	4.444E+00	4.453E+00

*At specific activity limit

Summed Dose/Source Ratios DSR(i,t) in (mrem/yr)/(pCi/g)
and Single Radionuclide Soil Guidelines G(i,t) in pCi/g
at tmin = time of minimum single radionuclide soil guideline
and at tmax = time of maximum total dose = 0.000E+00 years

Nuclide (i)	Initial (pCi/g)	tmin (years)	DSR(i,tmin)	G(i,tmin) (pCi/g)	DSR(i,tmax)	G(i,tmax) (pCi/g)
Ra-228	1.000E+00	2.603 ± 0.005	3.377E+00	7.402E+00	2.586E+00	9.669E+00
Th-228	1.000E+00	0.000E+00	2.942E+00	8.496E+00	2.942E+00	8.496E+00
Th-232	1.000E+00	88.8 ± 0.2	5.628E+00	4.442E+00	2.083E-01	1.200E+02

Individual Nuclide Dose Summed Over All Pathways
Parent Nuclide and Branch Fraction Indicated

Nuclide (j)	Parent (i)	BRF(i)	DOSE(j,t), mrem/yr t= 0.000E+00	1.000E+00	3.000E+00	1.000E+01	3.000E+01	1.000E+02	3.000E+02	1.000E+03
Ra-228	Ra-228	1.000E+00	2.043E+00	1.807E+00	1.413E+00	5.976E-01	5.114E-02	9.373E-06	1.973E-16	0.000E+00
Ra-228	Th-232	1.000E+00	1.253E-01	3.570E-01	7.432E-01	1.543E+00	2.078E+00	2.128E+00	2.127E+00	2.123E+00
Ra-228	∑DOSE(j)		2.168E+00	2.164E+00	2.156E+00	2.140E+00	2.130E+00	2.128E+00	2.127E+00	2.123E+00
Th-228	Ra-228	1.000E+00	5.426E-01	1.318E+00	1.953E+00	1.343E+00	1.250E-01	2.292E-05	4.824E-16	0.000E+00
Th-228	Th-228	1.000E+00	2.942E+00	2.048E+00	9.923E-01	7.856E-02	5,599E-06	5.412E-16	0.000E+00	0.000E+00
Th-228	Th-232	1.000E+00	2.270E-02	1.391E-01	5.518E-01	2.047E+00	3.318E+00	3.440E+00	3.438E+00	3.431E+00
Th-228	∑DOSE(j)		3.508E+00	3.506E+00	3.497E+00	3.468E+00	3.443E+00	3.440E+00	3.438E+00	3.431E+00
Th-232	Th-232	1.000E+00	6.034E-02	6.034E-02	6.034E-02	6.033E-02	6.033E-02	6.032E-02	6.029E-02	6.017E-02

BRF(i) is the branch fraction of the parent nuclide.

Individual Nuclide Soil Concentration
Parent Nuclide and Branch Fraction Indicated

Nuclide (j)	Parent (i)	BRF(i)	S(j,t), pCi/g t= 0.000E+00	1.000E+00	3.000E+00	1.000E+01	3.000E+01	1.000E+02	3.000E+02	1.000E+03
Ra-228	Ra-22	1.000E+00	1.000E+00	8.843E-01	6.916E-01	2.925E-01	2.503E-02	4.588E-06	9.657E-17	0.000E+00
Ra-228	Th-23	1.000E+00	0.000E+00	1.134E-01	3.025E-01	6.938E-01	9.561E-01	9.804E-01	9.799E-01	9.780E-01
Ra-228	∑S(j)		1.000E+00	9.978E-01	9.940E-01	9.863E-01	9.811E-01	9.804E-01	9.799E-01	9.780E-01
Th-228	Ra-228	1.000E+00	0.000E+00	2.849E-01	5.363E-01	4.023E-01	3.785E-02	6.943E-06	1.461E-16	0.000E+00
Th-228	Th-228	1.000E+00	1.000E+00	6.961E-01	3.372E-01	2.670E-02	1.903E-05	1.839E-16	0.000E+00	0.000E+00
Th-228	Th-232	1.000E+00	0.000E+00	1.863E-02	1.840E-01	5.599E-01	9.435E-01	9.804E-01	9.799E-01	9.780E-01
Th-228	∑S(j):		1.000E+00	9.996E-01	9.976E-01	9.890E-01	9.814E-01	9.804E-01	9.799E-01	9.780E-01
Th-232	Th-232	1.000E+00	1.000E+00	1.000E+00	1.000E+00	1.000E+00	9.999E-01	9.997E-01	9.992E-01	9.972E-01

BRF(i) is the branch fraction of the parent nuclide

RESCALC.EXE execution time = 1.00 seconds

Table of Contents

Part I: Mixture Sums and Single Radionuclide Guidelines

Dose Conversion Factor (and Related) Parameter Summary
File: FGR 13 Morbidity

Menu	Parameter	Current Value	Default	Parameter Name
B-1	Dose conversion factors for inhalation, mrem/pCi			
B-1	Ra-228+D	5.080E-03	5.080E-03	DCF2(1)
B-1	Th-228+D	3.450E-01	3.450E-01	DCF2(2)
B-1	Th-232	1.640E+00	1.640E+00	DCF2(3)
D-1	Dose conversion factors for ingestion, mrem/pCi			
D-1	Ra-228+D	1.440E-03	1.440E-	DCF3(1)
D-1	Th-228+D	8.080E-04	8.080E-	DCF3(2)
D-1	Th-232	2.730E-03	2.730E-	DCF3(3)
D-34	Food transfer factors:			
D-34	Ra-228+D , plant/soil concentration ratio, dimensionless	4.000E-02	4.000E-02	RTF(1,1)
D-34	Ra-228+D , beef/livestock-intake ratio, (pCi/kg)/(pCi/d)	1.000E-03	1.000E-03	RTF(1,2)
D-34	Ra-228+D , milk/livestock-intake ratio, (pCi/L)/(pCi/d)	1.000E-03	1.000E-03	RTF(1,3)
D-34				
D-34	Th-228+D , plant/soil concentration ratio, dimensionless	1.000E-03	1.000E-03	RTF(2,1)
D-34	Th-228+D , beef/livestock-intake ratio, (pCi/kg)/(pCi/d)	1.000E-04	1.000E-04	RTF(2,2)
D-34	Th-228+D , milk/livestock-intake ratio, (pCi/L)/(pCi/d)	5.000E-06	5.000E-06	RTF(2,3)
D-34				
D-34	Th-232 , plant/soil concentration ratio, dimensionless	1.000E-03	1.000E-03	RTF(3,1)
D-34	Th-232 , beef/livestock-intake ratio, (pCi/kg)/(pCi/d)	1.000E-04	1.000E-04	RTF(3,2)
D-34	Th-232 , milk/livestock-intake ratio, (pCi/L)/(pCi/d)	5.000E-06	5.000E-06	RTF(3,3)
D-5	Bioaccumulation factors, fresh water, L/kg			
D-5	Ra-228+D , fish	5.000E+01	5.000E+01	BIOFAC(1,1)
D-5	Ra-228+D , crustacea and mollusks	2.500E+02	2.500E+02	BIOFAC(1,2)
	Th-228+D fish	1.000E+02	1.000E+02	BIOFAC(2,1)
	Th-228+D crustacea and mollusks	5.000E+02	5.000E+02	BIOFAC(2,2)
	Th-232 , fish	1.000E+02	1.000E+02	BIOFAC(3,1)
	Th-232 , crustacea and mollusks	5.000E+02	5.000E+02	BIOFAC(3,2)

