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August 13, 2007

Mr. Amir Kouhestani
U.S. Nuclear Regulatory Commission
Two White Flint North Building
11545 Rockville Pike
Rockville, MD 20852-2738

Re: Docket 40-06563
License Number STB-401
Unreacted Ore Removal from Plant 6W

Dear Mr. Kouhestani:

Hereby, Mallinckrodt is applying for amendment to its NRC license STB-401 to authorize excavation of unreacted C-T ore now buried within Plant 6 west on its St. Louis, Missouri downtown plant site and disposal at a suitable facility off-site. Being submitted herewith are a description of the actions to be taken, a radiological safety assessment, and an environmental report. Altogether, these documents demonstrate the safety of the action proposed and conformance with NRC regulations and with license STB-401.
Please contact me if you need any additional information.

Sincerely yours,

Karen Burke

Karen Burke
Director, Environmental Remediation

REQUEST FOR NRC LICENSE AMENDMENT TO REMOVE URO FROM PLANT 6W

NRC Docket 40-06563
NRC License STB-401

Mallinckrodt, Inc.
3600 North Second Street
St. Louis MO 63147

August 10, 2007

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1. SUMMARY OF PROPOSED ACTION

During 1972 and 1973, in conformance with 10 CFR 20.304, Mallinckrodt buried approximately 300 cubic yards of unreacted ore (URO) from its columbium and tantalum extraction operation (*i.e.*, C-T Operations) in steel drums in a series of trenches located in Plant 6 within its St. Louis plant, where Manhattan Engineering District - Atomic Energy Commission (MED-AEC) activities had previously occurred. Mallinckrodt proposes to remove unreacted ore from burial sites 1 through 9 and dispose of it at an acceptable off-site disposal facility in accordance with Federal and State regulations. This action will remove this source of radioactive material from the applicable site.

Successful management and implementation activities similar to URO removal and disposal and an acceptable facility off-site was demonstrated during C-T Phase I decommissioning. Mallinckrodt proposes to utilize approved controls to administer URO removal and disposition in a manner that protects remediation workers, members of the public, and the environment. Provisions specific to the URO remediation project are described herein.

2. GENERAL INFORMATION

2.1. LICENSE STB-401

The name of the licensee holding STB-401 is Mallinckrodt Inc., which has its principal offices at 675 McDonnell Blvd, St. Louis, MO 63042. The licensed facility is located at the St. Louis Plant, which is located at 3600 North Second Street, St. Louis, MO 63147.

2.2. HISTORY

2.2.1. C-T Operations and URO

Mallinckrodt processed columbite mineral ore and tin slag to extract columbium and tantalum (C-T). Mallinckrodt's C-T process generated an unreacted ore (URO) residue containing materials that were not dissolved during the C-T processing steps. Specific URO composition varied with raw material composition and process conditions. It contained some natural uranium, natural thorium, and their progeny in addition to non-radioactive constituents. In 1972 and 1973, approximately 300 cubic yards of URO was buried in conformance with 10 CFR 20.304 as approved by the Nuclear Regulatory Commission (NRC) in a series of trenches located in Plant 6, where MED-AEC activities had occurred. URO burial trenches were generally excavated to a depth of six feet. An approximate two-foot thick layer of URO in drums was placed in the trench and compacted. The trench was then backfilled with excavated soil and compacted. URO burial trench locations are identified in Figure 3-1. A finished goods warehouse, Building 101, was subsequently constructed above one of the trenches.

2.2.2. MED/AEC Operations

MED-AEC facilities in the area previously known as the Destrehan Street Plant were partially decommissioned in 1950 and 1951. Further decommissioning was performed in the early 1960's. This includes areas now known as Plants 6 and 7. Decommissioning activity included decontamination or demolition of buildings and removal of some soils and subsurface materials.

The Formerly Utilized Sites Remedial Action Program (FUSRAP) was created by the U.S. Congress to identify and control or remediate sites where residual radioactivity remains from activities conducted under contract to the MED and AEC during the early years of the nation's atomic energy program. Some facilities that produced radioactive materials for commercial sale are also included under FUSRAP at the direction of Congress.

The DOE, under the FUSRAP, had the initial responsibility for remediating radioactive and chemical contamination in the areas of the St. Louis Plant that formerly housed MED-AEC operations. However, in October 1997, Congress transferred the FUSRAP from DOE to the U.S. Army Corps of Engineers (USACE). Under FUSRAP, USACE is responsible for the cleanup of both radioactive and hazardous chemical contamination resulting from MED-AEC activities at the St. Louis Plant (SLDS) with oversight by the U. S. Environmental Protection Agency (EPA). These responsibilities are outlined in a Federal Facilities Agreement (FFA) negotiated by EPA Region VII and DOE[1]. The FFA has been amended to transfer these responsibilities to USACE. The FFA further defines the conditions dictated by the EPA to manage remediation at St. Louis. The document creates broad obligations for clean up of all residual waste from uranium processing, including such waste that might have mixed or commingled with other radioactive or hazardous material substance at the SLDS site.

The USACE is currently remediating soils containing subsurface residues of MED/AEC operations as part of the FUSRAP. Some buildings and adjacent open areas in Plants 6 and 7 were used to support C-T manufacturing following their decontamination and release to Mallinckrodt by the AEC in the early 1960s. Some buildings and areas in Plants 6 and 7 were used solely for MED-AEC operations. Soils in these areas contain residues from uranium refining and are therefore subject to remediation by USACE under FUSRAP. The USACE will remediate Plant 6 and 7 soils.

3. LOCATION

3.1. PHYSICAL BOUNDARIES

URO was buried in Plant 6W in ten excavated trenches whose locations are identified in Figure 3-1. Dimensions and volume of each burial zone are identified in Table 1. As physical confirmation occurs, actual volume may vary somewhat.

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1 Federal Facilities Agreement between US Department of Energy and US Environmental Protection Agency, June of 1990, Docket No. VII-90-F-0005.

Table 1. URO Burial Data

Burial Site ID Number	Burial Zone Dimensions Length (ft)	Width (ft)	Depth (ft)	URO Burial Zone Volume (ft^3)
1	29	10	2	580.
2	29	10	1.5	435.
3	29	10	1.5	435.
4	35	10	2	700.
5	35	26	1	910.
6	29	10	2	580.
7	30	10	2	600.
8	30	12	2	720.
9	32	14	2	896.
10[b]	100	10	2	2000.
			total =	7856. ft^3
			total =	291. yd^3

[a] ref. Figures 3-1 and 3-2.

[b] Burial 10 is not subject to this request for removal.

Each burial trench has about 3 to 4 feet of compacted soil cover. In addition, trenches 1 thru 9 are covered by 3 to 5 inches of asphalt while trench 10 is covered by 5 to 10 inches of concrete floor slab. The building with its floor slab atop it make URO buried in trench 10 inaccessible for excavation at this time. Consequently, URO trench10 is excluded from this source removal project.

3.2. DELINEATION WITH FUSRAP

URO buried in Plant 6W is in the middle of the former Destrehan Street Plant used for MED-AEC activities and therefore is subject to the FUSRAP. Mallinckrodt has worked cooperatively with the USACE to agree on delineation of a geographical boundary between buried URO and surrounding land within which Mallinckrodt would remove all material, including the URO. Mallinckrodt proposes the boundary to be that depicted in Figures 3-1 and 3-2, which includes the encompassing trenches 1 through 9 as well as additional soils around these trenches. By removing all material within a designated boundary, a maximum acceptable residual radioactivity concentration specification will not be needed. Removal to a geographical boundary may be verified by measurement of the excavation width and depth; thus a final radiation status survey will not necessary.

The USACE has accepted responsibility under the FUSRAP for management of impacted soils or remediation of impacted soils in Plant 6W outside the boundary within which Mallinckrodt will remove URO. Once Mallinckrodt has completed removal of all soils as depicted on Figures 3-1 and 3-2, the USACE will follow and remediate deeper soils which are beneath the footprint of C-T trenches 1 through 9 and will backfill the area upon completion of the remediation.

4. DESCRIPTION OF URO

URO buried in sites 1 through 9 originated from C-T processing during the first half of 1973 or earlier, excluding 1970 processing, while that buried in site 10 originated from C-T processing during 1970. Available records indicate the composition of ore processed during this time was as summarized in Table 2.

Table 2. Composition of C-T Ore

Year	tin slag to columbite input weight ratio	Weight Fraction in Each Ore		Weight Percent in Ore Composite		U to Th weight ratio
		U in columbite	Th in tin slag	U	Th	
1969	2.7	4.2E-04	5.8E-03	0.011	0.43	0.03
1970	2.7	8.2E-04	5.9E-03	0.022	0.43	0.05
1971	3.4	9.1E-04	5.1E-03	0.021	0.40	0.05
1972	3.7	6.3E-04	5.2E-03	0.013	0.41	0.03
Jan - May 1973					0.52	

Minor amounts of refractory minerals containing U and Th occur in these mineral ores. In tin slag, refractory material also results as molten tin slag cools.