Site-Specific Parameter Summary

Menu	Parameter	User Input	Default	Used by RESRAD (If different from user input)	Parameter Name
R011	Area of contaminated zone (m**2)	4.300E+01	1.000E+04		AREA
R011	Thickness of contaminated zone (m)	2.000E+00	2.000E+00		THICK0
R011	Length parallel to aquifer flow (m)	6.550E+00	1.000E+02		LCZPAQ
R011	Basic radiation dose limit (mrem/yr)	2.500E+01	2.500E+01		BRDL
R011	Time since placement of material (yr)	0.000E+00	0.000E+00		TI
R011	Times for calculations (yr)	1.000E+00	1.000E+00		T(2)
R011	Times for calculations (yr)	3.000E+00	3.000E+00		T(3)
R011	Times for calculations (yr)	1.000E+01	1.000E+01		T(4)
R011	Times for calculations (yr)	3.000E+01	3.000E+01		T(5)
R011	Times for calculations (yr)	1.000E+02	1.000E+02		T(6)
R011	Times for calculations (yr)	3.000E+02	3.000E+02		T(7)
R011	Times for calculations (yr)	1.000E+03	1.000E+03		T(8)
R011	Times for calculations (yr)	not used	0.000E+00		T(9)
R011	Times for calculations (yr)	not used	0.000E+00		T(10)
R012	Initial principal radionuclide (pCi/g) Ra-228	1.000E+00	0.000E+00		S1(1)
R012	Initial principal radionuclide (pCi/g) Th-228	1.000E+00	0.000E+00		S1(2)
R012	Initial principal radionuclide (pCi/g) Th-232	1.000E+00	0.000E+00		S1(3)
R012	Concentration in groundwater (pCi/L) Ra-228	not used	0.000E+00		W1(1)
R012	Concentration in groundwater (pCi/L) Th-228	not used	0.000E+00		W1(2)
R012	Concentration in groundwater (pCi/L) Th-232	not used	0.000E+00		W1(3)
R013	Cover depth (m)	0.000E+00	0.000E+00		COVER0
R013	Density of cover material (g/cm**3)	not used	1.500E+00		DENSCV
R013	Cover depth erosion rate (m/yr)	not used	1.000E-03		VCV
R013	Density of contaminated zone (g/cm**3)	1.500E+00	1.500E+00		DENSCZ
R013	Contaminated zone erosion rate (m/yr)	1.000E-03	1.000E-03		VCZ
R013	Contaminated zone total porosity	4.000E-01	4.000E-01		TPCZ
R013	Contaminated zone field capacity	2.000E-01	2.000E-01		FCCZ
R013	Contaminated zone hydraulic conductivity (m/yr)	1.000E+01	1.000E+01		HCCZ
R013	Contaminated zone b parameter	5.300E+00	5.300E+00		BCZ
R013	Average annual wind speed (m/sec)	2.000E+00	2.000E+00		WIND
R013	Humidity in air (g/m**3)	not used	8.000E+00		HUMID
R013	Evapotranspiration coefficient	5.000E-01	5.000E-01		EVAPTR
R013	Precipitation (m/yr)	1.000E+00	1.000E+00		PRECIP
R013	Irrigation (m/yr)	2.000E-01	2.000E-01		
R013	Irrigation mode	overhead	overhead		IDITCH
R013	Runoff coefficient	2.000E-01	2.000E-01		RUNOFF
R013	Watershed area for nearby stream or pond (m**2)	1.000E+06	1.000E+06		WAREA
R013	Accuracy for water/soil computations	1.000E-03	1.000E-03		EPS
R014	Density of saturated zone (g/cm**3)	1.500E+00	1.500E+00		DENSAQ
R014	Saturated zone total porosity	4.000E-01	4.000E-01		TPSZ
R014	Saturated zone effective porosity	2.000E-01	2.000E-01		EPSZ
R014	Saturated zone field capacity	2.000E-01	2.000E-01		FCSZ
R014	Saturated zone hydraulic conductivity (m/yr)	1.000E+02	1.000E+02		HCSZ
R014	Saturated zone hydraulic gradient	2.000E-02	2.000E-02		HGWT
R014	Saturated zone b parameter	5.300E+00	5.300E+00		BSZ
R014	Water table drop rate (m/yr)	1.000E-03	1.000E-03		VWT
R014	Well pump intake depth (m below water table	1.000E+01	1.000E+01		DWIBWT

Site-Specific Parameter Summary (continued)

Menu	Parameter	User Input	Default	Used by RESRAD (If different from user input)	Parameter Name
R014	Model: Nondispersion (ND) or Mass-Balance (MB)	ND	ND		MODEL
R014	Well pumping rate (m**3/yr)	2.500E+02	2.500E+02		UW
R015	Number of unsaturated zone strata	1			NS
R015	Unsat. zone 1, thickness (m)	4.000E+00	4.000E+00		H(1)
R015	Unsat. zone 1, soil density (g/cm**3)	1.500E+00	1.500E+00		DENSUZ(1)
R015	Unsat. zone 1, total porosity	4.000E-01	4.000E-01		TPUZ(1)
R015	Unsat. zone 1, effective porosity	2.000E-01	2.000E-01		EPUZ(1)
R015	Unsat. zone 1, field capacity	2.000E-01	2.000E-01		FCUZ(1)
R015	Unsat. zone 1, soil-specific b parameter	5.300E+00	5.300E+00		BUZ(1)
R015	Unsat. zone 1, hydraulic conductivity (m/yr)	1.000E+01	1.000E+01		HCUZ(1)
R016	Distribution coefficients for Ra-228				
R016	Contaminated zone (cm**3/g)	7.000E+01	7.000E+01		DCNUCC(1)
R016	Unsaturated zone 1 (cm**3/g)	7.000E+01	7.000E+01	---	DCNUCU(1,1)
R016	Saturated zone (cm**3/g)	7.000E+01	7.000E+01	---	DCNUCS(1)
R016	Leach rate (/yr)	0.000E+00	0.000E+00	2.374E-03	ALEACH(1)
R016	Solubility constant	0.000E+00	0.000E+00	not used	SOLUBK(1)
R016	Distribution coefficients for Th-228				
R016	Contaminated zone (cm**3/g)	6.000E+04	6.000E+04		DCNUCC(2)
R016	Unsaturated zone 1 (cm**3/g)	6.000E+04	6.000E+04	---	DCNUCU(2,1)
R016	Saturated zone (cm**3/g)	6.000E+04	6.000E+04	---	DCNUCS(2)
R016	Leach rate (/yr)	0.000E+00	0.000E+00	2.778E-06	ALEACH(2)
R016	Solubility constant	0.000E+00	0.000E+00	not used	SOLUBK(2)
R016	Distribution coefficients for Th-232				
R016	Contaminated zone (cm**3/g)	6.000E+04	6.000E+04		DCNUCC(3)
R016	Unsaturated zone 1 (cm**3/g)	6.000E+04	6.000E+04		DCNUCU(3,1)
R016	Saturated zone (cm**3/g)	6.000E+04	6.000E+04	---	DCNUCS(3)
R016	Leach rate (/yr)	0.000E+00	0.000E+00	2.778E-06	ALEACH(3)
R016	Solubility constant	0.000E+00	0.000E+00	not used	SOLUBK(3)
R017	Inhalation rate (m**3/yr)	8.400E+03	8.400E+03		INHALR
R017	Mass loading for inhalation (g/m**3)	1.000E-04	1.000E-04	---	MLINH
R017	Exposure duration	3.000E+01	3.000E+01	---	ED
R017	Shielding factor, inhalation	4.000E-01	4.000E-01	---	SHF3
R017	Shielding factor, external gamma	7.000E-01	7.000E-01		SHF1
R017	Fraction of time spent indoors	5.000E-01	5.000E-01		FIND
R017	Fraction of time spent outdoors (on site)	2.500E-01	2.500E-01	---	FOTD
R017	Shape factor flag, external gamma	1.000E+00	1.000E+00	>0 shows circular AREA.	FS

Site-Specific Parameter Summary (continued)

Menu	Parameter	User Input	Default	Used by RESRAD (If different from user input)	Parameter Name
R017	Radii of shape factor array (used if FS = -1)				
R017	Outer annular radius (m), ring 1:	not used	5.000E+01		RAD_SHAPE(1)
R017	Outer annular radius (m), ring 2:	not used	7.071E+01		RAD_SHAPE(2)
R017	Outer annular radius (m), ring 3:	not used	0.000E+00		RAD_SHAPE(3)
R017	Outer annular radius (m), ring 4:	not used	0.000E+00		RAD_SHAPE(4)
R017	Outer annular radius (m), ring 5:	not used	0.000E+00		RAD_SHAPE(5)
R017	Outer annular radius (m), ring 6:	not used	0.000E+00		RAD_SHAPE(6)
R017	Outer annular radius (m), ring 7:	not used	0.000E+00		RAD_SHAPE(7)
R017	Outer annular radius (m), ring 8:	not used	0.000E+00		RAD_SHAPE(8)
R017	Outer annular radius (m), ring 9:	not used	0.000E+00		RAD_SHAPE(9)
R017	Outer annular radius (m), ring 10:	not used	0.000E+00		RAD_SHAPE(10)
R017	Outer annular radius (m), ring 11:	not used	0.000E+00		RAD_SHAPE(11)
R017	Outer annular radius (m), ring 12:	not used	0.000E+00		RAD_SHAPE(12)
R017	Fractions of annular areas within AREA:				
R017	Ring 1	not used	1.000E+00	---	FRACA(1)
R017	Ring 2	not used	2.732E-01	---	FRACA(2)
R017	Ring 3	not used	0.000E+00	---	FRACA(3)
R017	Ring 4	not used	0.000E+00	---	FRACA(4)
R017	Ring 5	not used	0.000E+00	---	FRACA(5)
R017	Ring 6	not used	0.000E+00	---	FRACA(6)
R017	Ring 7	not used	0.000E+00	---	FRACA(7)
R017	Ring 8	not used	0.000E+00	---	FRACA(8)
R017	Ring 9	not used	0.000E+00	---	FRACA(9)
R017	Ring 10	not used	0.000E+00		FRACA(10)
R017	Ring 11	not used	0.000E+00		FRACA(11)
R017	Ring 12	not used	0.000E+00		FRACA(12)
R018	Fruits, vegetables and grain consumption (kg/yr)	1.600E+02	1.600E+02	---	DIET(1)
R018	Leafy vegetable consumption (kg/yr)	1.400E+01	1.400E+01	---	DIET(2)
R018	Milk consumption (L/yr)	9.200E+01	9.200E+01	---	DIET(3)
R018	Meat and poultry consumption (kg/yr)	6.300E+01	6.300E+01	---	DIET(4)
R018	Fish consumption (kg/yr)	5.400E+00	5.400E+00		DIET(5)
R018	Other seafood consumption (kg/yr)	9.000E-01	9.000E-01		DIET(6)
R018	Soil ingestion rate (g/yr)	3.650E+01	3.650E+01		SOIL
R018	Drinking water intake (L/yr)	5.100E+02	5.100E+02		DWI
R018	Contamination fraction of drinking water	1.000E+00	1.000E+00		FDW
R018	Contamination fraction of household water	not used	1.000E+00		FHHW
R018	Contamination fraction of livestock water	1.000E+00	1.000E+00		FLW
R018	Contamination fraction of irrigation water	1.000E+00	1.000E+00		FIRW
R018	Contamination fraction of aquatic food	5.000E-01	5.000E-01	---	FR9
R018	Contamination fraction of plant food	-1	-1	0.215E-01	FPLANT
R018	Contamination fraction of meat	-1	-1	0.215E-02	FMEAT
R018	Contamination fraction of milk	-1	-1	0.215E-02	FMILK
R019	Livestock fodder intake for meat (kg/day)	6.800E+01	6.800E+01		LFI5
R019	Livestock fodder intake for milk (kg/day)	5.500E+01	5.500E+01		LFI6
R019	Livestock water intake for meat (L/day)	5.000E+01	5.000E+01		LWI5
R019	Livestock water intake for milk (L/day)	1.600E+02	1.600E+02		LWI6
R019	Livestock soil intake (kg/day)	5.000E-01	5.000E-01		LSI

Site-Specific Parameter Summary (continued)