The C-T URO buried in Plant 6W resulted from C-T feed material that was primarily tin slag with a lesser fraction of columbite ore. The tin slag and columbite ore were pulverized and leached with acid to dissolve the columbium and tantalum. After filtration, undissolved ore was neutralized, washed, and dewatered. Thus, URO is comprised of tin slag ore and columbite that did not dissolve by acid leaching. Uranium or thorium that might have dissolved in the C-T process would have reacted with hydrofluoric acid during ore digestion to form insoluble compounds UF_4 and ThF_4.[2]

Moisture content of URO was reported to be 39% at the time of burial. The URO was packaged in thirty-gallon steel drums before burial. Bulk density of the URO was reported to average 65 lb/ft^3.

The radioactivity concentration in URO is described in separate sources. Summary records of burial report the average thorium content in buried URO to have been 1.8 wt% Th.[3] Measurements by Mallinckrodt report columbite processed during December 1968 through April 1969 contained 0.15 wt% U. Tin slag processed during February and March 1969 contained

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[2] USNRC. *Environmental Impact Appraisal* for renewal of Source Material License No. SMB-920. Docket 40-6940. NUREG-1027. Nov. 1983.

[3] Brown George and Clifford Whithaus, "Record of Burial or Radioactive Materials," Mallinckrodt Chemical Works, for date of burial July 2 thru 16, 1973.

1.96 wt% Th.[4] Sources have identified concentrations as noted in Table 3. The best estimate is that URO contains about 1.8 wt% thorium and about 0.1 as much uranium, or about 0.15 wt% U.

Table 3. Radionuclide Concentration in Unreacted Ore

Data Source	U^{238} (pCi/g)	Th^{230} (pCi/g)	Ra^{226} (pCi/g)	Th^{232} (pCi/g)
ORNL composite CH 21[A]	620	na	590	1100
Tin Slag URO, 1969	na	na	na	2000
Columbite URO, 1969	500	na	na	< 18
NUS, 1980	2000	na	1500	460

na = not analyzed

[A] 1977 composite sample

5. ORGANIZATION AND ADMINISTRATION

5.1. Introduction

The URO remediation project will be administered in accordance with the provisions in this section. As the project progresses, changes to the project organization may be justified in response to the varying level of site activities. Effective with NRC approval of this license amendment, the licensee may make changes to the organizational structure provided that the safety and quality functions maintain an independent reporting relationship from that of operations, and that the persons responsible for safety functions satisfy educational and experience qualifications.

5.2. Management Organization[5]

5.2.1. Organization

Implementation of the URO removal project will be managed by a team comprised of management, radiation safety, and occupational safety personnel from the Mallinckrodt and contractor organizations. The URO project organization is illustrated in Figure 1.

While Mallinckrodt is responsible for ensuring overall successful implementation of the URO removal, it will contract the services of a remediation contractor to perform the tasks required by the license amendment.

The contractor will develop and/or implement the radiological safety, occupational safety, and environmental protection programs and the procedures required by this URO license amendment. The contractor will provide the equipment, materials, and a trained and experienced labor force to perform the URO removal activities. The contractor will also provide an independent quality assurance program as required by the URO project license amendment.

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4 Kuebler, J.R., Mallinckrodt. "Summary" memo. April 8, 1969

5 C-T Phase II DP, §9.1, Feb. 26, 2003.

Mallinckrodt will use consultants to assist in the management of the activity. These persons and/or organizations take their direction from the Mallinckrodt Project Manager and may interact directly with the contractor Project Manager and personnel at the request of the Mallinckrodt Project Manager.

Mallinckrodt managers responsible for site contract administration, quality assurance, project engineering, corporate environmental affairs, and legal will support the Mallinckrodt Project Manager. These support functions will be utilized as appropriate and are not identified on Figure 1.

The responsibilities of the primary managers with safety-related responsibilities are provided below.

5.2.2. Mallinckrodt URO Project Manager

The Mallinckrodt URO Project Manager/RSO will provide overall leadership and management of the URO removal project. He or she reports to a Vice President of the Company. The Site Safety Manager and project management and consultants will support the Project Manager.

The URO Project Manager/RSO is responsible for ensuring that the overall URO removal project, including the work performed by contractors and subcontractors, is accomplished in conformance with this license amendment and with applicable health, safety, quality, technical, and contractual requirements. The Mallinckrodt Project Support Engineer is responsible for assuring that NRC requirements are met. He or she also is responsible for coordinating activities between plant operations and the URO removal contractor. He or she will use other Mallinckrodt staff or consultants as appropriate to perform this coordination. The Project Manager/RSO has full authority to halt any operation that he or she believes has the potential to threaten the health and safety of site or contractor personnel, the public, or the environment, is not in conformance with License STB-401, or is otherwise not meeting NRC requirements. He or she is also responsible for ensuring that established environmental programs and contractor environmental programs are in compliance with applicable and relevant laws and regulations. The URO Project Manager is the designated contact with the NRC.

The Mallinckrodt URO Project Manager and Radiation Safety Officer (RSO), is also responsible for ensuring that radiation safety programs are in compliance with applicable and relevant laws and regulations and for auditing the contractor's compliance with these programs. The RSO reports to a Company Vice President.

5.2.3. Mallinckrodt HSE Manager

The Health, Safety, and Environment Manager (HSE Manager) is responsible for ensuring that the URO removal project occupational safety program is in conformance with applicable and relevant laws, regulations, and NRC requirements. He or she may also audit contractor performance to ensure compliance with this URO removal license amendment and other generally applicable requirements. The HSE Manager reports to the Plant Manager. The HSE Manager advises the Mallinckrodt URO Project Manager/RSO on matters pertaining to occupational safety. The HSE Manager has the authority to halt any operation that they believe has the potential to threaten the health and safety of personnel, the public, or the environment.

5.2.4. Contractor Project Manager

The contractor's Project Manager is responsible for the execution of all of the URO removal activities. He is the primary interface with the Mallinckrodt URO Project Manager/RSO. The contractor's Project Manager is directly responsible for all field work being performed by the contractor. As such, he is responsible for field work being conducted in accordance with applicable health, safety, quality, and technical requirements, including Mallinckrodt procedures. The contractor's Project Manager has full authority to halt any operation when he believes these requirements are not being met.

5.2.5. Contractor Radiation Safety Officer

The contractor Radiation Safety Officer (RSO) is responsible for implementation of safety and environmental protection, including radiation protection, environmental protection, and occupational health and safety in the URO removal project. The contractor RSO reports directly to the contractor Project Manager and is functionally independent of Operations, thus assuring independence of action in matters pertaining to radiation and environmental protection, health, and safety. The contractor RSO has the authority to halt any operation that they believe has the potential to threaten the health and safety of personnel, the public, or the environment.

5.2.6. Contractor Operations Manager

The contractor's Operations Manager reports directly to the contractor's Project Manager and receives program and task directives directly from the contractor's Project Manager. The contractor's Operations Manager is responsible for nuclear materials accounting, field engineering, waste management, daily work assignments for all field personnel and the physical execution of the field operational activities for the implementation of the URO removal project. The Operations Manager will ensure that all personnel are properly trained to perform assigned tasks and that the training is appropriately documented. The contractor Operations Manager has the direct responsibility to ensure that all field activity is protective of the health and safety of personnel, the public, and the environment and has the responsibility and authority to halt work in the event they are put at risk.

5.2.7. Contractor Quality Assurance Manager

The contractor's Quality Assurance representative is responsible for establishing and assuring implementation of the contractor quality assurance program, including periodic audits. This function is independent of Operations and will report directly to the Mallinckrodt URO Project Manager/RSO with copies of audits provided to the contractor's Project Manager.