Menu	Parameter	User Input	Default	Used by RESRAD (If different from user input)	Parameter Name
R019	Mass loading for foliar deposition (g/m**3)	1.000E-04	1.000E-04		MLFD
R019	Depth of soil mixing layer (m)	1.500E-01	1.500E-01		DM
R019	Depth of roots (m)	9.000E-01	9.000E-01	---	DROOT
R019	Drinking water fraction from ground water	1.000E+00	1.000E+00	---	FGWDW
R019	Household water fraction from ground water	not used	1.000E+00	---	FGWHH
R019	Livestock water fraction from ground water	1.000E+00	1.000E+00	---	FGWLW
R019	Irrigation fraction from ground water	1.000E+00	1.000E+00	---	FGWIR
R19B	Wet weight crop yield for Non-Leafy (kg/m**2)	7.000E-01	7.000E-01		
R19B	Wet weight crop yield for Leafy (kg/m**2)	1.500E+00	1.500E+00		YV(2)
R19B	Wet weight crop yield for Fodder (kg/m**2)	1.100E+00	1.100E+00		YV(3)
R19B	Growing Season for Non-Leafy (years)	1.700E-01	1.700E-01		TE(1)
R19B	Growing Season for Leafy (years)	2.500E-01	2.500E-01		TE(2)
R19B	Growing Season for Fodder (years)	8.000E-02	8.000E-02		TE(3)
R19B	Translocation Factor for Non-Leafy	1.000E-01	1.000E-01		TIV(1)
R19B	Translocation Factor for Leafy	1.000E+00	1.000E+00		TIV(2)
R19B	Translocation Factor for Fodder	1.000E+00	1.000E+00		TIV(3)
R19B	Dry Foliar Interception Fraction for Non-Leafy	2.500E-01	2.500E-01		RDRY(1)
R19B	Dry Foliar Interception Fraction for Leafy	2.500E-01	2.500E-01		RDRY(2)
R19B	Dry Foliar Interception Fraction for Fodder	2.500E-01	2.500E-01		RDRY(3)
R19B	Wet Foliar Interception Fraction for Non-Leafy	2.500E-01	2.500E-01		RWET(1)
R19B	Wet Foliar Interception Fraction for Leafy	2.500E-01	2.500E-01		RWET(2)
R19B	Wet Foliar Interception Fraction for Fodder	2.500E-01	2.500E-01		RWET(3)
R19B	Weathering Removal Constant for Vegetation	2.000E+01	2.000E+01		WLAM
C14	C-12 concentration in water (g/cm**3)	not used	2.000E-05		C12WTR
C14	C-12 concentration in contaminated soil (g/g)	not used	3.000E-02		C12CZ
C14	Fraction of vegetation carbon from soil	not used	2.000E-02		CSOIL
C14	Fraction of vegetation carbon from air	not used	9.800E-01		CAIR
C14	C-14 evasion layer thickness in soil (m)	not used	3.000E-01		DMC
C14	C-14 evasion flux rate from soil (1/sec)	not used	7.000E-07		EVSN
C14	C-12 evasion flux rate from soil (1/sec)	not used	1.000E-10		REVSN
C14	Fraction of grain in beef cattle feed	not used	8.000E-01		AVFG4
C14	Fraction of grain in milk cow feed	not used	2.000E-01		AVFG5
C14	DCF correction factor for gaseous forms of C14	not used	8.894E+01		CO2F
STOR	Storage times of contaminated foodstuffs (days)				
STOR	Fruits, non-leafy vegetables, and grain	1.400E+01	1.400E+01		STOR_T(1)
STOR	Leafy vegetables	1.000E+00	1.000E+00		STOR_T(2)
STOR	Milk	1.000E+00	1.000E+00		STOR_T(3)
STOR	Meat and poultry	2.000E+01	2.000E+01		STOR_T(4)
STOR	Fish	7.000E+00	7.000E+00		STOR_T(5)
STOR	Crustacea and mollusks	7.000E+00	7.000E+00		STOR_T(6)
STOR	Well water	1.000E+00	1.000E+00		STOR_T(7)
STOR	Surface water	1.000E+00	1.000E+00		STOR_T(8)
STOR	Livestock fodder	4.500E+01	4.500E+01		STOR_T(9)
R021	Thickness of building foundation (m)	not used	1.500E-01		FLOOR1
R021	Bulk density of building foundation (g/cm**3)	not used	2.400E+00		DENSFL
R021	Total porosity of the cover material	not used	4.000E-01		TPCV

Site-Specific Parameter Summary (continued)

Menu	Parameter	User Input	Default	Used by RESRAD (If different from user input)	Parameter Name
R021	Total porosity of the building foundation	not used	1.000E-01		TPFL
R021	Volumetric water content of the cover material	not used	5.000E-02		PH2OCV
R021	Volumetric water content of the foundation	not used	3.000E-02		PH2OFL
R021	Diffusion coefficient for radon gas (m/sec):				
R021	in cover material	not used	2.000E-06		DIFCV
R021	in foundation material	not used	3.000E-07	---	DIFFL
R021	in contaminated zone soil	not used	2.000E-06	---	DIFCZ
R021	Radon vertical dimension of mixing (m)	not used	2.000E+00	---	HMIX
R021	Average building air exchange rate (1/hr)	not used	5.000E-01	---	REXG
R021	Height of the building (room) (m)	not used	2.500E+00	---	HRM
R021	Building interior area factor	not used	0.000E+00	---	FAI
R021	Building depth below ground surface (m)	not used	-1.000E+00	---	DMFL
R021	Emanating power of Rn-222 gas	not used	2.500E-01		EMANA(1)
R021	Emanating power of Rn-220 gas	not used	1.500E-01		EMANA(2)
TITL	Number of graphical time points	32			NPTS
TITL	Maximum number of integration points for dose	17			LYMAX
TITL	Maximum number of integration points for risk	257			KYMAX

Summary of Pathway Selections

Pathway	User Selection
1 -- external gamma	active
2 -- inhalation (w/o radon)	active
3 -- plant ingestion	active
4 -- meat ingestion	active
5 -- milk ingestion	active
6 -- aquatic foods	active
7 -- drinking water	active
8 -- soil ingestion	active
9 -- radon	suppressed
Find peak pathway doses	active

Contaminated Zone Dimensions		Initial Soil Concentrations, pCi/g	
Area:	43.00 square meters	Ra-228	1.000E+00
Thickness:	2.00 meters	Th-228	1.000E+00
Cover Depth:	0.00 meters	Th-232	1.000E+00

Total Dose TDOSE(t), mrem/yr
Basic Radiation Dose Limit = 2.500E+01 mrem/yr
Total Mixture Sum M(t) = Fraction of Basic Dose Limit Received at Time (t)

t (years):	0.000E+00	1.000E+00	3.000E+00	1.000E+01	3.000E+01	1.000E+02	3.000E+02	1.000E+03
TDOSE(t):	7.020E+00	7.011E+00	6.992E+00	6.937E+00	6.893E+00	6.887E+00	6.884E+00	6.870E+00
M(t):	2.808E-01	2.805E-01	2.797E-01	2.775E-01	2.757E-01	2.755E-01	2.753E-01	2.748E-01

Maximum TDOSE(t) 7.020E+00 mrem/yr at t = 0.000E+00 years

Total Dose Contributions TDOSE(i,p,t) for Individual Radionuclides (i) and Pathways (p)
As mrem/yr and Fraction of Total Dose At t = 0.000E+00 years

Water Independent Pathways (Inhalation excludes radon

Radio-Nuclide	Ground mrem/yr	Ground fract.	Inhalation mrem/yr	Inhalation fract.	Radon mrem/yr	Radon fract.	Plant mrem/yr	Plant fract.	Meat mrem/yr	Meat fract.	Milk mrem/yr	Milk fract.	Soi mrem/yr	Soi fract
Ra-228	2.999E+0(	0.4272	096E-03	0.0003	0.000E+00	0.0000	2.045E-01	0.0291	5.986E-04	0.0001	7.243E-04	.0001	742E-03	0.0002
Th-228	3.541E+0(	0.5045	044E-02	0.0015	0.000E+00	0.0000	2.537E-03	0.0004	5.216E-06	0.0000	3.721E-07	.0000	979E-04	0.0001
Th-232	1.718E-0:	0.0245	.927E-02	0.0084	0.000E+00	0.0000	2.203E-02	0.0031	4.780E-05	0.0000	3.814E-05	.0000	318E-03	0.0005
Total	6.712E+00	0.9561	7.181E-02	0.0102	0.000E+00	0.0000	2.290E-01	0.0326	6.516E-04	0.0001	7.628E-04	0.0001	5.858E-03	0.0008