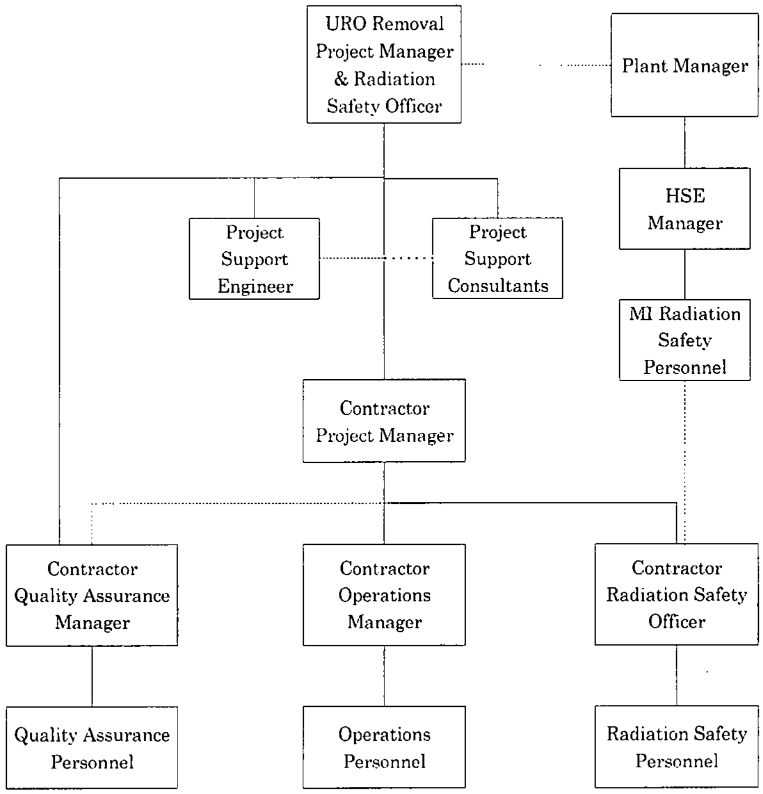

Figure 1. URO Removal Project Organization

Work Controls[6]

Remediation activities for the URO removal project will be performed in accordance with written instructions. There will be four general types of written instructions in use for the URO Project: Plans, Procedures, Field Instructions, Safety Permits (Safety Work Permits, Radiation Work Permits, Hot Work Permits, *etc.*). These written instructions will be reviewed and approved by the contractor operations representative and the RSO, as well as being reviewed and approved by the Mallinckrodt Project Manager/ROS or his or her designated representative where applicable, *e.g.*, when health, safety, and quality of the URO removal issues are addressed.

> **Plans** are broad-based documents that provide management guidance for operations in the field. Plans include URO removal contractor developed plans such as a Health and Safety Plan, Waste Management Plan, Quality Assurance Plan, and the Industrial Safety Plan. All plans affecting the health, safety, and quality of the URO removal will be reviewed by Mallinckrodt. Specific procedures, field instructions, and radiation work permits, as discussed below implement these programs and plans.

[6] C-T Phase I DP, §2.4.4, July 30, 2002.

Procedures are essential, written instructions and specifications to provide the controls needed to ensure safety and other objectives of the procedure are achieved. A procedure is ordinarily appropriate for repetitive activities such as defining how to operate equipment, calibration methods, or other routine work activities.

Field Instructions are the primary written instructions for remediation work for the URO removal project. They may be as short as a simple job order (e.g. run temporary electricity into Building XX), or as detailed as necessary to safely accomplish the work. The detailed field instructions provide specific instructions in a logical and sequenced manner for one-time or short duration activities requiring a disciplined approach to ensure that health and safety requirements are met.

Safety Work Permits (SWP), or Radiation Work Permits (RWP), specify necessary industrial and radiation safety controls, including personnel monitoring, monitoring devices, protective clothing, respiratory protection equipment, special air sampling, and additional precautionary measures. SWP or RWP are issued for non-routine activities where there is a need to prescribe the conditions under which the work may be done in order to assure adequate protection of workers and the public from the potential hazards that may be encountered. SWP required for remediation activities are usually identified during the preparation and review of procedures and field instructions. SWP or RQP will be prepared in accordance with the contractors written procedure that will be reviewed by Mallinckrodt.

Daily Safety Permits check for hazardous conditions, allow use of spark-generating tools and equipment, ensure adequate ventilation, *etc.*

Mallinckrodt will implement administrative controls that establish guidelines for creation, use, and control of these administrative documents to ensure that URO removal is performed safely, and in conformance with governing regulations, and the NRC license. It will also implement a procedure to manage URO removal records.

5.3. ADJUSTMENTS TO THE ADMINISTRATIVE PROCESS[7]

URO source removal is intended to remove radioactive sources, thereby diminishing the extent of controls needed to assure protection of health, safety, and the environment as it progresses. Mallinckrodt may make justified changes related to the URO removal process without filing an application for an amendment to the license to change the URO removal project when the following conditions are satisfied:

a. the change does not conflict with requirements specifically stated in license STB-401 or impair Mallinckrodt's ability to meet all applicable NRC regulations;
b. there is no degradation in safety or environmental commitments addressed in the NRC-approved license amendment for the activity being performed;

[7] C-T Phase I DP §2.6, Jan. 9, 2002

c. the quality of the work, the remediation objectives, or health and safety will not be adversely affected significantly;
d. the change is consistent with the conclusions of actions analyzed in the Environmental Report;
e. does not result in there no longer being reasonable assurance that adequate funds will be available for URO removal; and
f. does not reduce the coverage requirements for scan measurements and/or sample density.

Persons having managerial responsibilities as identified in Section 5.2, including proponents of controlled documents, will be asked to report any change to the URO removal process that would seem to violate either of conditions a through f. Determination of whether the conditions are met will be made by and each change shall require approval by Mallinckrodt's URO Project Manager/RSO, the contractor's Project Manager, and the contractor's RSO. The contractor's and Mallinckrodt's URO Project Managers are responsible for ensuring that the project is in accordance with applicable health, safety, quality, and technical requirements. Mallinckrodt's URO Project Manager/RSO shall be responsible for approval of operational and engineering changes. The contractor's RSO and Mallinckrodt's Radiation Safety Officer are responsible for assuring that each change conforms to health and safety program requirements.

Mallinckrodt shall retain records including written safety and environmental evaluations of each authorized change that provide the basis for determining that conditions in this 5.3 have been met. The records of each evaluation shall be retained until license termination.

5.4. CONTRACTOR

Mallinckrodt will select an experienced and qualified contractor to perform the URO removal. By letter to the NRC, Mallinckrodt will identify persons occupying positions in the organization named herein, their experience, and qualifications.

5.5. PROPOSED SCHEDULE

Mallinckrodt intends to have its contractor begin the URO removal project as soon as reasonable after NRC approval of this application for license amendment. Due to the coordination with the US Corps of Engineers under the delineation agreement concerning Plant 6W, the URO removal will have to be performed in phases. In general, this means that URO removal activities will be conducted alternately with FUSRAP activities. Mallinckrodt expects it will complete the overall URO removal within 12 months after NRC approval to do the project.

6. HEALTH AND SAFETY

A Health and Safety Program for the URO removal Project will be developed to ensure the safety of all contractors and Mallinckrodt employees, visitors, and members of the public during URO removal. This section describes the measures to protect workers, the public, and the environment during remediation. In recognition that both the amount of radioactivity and the general safety hazards will be reduced as the project progresses, the Health and Safety Program may be modified to be commensurate with the activities being performed. Mallinckrodt will review and approve the Health and Safety Program, and any revisions that are made during the project. Any such adjustment to the requirements of this health and safety program shall be made in accordance with §5.4 herein.

The Health and Safety Program will consist of the following three parts:

- Industrial Safety Program
- Radiation Protection Program
- Environmental Protection Program

6.1. Industrial Safety Program

Industrial safety provisions have been adopted for the URO removal project that augment Mallinckrodt Health, Safety and Environmental Guidelines by adding procedures specific to URO removal when needed. The procedures and administration form the Industrial Safety Program for URO removal. Provisions of the industrial safety program that apply to the URO remediation project are described herein. The total package of procedures and administration will then form the Industrial Safety Program for the URO Project. Table 6-1 lists typical industrial safety procedures that will be used for the planned remediation activities.

Table 6-1

Industrial Safety Procedures
Accident Investigation, Reporting, and Recordkeeping
Safety Color Code for Marking Physical Hazards
Working with Hazardous Chemicals
Welding and Thermal Cutting
Posting Requirements
Safety Training
Selection and Use of Personal Protective Equipment
Aerial Work Platforms
Scaffolds
Housekeeping
Equipment Lockout/Tagout
Operation of Lifting and Handling Equipment
Hand and Portable Power Tools
Electrical
Fall Protection
Guarding Floor Holes and Openings, Wall Holes and Openings
Fire Protection Program
Permit-Required Confined Space Entry Program
Excavation, Trenching, and Shoring
Drum Handling Procedure
Operation of Motorized Vehicles and Mechanized Equipment
Handling, Use, and Storage of Compressed Gas Cylinders
Hot Work
Heat Stress Program

6.1.1. Industrial Safety Training

The St. Louis Plant site-wide industrial safety program or contractor equivalent will be used for training all unescorted individuals involved in activities at the URO project. The purpose of the program is to promote an awareness of the potential risks, and to provide knowledge and proficiency in industrial safety consistent with the assigned tasks. Training takes place on a continuing basis.

Personnel involved in the URO Project will be trained to perform their assigned responsibilities safely. On-the-job training and equipment-specific training will supplement the Mallinckrodt site-wide training program. Training in the proper use of specialized equipment is given before the individual uses that equipment. Credit may be given for applicable training received off-site.

The primary objectives of the industrial safety training program for the URO Project:

- provide information on the industrial safety and hygiene hazards associated with working at the URO Project, and the steps to be taken to provide a safe work environment including those hazards unique to building demolition;
- enable each person to comply with plant rules and respond properly to warnings and alarms under normal and accidental conditions; and,
- enable individuals to recognize potential site specific hazards and to take appropriate measures to prevent personal injury or damage to facilities and equipment

The industrial safety training program will be reviewed and revised as needed to meet changing conditions and ensure that instructions are sufficiently well understood to permit practical application. The status and extent of the training of each individual will be documented to verify that workers are adequately trained for each assigned job.

The industrial safety training program includes:

- weekly shop-talks on pertinent industrial safety information, injury statistics, and specific safety issues;
- specific training on specialized equipment including the use of cranes, forklift trucks, front-end loaders, and scissors lifts;
- general industrial safety training including proper lifting, hearing conservation, eye protection, slips and falls, hazardous material handling, and use of power tools; and,
- specialized training including first aid, CPR, fire fighting, use of respirators, and HAZWOPER.
- safety work permits addressing confined space entry, asbestos removal, lock-out/tag-out, *etc.*

6.2. RADIATION PROTECTION PROGRAM

Provisions to ensure radiation safety that are proposed to apply to the URO remediation project are described herein. The provisions of the program were previously approved by NRC staff,[8] have been exercised, and are implemented by Mallinckrodt procedures.

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[8] CT Phase I DP, §3.3, Jan. 9, 2002

6.2.1. Radiation Protection

The Radiation Protection Program will consist of procedures to protect workers, the public, and the environment from ionizing radiation.

A radiation protection program will be adopted for the URO Project that addresses the following topics. The contractor will be required to implement the program with oversight by the Site RSO.

- health and safety protection measures and policies
- instrumentation, calibration, and equipment
- use of air samplers, monitoring policy methods, frequency, and procedures
- contamination control and personnel decontamination
- external exposure control
- airborne releases and monitoring
- Safety Work Permits, including ALARA
- engineering controls
- transportation
- accident response
- posting and labeling
- records and reports
- potential sources of contamination exposure

An analysis of potential radiological dose during occupational work is presented in Appendix 1.

6.2.2. Radiation Safety Training

All unescorted individuals involved in activities on-site for the URO Project will be required to complete the Mallinckrodt radiation safety training course or the contractor equivalent course. The purpose of the training is to increase awareness of the potential radiation risks during URO removal, and to provide a level of proficiency in personal radiation protective measures consistent with assigned tasks. On-the-job training, as deemed necessary by the contractor RSO, will be used to complement the formal radiation safety training.

All individuals will be trained before entering a controlled area to perform work and workers will be retrained every year. Credit may be given for applicable training received off-site, but plant-specific training is required for all URO removal personnel. Training and examination results will be formally documented.

A primary objective of the radiation safety training program is to comply with the instruction requirements of 10 CFR 19.

The radiation safety training will be reviewed and revised as appropriate to meet changing conditions and ensure that instructions are sufficiently well understood to permit practical application.

The radiation safety training program includes the following topics:

- radiation fundamentals - basic characteristics of radiation and contamination
- radiation exposure limits, administrative control levels, and controls - external radiation exposure control methods, procedures, and equipment

- radiation contamination limits and controls - contamination and internal radiation exposure control methods, procedures, and equipment
- contaminated materials associated with URO removal work - potential radiological problems
- radiological work planning - integrating radiation safety and operational requirements to ensure safe conduct of work
- emergency procedures and systems - work related information and actions
- biological effects of radiation - basic understanding of biological effects and methods of assessment
- the Radiation Protection Program
- workers rights and responsibilities
- radiation exposure reports which workers may request pursuant to 10 CFR 19.13
- ALARA

6.2.3. Radiation Protection Instrumentation

Instrumentation utilized for personnel monitoring will be calibrated and maintained in accordance with radiation safety procedures. These procedures utilize the manufacturers calibration guidance. Portable instruments are calibrated on a semi-annual basis or as required due to maintenance. Specific requirements for instrumentation include traceability to NIST or other recognized standards, field checks for operability, background radioactivity checks, operation of instruments within established environmental bounds (*i.e.*, temperature and pressure), training of individuals, scheduled performance checks, calibration with isotopes with energies similar to those to be measured, quality assurance tests, data review, and record keeping. Where applicable, activities of sources utilized for calibration are also corrected for decay. All calibration and source check records are completed, reviewed, signed off and retained in accordance with Quality Assurance Program requirements. A list of typical radiation instrumentation and minimum detectable activities (MDA) is given in Table 6-2. Typical personnel monitoring equipment is shown in Table 6-3. In the event an instrument of the type listed in Table 6-2 is employed on URO removal, its background count rate or exposure rate and its lower limit of detection will be estimated for its application.

In the event alternative radiation survey instrumentation is employed, it will be selected to meet the functional objectives tabulated in this §6.2.3. Alternative instrumentation must also be able to measure adequately to assess compliance with radiological protection requirements.

Table 6-2
Typical Instruments for Performing Radiation Protection Surveys

Instrument Type	Radiation Detected	Scale Range	BKG	Typical MDA 95% confidence Level
Scintillation (Ludlum 2224) Scaler/Ratemeter with 43-89 probe	Alpha Beta Beta	0-500,000 cpm	<10 cpm <300 cpm	100 dpm/100 cm^2 500 dpm/100 cm^2 4500 dpm/100 cm^2 (scan)
Micro-R Meter (Ludlum) 1" x 1" NaI Detector	Gamma	0-3,000 μR/h or 0-5,000 μR/h	7 μR/h	1-2 μR/h
Ion Chamber (Victoreen)	Gamma	0.1-300 mR/h	<0.1 mR/h	<0.2 mR/h
3" x ½" NaI Scintillation Detector Digital Scaler	Gamma	0-500,000 cpm	3,000 cpm avg shielded 9,000 cpm avg unshielded	250 cpm 500 cpm

435 cm^2 gas flow (43-27) Digital Scaler	Alpha	0-500,000 cpm	<10 cpm	20 dpm/100 cm^2
100 cm^2 gas flow (43-68) Digital Scaler	Alpha Beta Beta	0-500,000 cpm	<10 cpm <300 cpm	100 dpm/100 cm^2 500 dpm/100 cm^2 4500 dpm/100 cm^2 (scan)
60 cm^2 gas flow (43-4) Digital Scaler	Alpha	0-500,000 cpm	<10 cpm	200 dpm/100 cm^2
60 cm^2 Count Rate Meter (PRM-6)	Alpha	0-500,000 cpm	<100 cpm	350 dpm/100 cm^2
50 cm^2 Personnel Room Monitor (Ludlum 177)	Alpha	0-500,000 cpm	<100 cpm	500 dpm/100 cm^2
Ludlum 2" GM Tube (Pancake)	Beta Gamma	0-500,000 cpm 720 cpm = 0.2 mR/h	<200 cpm	70 cpm
Bicron AB-100 Scintillation Probe	Beta	0-500,000 cpm	<200 cpm	200 dpm/100 cm^2

Notes:

1) Instrument MDAs are based upon static measurements, one minute count times unless otherwise noted.
2) Instrument MDAs depend upon background.

Table 6-3
Typical Equipment for Performing Personnel Monitoring

Equipment Description	Purpose
Personal Air Samplers (BZ) Gillian or equivalent	Breathing zone air monitoring
Area Air Samplers SAIC or equiv.	High volume air monitoring
Area Air Samplers SAIC or equiv.	Work area low volume air monitoring
Personnel Dosimetry TLD, OSL, or equiv.	Deep dose, eye dose, skin dose
Alpha Frisker Ludlum 43-68 or equiv.	Contamination monitoring
Alpha Frisker Ludlum 177	Contamination monitoring
Beta Frisker Bicron AB100	Contamination monitoring
Micro-R meter Ludlum or equiv.	Exposure rate
Ion Chamber	Dose rate

6.2.4. ALARA

An objective of radiation protection during URO removal is to achieve as low as reasonable exposure to regulated radioactive material and radiation from it. The most effective emphasis will be to consider during preparation of each radiation safety work permit whether any particular action and or engineered control beyond good health physics practice would be reasonable to specify to try to reduce exposure.

6.2.5. Survey And Release Criteria For Equipment[9, 10]

Although Mallinckrodt prefers to dispose of contaminated equipment when it is cost-effective, equipment that is to be released without restriction on use will be subject to NRC "Guidelines for Decontamination of Facilities and Equipment Prior to Release for Unrestricted Use or Termination of Licenses for Byproduct, Source, or Special Nuclear Material," as specified in Materials License STB-401, condition 16. Table 6-4 lists equipment surface release limits for the uranium series and thorium series distributions representative of C-T URO. The composite maximum acceptable average areal density ($MAAAD_{\alpha}$) for equipment, 2400 dpmα/100 cm^2 is derived by the sum-of-fractions method. A composite MAAADα = 2400 αdpm/100 cm^2 applies to surfaces of all URO affected equipment surveyed for unrestricted release.