Total Dose Contributions TDOSE(i,p,t) for Individual Radionuclides (i) and Pathways (p
As mrem/yr and Fraction of Total Dose At t = 0.000E+00 years

Water Dependent Pathways

Radio-Nuclide	Water mrem/yr	Water fract.	mrem/yr	fract.	Radon mrem/yr	Radon fract.	Plant mrem/yr	Plant fract.	Meat mrem/yr	Meat fract.	Milk mrem/yr	Milk fract.	All Pathways* mrem/yr	All Pathways* fract
Ra-228	000E+00	0.0000	000E+00	0.0000	0.000E+00	0.0000	0.000E+00	0.0000	0.000E+00	0.000C	0.000E+00	0.0000	3.208E+00	0.4570
Th-228	.000E+00	0.0000	.000E+00	0.0000	0.000E+00	0.0000	0.000E+00	0.0000	0.000E+00	0.0000	0.000E+00	0.0000	3.555E+00	0.5064
Th-232	.000E+00	0.0000	.000E+00	0.0000	0.000E+00	0.0000	0.000E+00	0.0000	0.000E+00	0.000(	0.000E+00	0.0000	2.565E-01	0.0365
Total	0.000E+00	0.0000	0.000E+00	0.0000	0.000E+00	0.0000	0.000E+00	0.0000	0.000E+00	0.0000	0.000E+00	0.0000	7.020E+00	1.0000

*Sum of all water independent and dependent pathways

Total Dose Contributions TDOSE(i,p,t) for Individual Radionuclides (i) and Pathways (p)
As mrem/yr and Fraction of Total Dose At t = 1.000E+00 years

Water Independent Pathways (Inhalation excludes radon)

Radio-	Ground		Inhalation		Radon		Plant		Meat		Milk		Soil	
Nuclide	mrem/yr	fract.	mrem/yr	fract.	mrem/yr	fract.	mrem/yr	fract.	mrem/yr	fract.	mrem/yr	fract.	mrem/yr	fract.
Ra-228	3.661E+00	0.5221	4.829E-03	0.0007	0.000E+00	0.0000	1.817E-01	0.0259	5.319E-04	0.0001	6.407E-04	0.0001	1.768E-03	0.0003
Th-228	2.465E+00	0.3516	7.269E-03	0.0010	0.000E+00	0.0000	1.766E-03	0.0003	3.631E-06	0.0000	2.590E-07	0.0000	5.554E-04	0.0001
Th-232	5.779E-01	0.0824	5.970E-02	0.0085	0.000E+00	0.0000	4.516E-02	0.0064	1.142E-04	0.0000	1.190E-04	0.0000	3.530E-03	0.0005
Total	6.704E+00	0.9561	7.180E-02	0.0102	0.000E+00	0.0000	2.286E-01	0.0326	6.498E-04	0.0001	7.600E-04	0.0001	5.853E-03	0.0008

Total Dose Contributions TDOSE(i,p,t) for Individual Radionuclides (i) and Pathways (p)
As mrem/yr and Fraction of Total Dose At t = 1.000E+00 years

Water Dependent Pathways

Radio-	Water				Radon		Plant		Meat		Milk		All Pathways*	
Nuclide	mrem/yr	fract.	mrem/yr	fract.	mrem/yr	fract.	mrem/yr	fract.	mrem/yr	fract.	mrem/yr	fract.	mrem/yr	fract.
Ra-228	0.000E+00	0.0000	0.000E+00	0.0000	0.000E+00	0.0000	0.000E+00	0.0000	0.000E+00	0.0000	0.000E+00	0.0000	3.850E+00	0.5492
Th-228	0.000E+00	0.0000	0.000E+00	0.0000	0.000E+00	0.0000	0.000E+00	0.0000	0.000E+00	0.0000	0.000E+00	0.0000	2.474E+00	0.3529
Th-232	0.000E+00	0.0000	0.000E+00	0.0000	0.000E+00	0.0000	0.000E+00	0.0000	0.000E+00	0.0000	0.000E+00	0.0000	6.865E-01	0.0979
Total	0.000E+00	0.0000	0.000E+00	0.0000	0.000E+00	0.0000	0.000E+00	0.0000	0.000E+00	0.0000	0.000E+00	0.0000	7.011E+00	1.0000

*Sum of all water independent and dependent pathways

Total Dose Contributions TDOSE(i,p,t) for Individual Radionuclides (i) and Pathways (p)
As mrem/yr and Fraction of Total Dose At t = 3.000E+00 years

Independent Pathways (Inhalation excludes radon

Radio-	Ground		Inhalation		Radon		Plant		Meat		Milk		Soil	
Nuclide	mrem/yr	fract.	mrem/yr	fract.	mrem/yr	fract.	mrem/yr	fract.	mrem/yr	fract.	mrem/yr	fract.	mrem/yr	fract.
Ra-228	3.973E+00	0.5682	7.050E-03	0.0010	0.000E+00	0.0000	1.429E-01	0.0204	4.176E-04	0.0001	5.012E-04	0.0001	1.633E-03	0.0002
Th-228	1.194E+00	0.1708	3.522E-03	0.0005	0.000E+00	0.0000	8.557E-04	0.0001	1.759E-06	0.0000	1.255E-07	0.0000	2.691E-04	0.0000
Th-232	1.518E+00	0.2171	6.120E-02	0.0088	0.000E+00	0.0000	8.411E-02	0.0120	2.282E-04	0.0000	2.559E-04	0.0000	3.944E-03	0.0006
Total	6.685E+00	0.9561	177E-02	0.0103	0.000E+00	0.0000	2.279E-01	0.0326	6.475E-04	0.0001	7.573E-04	0.0001	5.845E-03	0.0008

Total Dose Contributions TDOSE(i,p,t) for Individual Radionuclides (i) and Pathways (p)
As mrem/yr and Fraction of Total Dose At t = 3.000E+00 years

Water Dependent Pathways

Radio-	Water		Fish		Radon		Plant		Meat		Milk		All Pathways*	
Nuclide	mrem/yr	fract.	mrem/yr	fract.	mrem/yr	fract.	mrem/yr	fract.	mrem/yr	fract.	mrem/yr	fract.	mrem/yr	fract.
Ra-228	0.000E+00	0.0000	0.000E+00	0.0000	0.000E+00	0.0000	0.000E+00	0.0000	0.000E+00	0.0000	0.000E+00	0.0000	4.125E+00	0.5900
Th-228	0.000E+00	0.0000	0.000E+00	0.0000	0.000E+00	0.0000	0.000E+00	0.0000	0.000E+00	0.0000	0.000E+00	0.0000	1.199E+00	0.1715
Th-232	0.000E+00	0.0000	0.000E+00	0.0000	0.000E+00	0.0000	0.000E+00	0.0000	0.000E+00	0.0000	0.000E+00	0.0000	1.668E+00	0.2385
Total	0.000E+00	0.0000	0.000E+00	0.0000	0.000E+00	0.0000	0.000E+00	0.0000	0.000E+00	0.0000	0.000E+00	0.0000	6.992E+00	1.0000

*Sum of all water independent and dependent pathways.