Table 6-4
Equipment Surface Release Limits

Equipment Location	Average[a] (dpmα/100 cm^2)	Maximum (dpmα/100 cm^2)	Removable (dpmα/100 cm^2)
Any	2400	7200	500

[a] Basis is average of 69 derivations based on 69 C-T samples. U series -to- Th series ratio averaged 2 -to- 1.[11]

6.3. ENVIRONMENTAL PROTECTION PROGRAM

An environmental protection program has been developed as needed to monitor air and water effluents discharged from the URO removal project.[12] Those provisions, described herein, shall apply to the URO removal project.

In recognition that both the amount of radioactivity and the general environmental hazards may be reduced as URO remediation progresses, the Environmental Protection Program may be modified to be commensurate with the activities being performed.

9 C-T Phase I DP, §2.2.2.
10 Examples of *equipment* are described in CT Phase I DP, section 4.4.1.1.
11 C-T Phase I DP, Appendix D
12 C-T Phase I DP, §3.4, Jan 9, 2002.

6.3.1. The Program

An Environmental Safety Program will be developed and implemented as required to monitor air and water effluents discharged from the C-T URO removal project. During URO-soil handling, samples will be routinely collected or measurements routinely made at on-site and site boundary or off-site locations to determine the extent of environmental discharges during remediation. Monitoring locations will be chosen commensurate with remediation activities.

In recognition that both the amount of radioactivity and the general environmental hazards will be reduced as URO removal progresses, the Environmental Safety Program may be modified to be commensurate with the activities being performed by following the criteria described in Section 5.3.

6.3.2. Environmental Air Monitoring

Environmental sampling stations will be provided during remediation or decontamination activities as required by 10 CFR Part 20 (Appendix B limits) to verify there are no adverse impacts to on-site workers and the public. Each environmental sampling station will be equipped with an air sampler.

Collection and analysis of the continuous air samples will be performed during remediation or decontamination activities as required by 10 CFR Part 20. The samples will be analyzed for gross alpha and gross beta activity to interpret the uranium and thorium series. The analytical instruments will be calibrated using standards traceable to the National Institute of Science & Technology (NIST) or other recognized standards.

6.3.3. Liquid Effluent Monitoring

It will be the policy of Mallinckrodt during the URO Project to minimize the production of contaminated aqueous liquids. There are four possible sources of contaminated aqueous liquids: water collection in an excavation pit, sink and shower water, decontamination fluids, and water used for dust suppression. Mallinckrodt expects sink and shower water to contain insignificant amount of regulated radioactive material in readily dispersible biological material, and thereby may be discharged to sanitary sewerage in accordance with 10 CFR Part 20.2003 without monitoring. Should rain water or surface water be collected, it will ordinarily be used for dust suppression of solid waste destined for NRC-approved disposal. In the event other aqueous waste potentially containing significant concentration of regulated radioactive material were considered for discharge to sewerage, Mallinckrodt would, beforehand, filter it to remove non-dispersible solids, sample and analyze it, estimate the concentration in sewage, compare it with the 10 CFR Part 20, Appendix B, Table 3, monthly average concentration limit, and estimate the total radioactivity inventory discharged.

6.3.4. Direct Radiation Monitoring

The environmental safety program is designed to assure that direct radiation in unrestricted areas does not exceed limits in 10 CFR 20.1301. The objective of direct radiation monitoring is to verify the effectiveness of the environmental safety program in meeting the limits.

The monitoring of penetrating radiation will be performed using standard environmental thermoluminescent dosimeters that are placed at various locations around the perimeter of the restricted remediation area. These dosimeters will be collected by Health and Safety personnel and analyzed quarterly by a qualified contract vendor to measure the integrated gamma dose for each location.

6.3.5. Action Levels

The following action levels will be established in procedures to aid in compliance with environmental safety regulations in 10 CFR 20.

Medium	Action Level (fraction of limit)	Regulation 10 CFR 20
Environmental air	≤ 0.75	App. B, Table 2, col 1
Effluent water	≤ 0.6	App. B, Table 2, col 2
Sewage	≤ 0.6	App. B, Table 3
Gamma radiation	≤ 0.5	Part 20.1301(a)(1)
Gamma radiation	≤ 0.5	Part 20.1301(a)(2)

If an action level is exceeded, the Mallinckrodt RSO and the contractor RSO will be notified and corrective action will be implemented as appropriate. Investigation may include additional measurements or analysis to assess compliance with the regulation and to ensure that the total radiological dose from inhalation and irradiation by external gamma-rays does not exceed 100 mrem/yr with emphasis to attain levels as low as reasonably achievable.

7. REMOVAL ACTION

7.1. REMEDIATION CRITERIA

URO buried in Plant 6W is surrounded by land that is subject to the FUSRAP. Mallinckrodt has cooperated with the USACE to agree on delineation of a geographical boundary between buried URO, within which Mallinckrodt would remove all material, including the URO, and surrounding land. Mallinckrodt proposes the boundary to be that depicted in Figures 3-1 and 3-2 enclosing URO. By removing all material within a designated boundary, a maximum acceptable residual radioactivity concentration specification will not be needed. The USACE has accepted responsibility for remediation under the FUSRAP outside the boundary within which Mallinckrodt will remove URO.

The estimated volume of URO to be removed is 5856 ft^3 = 217 yd^3 (ref. Table 1 without URO site 10). Within the geographical boundaries described in Figures 3-1 and 3-2, an additional 2340 cubic yards of soil (ref. Table 4) is estimated to be subject to removal by Mallinckrodt in accordance with the delineation agreement between Mallinckrodt and the USACE. This additional excavation will includes soil buried the buried URO and will include soil excavated to accommodate sloping excavation side walls.

7.2. Source Removal Tasks

Utility lines, including water, electricity, gas, *etc*., within the excavation boundary will be located and marked prior to initiation of remediation activities and will be relocated as necessary to perform this work.

Macadam pavement atop URO burials 1 through 9 will be removed. Next the soil covering the buried URO will be removed by excavation. URO contents will be removed and transported to the rail loading facility in Plant 6W.

A finished goods warehouse, Building 101, including a concrete floor slab, was constructed above burial number 10. URO in Burial 10 is unavailable until such time as absence of use of Building 101 allows access to the URO beneath it.

Extent of the removal of URO is to be verified by visual inspection. Trench cover will be distinguished from buried URO by visual inspection And engineering measurements compared with original CT URO plot plan drawings. Excavated material may be segregated or mixed as a function of radioactivity concentration by radioactivity measurement in order to manage disposal options. URO contents will be transported to the rail loading facility on site for loading into a shipping container for transport.

Sloping, benching, and or shoring techniques may be utilized as the excavation depth is increased. It is prudent to plan for the prospect of excavating some soil beyond the boundaries of buried URO itself. The extent of removal will be in accordance with agreed dimensions and will be verified by visual inspection. Allowing for excavation of one foot beyond the boundaries of the buried URO and for a side wall slope factor results in a contingent estimated volume of URO, intermingled fill, and adjacent soil that is tabulated in Table 4. Some additional excavation may be necessary to enable USACE access.

As soon as reasonable after URO is removed, Mallinckrodt will notify the USACE and the USACE will be admitted to areas affected in order to remediate residual MED-AEC material. In the event of unanticipated delay by USACE in assuming access, excavation(s) would be lined with sheeting and backfill would be specified to ensure no subsidence.

7.3. Radiation Protection Specific to URO Removal

Personnel accessing the site to work on this project shall receive Mallinckrodt Site Orientation and Safety Training.

Radioactivity concentration in URO is expected to be greater than encountered during C-T Phase I decommissioning. While URO is being excavated and handled, monitoring and control of potential worker exposure via inhalation and direct irradiation will be emphasized. Workplace air will be sampled for airborne particulate to evaluate potential inhalation exposure to remediation workers. Gamma radiation emitted by URO will be measured by a dosimeter on each worker and by area radiation survey.

7.4. Procedures

Applicable procedures already developed may be used to implement the URO removal project. Procedures will be revised and or supplemented as needed to apply to URO removal and disposition. Mallinckrodt will ensure that all procedures are protective of human health and the environment and are in accordance with applicable regulatory requirements.

8. WASTE MANAGEMENT

8.1. Overview

Radioactive waste from the URO removal project will be managed in accordance with the requirements of this URO Waste Management Plan. This plan ensures that radioactive waste from the URO removal project will be handled, stored and disposed of in a manner protective of human health and the environment and in accordance with applicable regulatory requirements.

8.1.1. Overview

Preliminary planning envisions excavation of the URO burials in a phased approach to coordinate requirements of the USACE for the FUSRAP area encompassing URO burials 1 through 6 and shipping the URO-soil will be performed first. Afterward, areas encompassing 7 and 8 and area 9 would be excavated and the URO-soil shipped. Mallinckrodt proposes to:

1. delinate excavation boundaries in accordance with the URO engineering plot plan and the Mallinckrodt-USACE delineation agreement;
2. excavate open-pit by conventional bucket excavator;
3. transport excavated URO and soil to the rail loading facility on-site (also used by the USACE for MED-AEC waste);
4. Manage disposal options by recombining or mixing excavated URO-soil if needed for the purpose of managing the radioactivity concentration in shipment to meet waste acceptance criteria of a disposal facility off-site;
5. load URO and or soil into gondola-type rail cars, intermodal containers for rail shipment, or highway trailers to be delivered to a carrier for transport to an appropriate disposal facility off-site acceptable to the NRC and State in which it is located; and
6. comply with specifications for delivery to a carrier and to the recipient waste disposal facility.

8.1.2. Regulatory Requirements

Processing and disposal of radioactive waste will be performed in accordance with the relevant requirements of 10 CFR 20, 10 CFR 40, 10 CFR 71, DOT regulations, and 49 CFR 172-178 and the applicable disposal site waste acceptance criteria.

Non-impacted wastes that are indistinguishable from background radioactivity will be managed in accordance with applicable State and Federal solid and/or hazardous material requirements as appropriate. *Mixed waste*, if any, will also be managed in conformance with State and Federal hazardous waste regulations.

Subject to coordination with the USACE, Mallinckrodt may either 1) leave excavations without filling or restoration and agree to immediate access by the USACE in order to facilitate USACE remediation of land beyond the boundary, or else 2) backfill with earth to prevent subsidence.

8.2. WASTE DESCRIPTION

Solid Waste. URO removal activity will generate two general categories of solid waste: debris of pavement and subsurface material. Pavement includes macadam and concrete pavement removed to access subsurface materials. Subsurface materials will include URO and adjacent cinder-fill soil. In this discussion, subsurface material will generally be referred to as "soil" or solid waste.

Radioactive Waste. URO radioactive waste contains natural uranium series and thorium series radionuclides. It will not contain any of the radionuclides listed in Tables 1 or 2 of 10 CFR 61.55, except those present in background due to atmospheric fallout. All URO radioactive waste will therefore be Class A.

Radioactive waste to be managed during URO remediation includes URO, intermingled soil, and adjacent soil or cinder fill excavated during URO removal. Solid waste would also include bulk material used during remediation and discarded. Allowing for excavation of a foot or so beyond the boundaries of the buried URO and for a side wall slope factor results in an estimated volume of URO, intermingled fill, and adjacent soil that is tabulated in Table 4.

Table 4. Estimate of Volume of URO and Surrounding Soil to be Excavated

Burial Site No.	Excavation			
	Area	Depth[A]	Volume[B]	
	(ft^2)	(ft)	(ft^3)	(yd^3)
1 thru 6	6719	8	42343	1568
7 and 8	2320	7	11072	410
9	2236	10.5	16940	627
			total =	2605

[A] average excavation depth
[B] accounts for URO and side wall slope

Mixed Waste. Mallinckrodt does not anticipate that buried URO contains mixed waste; although core sampling and analysis is planned to detect whether mixed waste may exist. If mixed waste were discovered, Mallinckrodt has a permit to manage hazardous waste on-site in accordance with a RCRA Part B permit with the State of Missouri. In the event mixed waste is identified during remediation activities, Mallinckrodt will characterize the wastes, identify a disposal method, assess the effect on the schedule, assess related disposal costs, modify handling procedures, as needed, and will notify the NRC and the Missouri DNR.

8.2.1. Solid Radioactive Waste Handling

Pavement and soil will be loaded into roll-off containers or dump trucks at the excavation site or will be loaded directly into rail cars for rail transport. Water misting or similar technique will be used as appropriate to control dust emissions during excavation and loading. Loose material generated during excavation will remain in the excavation. Loose material generated during loading will be removed from pavement and the exterior of containers and trucks before they are moved from the excavation area. Surveys will be performed as appropriate to ensure that loose contaminated material is not carried from Plant 6W on containers or vehicles.

8.2.2. Temporary On-Site Storage of Waste Prior to Shipping

To the extent practical, radioactive material will be loaded directly into intermodal containers or rail cars. Else, radioactively contaminated material may be staged on-site temporarily in a materials management area (MMA) in Plant 6W to (a) hold it for sampling and analysis; (b) accumulate sufficient quantities for economical shipment; (c) await intermodal containers and or rail cars, (d) to mix to meet waste acceptance criteria,[13] and or (e) coordinate shipments between the carrier and the disposal site. Contaminated material and equipment would be stored in designated staging areas in Plant 6W.

Mallinckrodt anticipates that no more than about 1,000 cubic yards of waste materials will be in temporary storage at any given time and for no longer than three months. Positive control is to be maintained. Soils and materials will be stored in covered containers or in covered piles if needed to control dust or erosion by wind or rain. Covers, surface coatings, or functionally similar techniques would be used. Stormwater run-on and run-off controls and monitoring will be used as appropriate. In the event that additional storage is needed, covered roll-off containers of URO solid waste may be temporarily stored in a MMA within Plant 6W.

Mallinckrodt does not anticipate treating radioactive solid wastes to any significant degree. Soils may be air dried or augmented with water to meet the disposal site moisture specifications. Size reduction of pavement and subsurface materials may be performed to the extent practical during excavation and removal. Additional size reduction may be performed in the MMA. In limited cases, small quantities of wastes exhibiting a hazardous toxicity characteristic may be treated (fixed and/or solidified) in containers to eliminate the characteristic.

Positive control is to be maintained in two ways: 1) An active 24-hour security system is in place for the entire Mallinckrodt facility and 2) each temporary radioactive material storage area will be enclosed by roping-off and appropriate posting.

It is expected that radiation levels at access points to temporary storage areas will be up to several times background, with the average being less that 50 μR/hr and the maximum less than 100 μR/hr. Thus, the low radiation level beside waste in storage will ensure compliance with 10 CFR 20.1301. In addition, appropriate training will be provided to workers regarding the waste materials temporarily stored on-site.

[13] NRC: W.D. Travers. "Results of the License Termination Rule Analysis of the Use of Intentional Mixing of Contaminated Soil." SECY-40-0035. Mar. 1, 2004.

8.3. WASTE DISPOSAL

8.3.1. Waste Packaging and Transportation

Wastes will be packaged, placarded and/or labeled, and transported in accordance with the requirements of the disposal site and applicable state and federal waste transportation regulations. Covers or similar devices to confine the waste and protect it from the environment will be employed as appropriate. Container liners may be used to minimize container decontamination requirements and costs at the disposal facility.

Wastes will be transported to the disposal facility by rail or truck, depending upon disposal site receiving facilities, equipment availability, cost, and other factors as appropriate.

C-T URO radioactive wastes that will be shipped by rail in gondola cars or intermodal containers will be loaded in Plant 6W. Soils may be loaded directly into a rail car or may be loaded into containers or trucks at the excavation site or at the MMA and be taken to the rail car loading area. Contractor personnel, working under agreement with Mallinckrodt, will load the wastes into rail gondola cars or intermodal containers. Contractor personnel will perform the work using health and safety procedures and protocols.

8.3.2. Waste Disposition

Material or equipment removed from a restricted area in Plant 6W into an unrestricted area shall be subject to appropriate radiation survey.

Non-impacted material, confirmed by radiation survey to be indistinguishable from natural background radioactivity, may be released without restriction.

Equipment or items subject to surficial contamination only shall be subjected to a radiation survey to determine whether it satisfies criteria in §6.2.5 herein before release. In the event material, equipment, or other item is surveyed and found compliant with Materials License STB-401, condition 16, as implemented in §6.2.5 herein, it may be released for unrestricted use and removal or under the provisions of 10 CFR 20.2002.[14] The criteria were derived to satisfy the NRC criteria for unrestricted release specified in NRC Regulatory Guide 1.86 or in NRC Policy and Guidance Directive FC 83-23.

Bulk solid waste may be blended to satisfy waste acceptance criteria specified by the receiving disposal facility. Solid waste material that is potentially contaminated will be characterized prior to release to a carrier for transport and to assess compliance with disposal site acceptance criteria. Radioactively contaminated solid wastes will be disposed of by transfer to a licensed disposal facility or by transfer to a disposal facility authorized to receive an unimportant quantity of source material.

If waste material, including URO, contains less than the *unimportant quantity* of source material as defined in 10 CFR 40.13(a), it shall be disposed by transfer to a disposal facility, either Waste Control Specialists in Texas or USEcology in Idaho, subject to approval from the cognizant state regulatory agency(ies) in which the disposal facility is located. Reports of

[14] C-T Phase I DP, §3.6.4.

analyses demonstrating potential radiological dose consequent to disposal at either site have been performed.[15, 16] Else, it shall be disposed at an NRC-regulated disposal facility authorized by , radioactive materials license to receive it.