Total Dose Contributions TDOSE(i,p,t) for Individual Radionuclides (i) and Pathways (p)
As mrem/yr and Fraction of Total Dose At t = 1.000E+01 years

Water Independent Pathways (Inhalation excludes radon)

Radio-			Inhalation		Radon		Plant		Meat		Milk		Soil	
Nuclide	mrem/yr	fract.	mrem/yr	fract.	mrem/yr	fract.	mrem/yr	fract.	mrem/yr	fract.	mrem/yr	fract.	mrem/yr	fract.
Ra-228	2.302E+00	0.3318	4.814E-03	0.0007	0.000E+00	0.0000	6.089E-02	0.0088	1.776E-04	0.0000	2.121E-04	0.0000	8.306E-04	0.0001
Th-228	9.454E-02	0.0136	2.788E-04	0.0000	0.000E+00	0.0000	6.774E-05	0.0000	1.393E-07	0.0000	9.935E-09	0.0000	2.130E-05	0.0000
Th-232	4.235E+00	0.6105	6.657E-02	0.0096	0.000E+00	0.0000	1.653E-01	0.0238	4.652E-04	0.0001	5.396E-04	0.0001	4.973E-03	0.0007
Total	6.631E+00	0.9560	7.166E-02	0.0103	0.000E+00	0.0000	2.263E-01	0.0326	6.429E-04	0.0001	7.517E-04	0.0001	5.825E-03	0.0008

Total Dose Contributions TDOSE(i,p,t) for Individual Radionuclides (i) and Pathways (p)
As mrem/yr and Fraction of Total Dose At t = 1.000E+01 years

Water Dependent Pathways

Radio-	Water		Fish		Radon		Plant		Meat		Milk		All Pathways*	
Nuclide	mrem/yr	fract.	mrem/yr	fract.	mrem/yr	fract.	mrem/yr	fract.	mrem/yr	fract.	mrem/yr	fract.	mrem/yr	fract.
Ra-228	0.000E+00	0.0000	0.000E+00	0.0000	0.000E+00	0.0000	0.000E+00	0.0000	0.000E+00	0.0000	0.000E+00	0.0000	2.369E+00	0.3415
Th-228	0.000E+00	0.0000	0.000E+00	0.0000	0.000E+00	0.0000	0.000E+00	0.0000	0.000E+00	0.0000	0.000E+00	0.0000	9.491E-02	0.0137
Th-232	0.000E+00	0.0000	0.000E+00	0.0000	0.000E+00	0.0000	0.000E+00	0.0000	0.000E+00	0.0000	0.000E+00	0.0000	4.473E+00	0.6448
Tota	000E+00	0.0000	0.000E+00	0.0000	0.000E+00	0.0000	0.000E+00	0.0000	0.000E+00	0.0000	0.000E+00	0.0000	6.937E+00	1.0000

*Sum of all water independent and dependent pathways

Total Dose Contributions TDOSE(i,p,t) for Individual Radionuclides (i) and Pathways (p)
As mrem/yr and Fraction of Total Dose At t = 3.000E+01 years

Water Independent Pathways (Inhalation excludes radon

Radio-	Ground		Inhalation		Radon		Plant		Meat		Milk		Soil	
Nuclide	mrem/yr	fract.	mrem/yr	fract.	mrem/yr	fract.	mrem/yr	fract.	mrem/yr	fract.	mrem/yr	fract.	mrem/yr	fract
Ra-228	2.091E-01	0.0303	4.478E-04	0.0001	0.000E+00	0.0000	5.219E-03	0.0008	1.521E-05	0.0000	1.815E-05	0.0000	7.381E-05	0.0000
Th-228	6.738E-05	0.0000	1.987E-07	0.0000	0.000E+00	0.0000	4.828E-08	0.0000	9.926E-11	0.0000	7.081E-12	0.0000	1.518E-08	0.0000
Th-232	6.380E+00	0.9256	7.112E-02	0.0103	0.000E+00	0.0000	2.200E-01	0.0319	6.245E-04	0.0001	7.297E-04	0.0001	5.736E-03	0.0008
Total	6.589E+00	0.9559	7.157E-02	0.0104	0.000E+00	0.0000	2.252E-01	0.0327	6.397E-04	0.0001	7.479E-04	0.0001	5.810E-03	0.0008

Total Dose Contributions TDOSE(i,p,t) for Individual Radionuclides (i) and Pathways (p)
As mrem/yr and Fraction of Total Dose At t = 3.000E+01 years

Water Dependent Pathways

Radio-	Water		Fish		Radon		Plant		Meat		Milk		All Pathways*	
Nuclide	mrem/yr	fract.	mrem/yr	fract.	mrem/yr	fract.	mrem/yr	fract.	mrem/yr	fract.	mrem/yr	fract.	mrem/yr	fract
Ra-228	0.000E+00	0.0000	0.000E+00	0.0000	0.000E+00	0.0000	0.000E+00	0.0000	0.000E+00	0.0000	0.000E+00	0.0000	2.149E-01	0.0312
Th-228	0.000E+00	0.0000	0.000E+00	0.0000	0.000E+00	0.0000	0.000E+00	0.0000	0.000E+00	0.0000	0.000E+00	0.0000	6.765E-05	0.0000
Th-232	0.000E+00	0.0000	0.000E+00	0.0000	0.000E+00	0.0000	0.000E+00	0.0000	0.000E+00	0.0000	0.000E+00	0.0000	6.678E+00	0.9688
Total	0.000E+00	0.0000	0.000E+00	0.0000	0.000E+00	0.0000	0.000E+00	0.0000	0.000E+00	0.0000	0.000E+00	0.0000	6.893E+00	0000

*Sum of all water independent and dependent pathways

Total Dose Contributions TDOSE(i,p,t) for Individual Radionuclides (i) and Pathways (p)
As mrem/yr and Fraction of Total Dose At t = 1.000E+02 years

Water Independent Pathways (Inhalation excludes radon)

Radio-Nuclide	Ground mrem/yr	Ground fract.	Inhalation mrem/yr	Inhalation fract.	Radon mrem/yr	Radon fract.	Plant mrem/yr	Plant fract.	Meat mrem/yr	Meat fract.	Milk mrem/yr	Milk fract.	Soil mrem/yr	Soil fract.
Ra-228	3.835E-05	0.0000	8.213E-08	0.0000	0.000E+00	0.0000	9.566E-07	0.0000	2.788E-09	0.0000	3.326E-09	0.0000	1.353E-08	0.0000
Th-228	6.514E-16	0.0000	1.921E-18	0.0000	0.000E+00	0.0000	4.667E-19	0.0000	9.595E-22	0.0000	6.845E-23	0.0000	1.468E-19	0.0000
Th-232	6.584E+00	0.9559	7.154E-02	0.0104	0.000E+00	0.0000	2.250E-01	0.0327	6.393E-04	0.0001	7.474E-04	0.0001	5.807E-03	0.0008
Total	6.584E+00	0.9559	7.154E-02	0.0104	0.000E+00	0.0000	2.250E-01	0.0327	6.393E-04	0.0001	7.474E-04	0.0001	5.807E-03	0.0008

Total Dose Contributions TDOSE(i,p,t) for Individual Radionuclides (i) and Pathways (p)
As mrem/yr and Fraction of Total Dose At t = 1.000E+02 years