If waste material, including URO, contains greater than an *unimportant quantity* of source material, *i.e.*, concentration, of source material as defined in 10 CFR 40.13(a) it shall be disposed at an NRC-regulated disposal facility or Agreement State-regulated disposal facility authorized by radioactive materials license to receive it.

In the event mixed waste is identified during remediation activities, Mallinckrodt will characterize such wastes, identify a disposal method, assess the effect on the schedule, assess related disposal costs, and modify handling procedures, as needed, and will notify the NRC.[17]

8.4. LIQUID RADWASTE

URO removal operations will not involve use of significant quantities of liquid chemicals requiring treatment and/or disposal.

Soil management and housekeeping activities will be designed to minimize the exposure of contaminated soils to stormwater. However, stormwater in active remediation areas, decontamination areas, and the Material Management Area may contain contaminated soil particles. Management of potentially contaminated soil that is collected will be the same as for URO and other subsoil excavated during the project.

Should rain water or surface water collect in an excavation pit, it will ordinarily be used for dust suppression of solid waste destined for NRC-approved release for disposal. Minimum use of water is anticipated for dust control during soil remediation and demolition of paved surfaces. No free water will be generated by dust control activity.

Otherwise, water removed from an excavation cavity will be filtered or otherwise treated to remove suspended solids prior to discharge to the plant sewer system in accordance with the FUSRAP MSD wastewater permit. As in the case of radioactive solid waste discussed above, any aqueous radioactive waste generated during URO removal will be Class A.

Used filters and treatment sludge, if any, will be solidified and or dewatered and managed as a solid radioactive waste.

8.4.1. Aqueous Effluent

In the event water containing significant concentration of regulated radioactive material were considered for discharge to sewerage, Mallinckrodt would transfer it into the FUSRAP water treatment system where it would be treated, sampled, analyzed, the concentration in

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15 "Disposal of Mallinckrodt 10 CFR Part 40 Section 40.13(a) Material at the USEcology Idaho Site." June 24, 2002. Submitted by Mallinckrodt to NRC on June 24, 2002.

16 "Analysis of Disposal of Unimportant Quantity of Source Material at WCS Andrews Facility." April 17, 2000. Submitted by Mallinckrodt to NRC on April 17, 2000.

17 C-T Phase 1 DP §2.2.4.

effluent water determined, compared with the 10 CFR Part 20, Appendix B, Table 3, monthly average concentration limit, and the total radioactivity inventory discharged would be estimated. Thereby, Mallinckrodt would assure discharge to sewerage in accordance with 10 CFR Part 20.2003.

The treated water may be disposed to the Metropolitan St. Louis Sewer District (MSD) subject to the FUSRAP MSD permit.

8.5. Mixed Waste

Characterization efforts performed to date have not identified any mixed wastes in the soil or other materials to be remediated during URO removal. Mallinckrodt does not anticipate that mixed waste will be generated by URO removal efforts. In the event mixed waste were to be identified during remediation activities, Mallinckrodt would characterize the wastes, identify a disposal method, assess the effect on the schedule, assess related disposal costs, modify handling procedures, as needed, and would notify the NRC. Mallinckrodt has a RCRA Part B permit authorizing on-site storage of hazardous and mixed waste. Other than the presence of hazardous chemicals, storage in Mallinckrodt's hazardous waste storage facility, and the labeling and transportation requirements of RCRA and State hazardous waste agencies, mixed wastes will have the same radioactive character and will be managed as solid radioactive wastes described above.

A small quantity of radioactive waste that exhibits a hazardous toxicity characteristic may be treated in a container to eliminate the characteristic. Neutralization, stabilization, fixation, and of solidification techniques may be used. Such treatment would typically be performed in the MMA.

8.5.1. Records

Mallinckrodt will maintain records of waste material released from the URO area in Plant 6W or controlled areas. The Document Control procedure presents the record retention requirement.

9. QUALITY ASSURANCE[18]

9.1. Overview

Provisions to ensure quality of performance that are proposed to apply to the URO remediation project are described in this section.[19] The provisions of the quality assurance program are implemented by procedures.

URO source removal activities will be performed in a manner to ensure the results are accurate and that uncertainties have been adequately considered. The quality assurance program

[18] C-T Phase I DP, §5, Jan. 9, 2002.

[19] C-T Phase I DP, §5 Quality Assurance, Jan. 9, 2002.

will operate in all stages of URO removal, through validation of the data and the interpretation of the results to verify that this has occurred.

Persons or organizations responsible for ensuring that the quality assurance program has been established and verifying that activities affecting quality have been correctly performed will have sufficient authority, access to work areas, and organizational freedom to:

- identify quality problems;
- initiate, recommend, or provide solutions to quality problems through designated channels;
- verify implementation of solutions; and,
- ensure that further URO removal activities are controlled until proper disposition of a nonconformance or deficiency has occurred.

Such persons or organizations will have direct access to responsible management at a level where appropriate action can be taken. Such persons or organizations will report to a management level such that required authority and organizational freedom are provided, including sufficient independence from cost and schedule considerations.
The major aspects of the quality assurance program for the URO removal activities are discussed in the following sections.

9.2. QUALITY ASSURANCE PROJECT PLAN

For execution of URO removal activities at the Mallinckrodt URO Project, a Quality Assurance Project Plan (QAPP), consistent with applicable guidelines will be developed. The QAPP will be reviewed and approved by Mallinckrodt prior to implementation. The objective of the QAPP is to ensure confidence in the sampling, analysis, interpretation and use of radiological data generated during the URO removal project.

The QAPP will ensure collection of reliable data by serving as the instrument of control for field and analytical activities associated with the project. Stated within the QAPP are the quality assurance policies, quality control criteria, and reporting requirements that must be followed by all site and contractor personnel when carrying out their assigned responsibilities on this project. The QAPP describes the functional activities and quality assurance/quality control (QA/QC) protocols necessary to collect data of adequate quality.

9.3. PROCEDURES

Supporting Quality Implementing Procedures (QIPs) will provide step-by-step details for complying with project QA requirements. Each radiological survey, including development of sampling plans, direct measurements, sample analysis, instrument calibration, daily functional checks of instruments, and sampling methods will be performed according to written procedures. These written procedures will be reviewed and approved by the Mallinckrodt project manager.

9.4. SUBCONTRACTORS

The activities to be conducted during URO removal will require the services of a contractor and various specialty subcontractors such as a qualified drilling contractor or a licensed surveyor. Contractor activities will be under the direct supervision of Mallinckrodt personnel in accordance with the QAPP. Subcontractor activities will be under the direct supervision of the contractor personnel, also in accordance with the QAPP.

9.5. LABORATORY SERVICES

In the event off-site analysis of a sample is required, a qualified laboratory recommended by the URO removal contractor and approved by Mallinckrodt will perform those radiological analytical laboratory services for the project. The laboratory will be responsible for all bench level QA/QC, data reduction, data reporting, and analytical performance monitoring. Laboratory accuracy will be evaluated by the analysis of blank and spiked samples. Sample handling protocols, analytical procedures, and reporting procedures employed by the analytical laboratory will be described in the laboratory's Quality Assurance Plan.

The off-site laboratory will be responsible for assuring that all appropriate laboratory personnel are thoroughly familiar with the Quality Assurance Project Plan and good laboratory practices, and that all appropriate laboratory personnel meet the requisite qualifications for their positions within the laboratory. The laboratory Director, or his equivalent/representative, will review and approve all reports. The Director will also be responsible for assuring laboratory personnel have appropriate training to perform assigned responsibilities, and for daily management of the laboratory and its staff.

The off-site laboratory will have a QA designee who will be responsible for assuring that the QA/QC requirements of the QAPP, the laboratory Quality Assurance Plan, and its associated operating procedures are strictly followed. The QA designee will be responsible for review of data, alerting the Mallinckrodt URO removal project Manager and the Contractor Project Manager of the need for corrective action (when necessary), performing internal audits as specified by the QAPP, and maintenance of the QC records. The QA designee will also be responsible for preparing project specific QA/QC plans, as necessary.

9.6. SURVEYS AND SAMPLING ACTIVITIES

Trained individuals following written procedures will perform surveys using properly calibrated instruments. The custody of samples will be tracked from collection to analysis. Final survey data will be retained until License STB-401 is terminated by the NRC.[20] The designated sampler or analytical laboratory will collect a split sample when desired by the NRC to obtain samples that are duplicates of those to be analyzed. When this operation is performed, the procedure for obtaining duplicate samples will be followed.

QC hold points will be utilized as necessary to ensure quality of surveys and sampling. Hold points will also be used to ensure that debris is moved only after QA has verified that the proper sampling and survey information for the debris in question has been obtained.