Water Dependent Pathways

Radio-Nuclide	Water mrem/yr	Water fract.	Fish mrem/yr	Fish fract.	Radon mrem/yr	Radon fract.	Plant mrem/yr	Plant fract.	Meat mrem/yr	Meat fract.	Milk mrem/yr	Milk fract.	All Pathways* mrem/yr	All Pathways* fract.
Ra-228	0.000E+00	0.0000	0.000E+00	0.0000	0.000E+00	0.0000	0.000E+00	0.0000	0.000E+00	0.0000	0.000E+00	0.0000	3.940E-05	0.0000
Th-228	0.000E+00	0.0000	0.000E+00	0.0000	0.000E+00	0.0000	0.000E+00	0.0000	0.000E+00	0.0000	0.000E+00	0.0000	6.539E-16	0.0000
Th-232	0.000E+00	0.0000	0.000E+00	0.0000	0.000E+00	0.0000	0.000E+00	0.0000	0.000E+00	0.0000	0.000E+00	0.0000	6.887E+00	1.0000
Total	0.000E+00	0.0000	0.000E+00	0.0000	0.000E+00	0.0000	0.000E+00	0.0000	0.000E+00	0.0000	0.000E+00	0.0000	6.887E+00	1.0000

*Sum of all water independent and dependent pathways

Dose Contributions TDOSE(i,p,t) for Individual Radionuclides (i) and Pathways (p)
As mrem/yr and Fraction of Total Dose At t = 3.000E+02 years

Water Independent Pathways (Inhalation excludes radon)

Radio-	Ground		Inhalation		Radon		Plant		Meat		Milk		Soil	
Nuclide	mrem/yr	fract.	mrem/yr	fract.	mrem/yr	fract.	mrem/yr	fract.	mrem/yr	fract.	mrem/yr	fract.	mrem/yr	fract.
Ra-228	8.071E-16	0.0000	1.729E-18	0.0000	0.000E+00	0.0000	2.014E-17	0.0000	5.868E-20	0.0000	7.001E-20	0.0000	2.848E-19	0.0000
Th-228	0.000E+00	0.0000	0.000E+00	0.0000	0.000E+00	0.0000	0.000E+00	0.0000	0.000E+00	0.0000	0.000E+00	0.0000	0.000E+00	0.0000
Th-232	6.580E+00	0.9559	7.150E-02	0.0104	0.000E+00	0.0000	2.249E-01	0.0327	6.389E-04	0.0001	7.470E-04	0.0001	5.804E-03	0.0008
Total	6.580E+00	0.9559	7.150E-02	0.0104	0.000E+00	0.0000	2.249E-01	0.0327	6.389E-04	0.000	7.470E-04	0.0001	5.804E-03	0.0008

Dose Contributions TDOSE(i,p,t) for Individual Radionuclides (i) and Pathways (p)
As mrem/yr and Fraction of Total Dose At t = 3.000E+02 years

Water Dependent Pathways

Radio-	Water		Fish		Radon		Plant		Meat		Milk		All Pathways*	
Nuclide	mrem/yr	fract.	mrem/yr	fract.	mrem/yr	fract.	mrem/yr	fract.	mrem/yr	fract.	mrem/yr	fract.	mrem/yr	fract.
Ra-228	0.000E+00	0.0000	0.000E+00	0.0000	0.000E+00	0.0000	0.000E+00	0.0000	0.000E+00	0.0000	0.000E+00	0.0000	8.294E-16	0.0000
Th-228	0.000E+00	0.0000	0.000E+00	0.0000	0.000E+00	0.0000	0.000E+00	0.0000	0.000E+00	0.0000	0.000E+00	0.0000	0.000E+00	0.0000
Th-232	0.000E+00	0.0000	0.000E+00	0.0000	0.000E+00	0.0000	0.000E+00	0.0000	0.000E+00	0.0000	0.000E+00	0.0000	6.884E+00	1.0000
Total	0.000E+00	0.0000	0.000E+00	0.0000	0.000E+00	0.0000	0.000E+00	0.0000	0.000E+00	0.0000	0.000E+00	0.0000	6.884E+00	1.0000

*Sum of all water independent and dependent pathways

Summary : Great Lakes 43 sq meter area RESRAD Default Parameters for Th322
File GreatL3.RAD

Total Dose Contributions TDOSE(i,p,t) for Individual Radionuclides (i) and Pathways (p)
As mrem/yr and Fraction of Total Dose At t = 1.000E+03 years

Water Independent Pathways (Inhalation excludes radon

Radio-	Ground		Inhalation		Radon				Meat		Milk		Soil	
Nuclide	mrem/yr	fract.	mrem/yr	fract.	mrem/yr	fract.	mrem/yr	fract.	mrem/yr	fract.	mrem/yr	fract.	mrem/yr	fract.
Ra-228	0.000E+00	0.0000	0.000E+00	0.0000	0.000E+00	0.0000	0.000E+00	0.0000	0.000E+00	0.0000	0.000E+00	0.0000	0.000E+00	0.0000
Th-228	0.000E+00	0.0000	0.000E+00	0.0000	0.000E+00	0.0000	0.000E+00	0.0000	0.000E+00	0.0000	0.000E+00	0.0000	0.000E+00	0.0000
Th-232	6.567E+00	0.9559	7.137E-02	0.0104	0.000E+00	0.0000	2.245E-01	0.0327	6.377E-04	0.0001	7.455E-04	0.0001	5.793E-03	0.0008
Total	6.567E+00	0.9559	7.137E-02	0.0104	0.000E+00	0.0000	2.245E-01	0.0327	6.377E-04	0.0001	7.455E-04	0001	5.793E-03	0.0008

Tota[illegible] Contributions TDOSE(i,p,t) for Individual Radionuclides (i) and Pathways (p
As mrem/yr and Fraction of Total Dose At t = 1.000E+03 years

Water Dependent Pathways

Radio-	Water		Fish		Radon		Plant		Meat				All Pathways*	
	mrem/yr	fract	mrem/yr	fract	mrem/yr	fract	mrem/yr	fract	mrem/yr	fract	mrem/yr	fract	mrem/yr	fract
Ra-228	0.000E+00	0.0000	0.000E+00	0.0000	0.000E+00	0.0000	0.000E+00	0.0000	0.000E+00	0.0000	0.000E+00	0.0000	0.000E+00	0.0000
Th-228	0.000E+00	0.0000	0.000E+00	0.0000	0.000E+00	0.0000	0.000E+00	0.0000	0.000E+00	0.0000	0.000E+00	0.0000	0.000E+00	0.0000
Th-232	0.000E+00	0.0000	0.000E+00	0.0000	0.000E+00	0.0000	0.000E+00	0.0000	0.000E+00	0.0000	0.000E+00	0.0000	6.870E+00	1.0000
Total	0.000E+00	0.0000	0.000E+00	0.0000	0.000E+00	0.0000	0.000E+00	0.0000	0.000E+00	0.0000	0.000E+00	0.0000	6.870E+00	1

*Sum of all water independent and dependent pathways

Dose/Source Ratios Summed Over All Pathways
Parent and Progeny Principal Radionuclide Contributions Indicated

'arent (i)	Product (j)	Branch Fraction*	t= 0.000E+00	1.000E+00	3.000E+00	1.000E+01	3.000E+01	1.000E+02	3.000E+02	1.000E+03
Ra-228	Ra-22	1.000E+00	2.552E+00	2.257E+00	1.765E+00	7.465E-01	6.388E-02	1.171E-05	2.464E-18	0.000E+00
Ra-228	Th-22	1.000E+00	6.561E-01	1.593E+00	2.360E+00	1.622E+00	1.510E-01	2.769E-05	5.829E-16	0.000E+00
Ra-228	∑DSR(		3.208E+00	3.850E+00	4.125E+00	2.369E+00	2.149E-01	3.940E-05	8.294E-16	0.000E+00
Th-228	Th-228	1.000E+00	3.555E+00	2.474E+00	1.199E+00	9.491E-02	6.765E-05	6.539E-16	000E+00	0.000E+00
Th-232	Th-232	1.000E+00	7.287E-02	7.287E-02	7.287E-02	7.286E-02	7.286E-02	7.285E-02	7.280E-02	7.266E-02
Th-232	Ra-228	1.000E+00	1.562E-01	4.455E-01	9.279E-01	1.927E+00	2.596E+00	2.658E+00	2.657E+00	2.652E+00
Th-232	Th-228	1.000E+00	2.746E-02	1.681E-01	6.669E-01	2.473E+00	4.009E+00	4.156E+00	4.154E+00	4.146E+00
Th-232	∑DSR(j)		2.565E-01	6.865E-01	1.668E+00	4.473E+00	6.678E+00	6.887E+00	6.884E+00	6.870E+00

DSR(j,t) (mrem/yr)/(pCi/g)

*Branch Fraction is the cumulative factor for the j't principal radionuclide daughter CUMBRF(j) = BRF(1)*BRF(2)* BRF(j)
The DSR includes contributions from associated (half-life ≤ 0.5 yr) daughters.

Single Radionuclide Soil Guidelines G(i,t) in pCi/g
Basic Radiation Dose Limit = 2.500E+01 mrem/yr

Nuclide	0.000E+00	1.000E+00	3.000E+00	1.000E+01	3.000E+01	1.000E+02	3.000E+02	1.000E+03
Ra-228	7.793E+00	6.493E+00	6.060E+00	1.055E+01	1.163E+02	6.345E+05	*2.726E+14	*2.726E+14
Th-228	7.032E+00	1.010E+01	2.085E+01	2.634E+02	3.696E+05	*8.192E+14	*8.192E+14	*8.192E+14
Th-232	9.746E+01	3.641E+01	1.499E+01	5.589E+00	3.744E+00	3.630E+00	3.632E+00	3.639E+00

specific activity limit

Summed Dose/Source Ratios DSR(i,t) in (mrem/yr)/(pCi/g)
and Single Radionuclide Soil Guidelines G(i,t) in pCi/g
at tmin = time of minimum single radionuclide soil guideline
and at tmax = time of maximum total dose = 0.000E+00 years

Nuclide (i)	Initial (pCi/g)	tmin (years)	DSR(i,tmin)	G(i,tmin) (pCi/g)	DSR(i,tmax)	G(i,tmax) (pCi/g)
Ra-228	1.000E+00	2.562 ± 0.005	4.142E+00	6.036E+00	3.208E+00	7.793E+00
Th-228	1.000E+00	0.000E+00	3.555E+00	7.032E+00	3.555E+00	7.032E+00
Th-232	1.000E+00	88.9 ± 0.2	6.887E+00	3.630E+00	2.565E-01	9.746E+01

Individual Nuclide Dose Summed Over All Pathways
Parent Nuclide and Branch Fraction Indicated

Nuclide (j)	Parent (i)	BRF(i	DOSE(j,t), mrem/yr 000E+00	1.000E+00	3.000E+00	1.000E+01	3.000E+01	1.000E+02	3.000E+02	1.000E+03
Ra-228	Ra-228	1.000E+00	552E+00	2.257E+00	1.765E+00	7.465E-01	6.388E-02	1.171E-05	2.464E-16	0.000E+00
Ra-228	Th-232	1.000E+00	562E-01	4.455E-01	9.279E-01	1.927E+00	2.596E+00	2.658E+00	2.657E+00	2.652E+00
Ra-228	∑DOSE(j)		708E+00	2.702E+00	2.693E+00	2.673E+00	2.660E+00	2.658E+00	2.657E+00	2.652E+00
Th-228	Ra-228	1.000E+00	6.561E-01	1.593E+00	2.360E+00	1.622E+00	1.510E-01	2.769E-05	5.829E-16	0.000E+00
Th-228	Th-228	1.000E+00	3.555E+00	2.474E+00	1.199E+00	9.491E-02	6.765E-05	6.539E-16	0.000E+00	0.000E+00
Th-228	Th-232	1.000E+00	2.746E-02	1.681E-01	6.669E-01	2.473E+00	4.009E+00	4.156E+00	4.154E+00	4.146E+00
Th-228	∑DOSE(j)		4.239E+00	4.236E+00	4.226E+00	4.191E+00	4.160E+00	4.156E+00	4.154E+00	4.146E+00
	Th-23:	)00E+0	:87E-02	7.287E-02	287E-02	7.286E-02	7.286E-02	7.285E-02	:80E-02	:66E-0:

BRF(i is the branch fraction of the parent nuclide

Individual Nuclide Soil Concentration
Parent Nuclide and Branch Fraction Indicated

Nuclide	Parent	BRF(i)	S(j,t), pCi/g 000E+00	1.000E+00	3.000E+00	1.000E+01	3.000E+01	.000E+02	3.000E+02	.000E+03
Ra-228	Ra-22	1.000E+00	1.000E+00	8.843E-01	6.916E-01	2.925E-01	2.503E-02	4.588E-06	9.657E-17	0.000E+00
Ra-228	Th-23	1.000E+00	0.000E+00	1.134E-01	3.025E-01	6.938E-01	9.561E-01	9.804E-01	9.799E-01	9.780E-01
Ra-228	∑S(j)		1.000E+00	9.978E-01	9.940E-01	9.863E-01	9.811E-01	9.804E-01	9.799E-01	9.780E-01
Th-228	Ra-228	1.000E+00	0.000E+00	2.849E-01	5.363E-01	4.023E-01	3.785E-02	6.943E-06	1.461E-16	0.000E+00
Th-228	Th-228	1.000E+00	1.000E+00	6.961E-01	3.372E-01	2.670E-02	1.903E-05	1.839E-16	0.000E+00	0.000E+00
Th-228	Th-232	1.000E+00	0.000E+00	1.863E-02	1.240E-01	5.599E-01	9.435E-01	9.804E-01	9.799E-01	9.780E-01
Th-228	∑S(j):		1.000E+00	9.996E-01	9.976E-01	9.890E-01	9.814E-01	9.804E-01	9.799E-01	9.780E-01
Th-232	Th-232	1.000E+00	000E+00	1.000E+00	1.000E+00	1.000E+00	9.999E-01	9.997E-01	9.992E-01	9.972E·

BRF(i) is the branch fraction ›f the parent nucli

RESCALC.EXE execution time =   12 seconds