[20] 10 CFR Part 40.36(f)

9.7. DOCUMENTATION

Data will be recorded and documented in a data management system. Entries will include the location of the survey or sampling point on the appropriate land grid. Data management personnel will also ensure that chain-of-custody and data management procedures are followed for URO removal-related samples. The contractor's procedures for proper handling, shipping and storage of samples will be used.

Both direct measurements and analytical results will be documented. The results for each survey measurement or sample and its grid block location, will be listed in tabular form (*i.e.*, result versus sample or survey location).

Data will be recorded in an orderly and verifiable way and reviewed for accuracy and consistency. Every step of the URO removal process, from training personnel to calculating and interpreting the data, shall be documented in a way that lends itself to audit. Records of training to demonstrate qualification will also be maintained.

9.8. EQUIPMENT MAINTENANCE AND CALIBRATION

Measuring equipment will be maintained, calibrated, and tested according to Regulatory Guides 4.15 and 4.16 recommendations. Further, the procedures, responsibilities, and schedules for calibrating and testing equipment will be documented.

Proper maintenance of equipment varies, but maintenance information and use limitations are provided in the vendor documentation. Measuring and analyzing equipment will be tested and calibrated before initial use and will be recalibrated if maintenance or modifications could invalidate earlier calibrations. Field and laboratory equipment, specifically used for obtaining final radiological survey data, will be calibrated based on standards traceable to NIST. In those cases where NIST-traceable standards are not available, standards of an industry-recognized organization (for example, the New Brunswick Laboratory for various uranium standards) will be used. Minimum frequencies for calibrating equipment will be established and documented. Measuring equipment will be tested at least once on each day the equipment is used. Test results will be recorded in tabular or graphic form and compared to predetermined, acceptable performance ranges. Equipment that does not conform to the performance criteria will be promptly removed from service until the deficiencies can be resolved.

9.9. DATA MANAGEMENT

9.9.1. Laboratory Data

Data reduction, QC review, and reporting will be the responsibility of the analytical laboratory. Data reduction includes all automated and manual processes for reducing or organizing raw data generated by the laboratory. The laboratory will provide a data package for each set of analyses that will include a copy of the raw data in electronic format, and any other information needed to check and recalculate the analytical results.

Once a data package is received from the laboratory, the analytical results and pertinent QA/QC data will be compiled onto standardized data formats. The data packages will serve as basic reference sheets for data validation, as well as for project data use.

9.9.2. Field Survey Data

The generation, handling, computations, evaluation and reporting of final radiological survey data will be as specified in the contractor's procedures. Included in these procedures will be a system for data review and validation to ensure consistency, thoroughness and acceptability. Qualified health and safety, operations, and/or engineering personnel will review and evaluate survey data.

9.9.3. Data Evaluation

Prior to releasing data for use by project staff, selected data will undergo data evaluation based on intended end use of the data. Data points chosen for evaluation will be examined to determine compliance with QA requirements and other factors that determine the quality of the data. Data taken during a prior survey, *e.g.*, characterization survey, may be usable provided the data are subjected to quality verification and satisfy data quality objectives.

If sample data are rejected or data omissions are identified during the data validation, this data will be evaluated to judge the impact on the project. Other corrective action may include re-sampling and analyzing, evaluating and amending sampling and analytical procedures and accepting data acknowledging the level of uncertainty.

In the event survey data are processed by computer, the application program[21] and each modification thereof will be verified to perform as intended before its initial use. A knowledgeable person will verify that the algorithms are as intended and will compare an instance of computer-generated result and an independently derived result of the same process. Mallinckrodt or its contractor will document the application program, including its algorithms and a listing or copy of the program.

9.10. SAMPLE CHAIN-OF-CUSTODY

One of the most important aspects of sample management is to ensure that the integrity of the sample is maintained; that is, that there is an accurate record of sample collection, transport, analysis, and disposal. This ensures that samples are neither lost nor tampered with and that the sample analyzed in the laboratory is actually and verifiably the sample taken from a specific location in the field.

Sample custody will be assigned to one individual at a time. This will prevent confusion of responsibility. Custody is maintained when (1) the sample is under direct surveillance by the assigned individual, (2) the sample is maintained in a tamper-free container, or (3) the sample is within a controlled-access facility.

The individual responsible for sample collection will initiate a chain-of-custody record using a standard form provided by the URO removal contractor. A copy of this form will

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[21] An *application program* consists of instructions and or algorithms created specifically for processing data for the URO removal project. It does not pertain to generic software, including for example, a spreadsheet program such as Microsoft EXCEL™ or a database program such as Microsoft ACCESS.™

accompany the samples throughout transportation and analyses; and any breach in custody or evidence of tampering will be documented.

9.11. AUDITS

Periodic audits will be performed to verify that URO removal activities comply with established procedures and other aspects of the QAPP and to evaluate the overall effectiveness of the QA program. Mallinckrodt and Contractor Quality Assurance personnel will verify that qualified personnel are used to conduct audits to ensure that the applicable procedures are being properly implemented. The audits will be conducted on at least a quarterly basis, in accordance with written guidelines or checklists. Health and safety personnel will also conduct semiannual audits in their area of concern. External program audits may also be used at the discretion of either Mallinckrodt or contractor management. Audit results will be reported to both Mallinckrodt and contractor management in writing, and actions to resolve identified deficiencies will be tracked and appropriately documented.

10. SAFETY ANALYSIS

Radiological safety of workers performing URO removal has been evaluated. An occupational dose evaluation was modeled using the RESRAD computer code and site-specific information or estimates of input parameters. The modeling yielded an estimate of 83 mrem for a representative remediation worker, which is less than 10% of the maximum tolerable radiological dose to a worker annually.

An ALARA evaluation was performed to assess defensible cost-benefit balance for averting dose. Based upon an estimate of 10 workers subject to exposure on the project, the prospective collective dose was estimated to be 0.83 person-rem. This evaluation suggests that routine health physics measures already planned for the project should be acceptable to maintain doses ALARA during the URO removal project.

A safety evaluation report for the URO removal project is provided as Appendix 1 herewith.

11. ENVIRONMENTAL REPORT

An environmental report for the URO removal project is provided as Appendix 2 herewith.

APPENDIX 1

SAFETY EVALUATION REPORT FOR URO REMOVAL

1. INTRODUCTION

The goal of the Columbium-Tantalum decommissioning project is to remediate those areas of the site associated with C-T production to the extent necessary to terminate License STB-401. Mallinckrodt has elected to decommission the C-T project areas of the site in two phases. On November 20, 1997, Mallinckrodt Chemical, Inc. (Mallinckrodt) submitted a C-T Project Decommissioning Plan, Part I (DP), for its radioactive materials license STB-401. In response to request for additional information, Mallinckrodt revised its DP by submittals dated January 10, 2002, February 13, 2002, and March 8, 2002. On May 3, 2002, the NRC approved Phase I by license amendment. During Phase I, Mallinckrodt decommissioned the buildings and equipment to the extent necessary to meet the Nuclear Regulatory Commission's (NRC's) guidelines for unrestricted release.

Phase II will include the remediation of the building slabs, paved surfaces, sewerage, wastewater basins, and subsurface materials. Mallinckrodt submitted the DP for Phase II to the NRC for review and approval on May 14, 2003 and has responded to NRC requests for additional information.

In order to coordinate schedules for remediation of Plant 6W with the USACE, Mallinckrodt proposes to remove URO buried in Plant 6W that originated from C-T processing. This Safety Evaluation Report (SER) applies only to the URO removal activities. Much of the information contained in this safety evaluation report (SER) was derived from and is consistent with the Mallinckrodt Phase I DP.

2. BACKGROUND

Mallinckrodt has been operating at the St. Louis Plant since 1867 producing various products, including metallic oxides and salts, ammonia, organic chemicals, and various uranium compounds for the Manhattan Engineering District and the Atomic Energy Commission (MED-AEC). The St. Louis Plant, comprised of over 50 buildings on approximately 43 acres.

Between 1942 and 1958, Mallinckrodt refined uranium ore and concentrate to produce uranium compounds and metal in support of early Federal Government programs to develop atomic weapons under the Manhattan Engineering District and later the Atomic Energy Commission (MED-AEC).

From 1956 to 1960, Mallinckrodt extracted columbium, tantalum, uranium, thorium, and rare earth elements from euxenite mineral ore for delivery to the AEC and the General Services Administration (GSA) as part of the Defense Materials Procurement Program. The Euxenite operation was performed under AEC source material license R-226. The license expired in 1960. The same processing facilities were subsequently used to extract columbium and tantalum compounds under NRC License STB-401.

In 1961, Mallinckrodt was issued License No. STB-401 to extract columbium and tantalum (C-T) from natural ores and tin slags. While C-T production occurred within Plant 5, whose area is about one city block, some unreacted ore was buried in 10 trenches in Plant 6W. From 1961 to 1985 Mallinckrodt purchased and processed feed materials for C-T production, including columbite ore and tin slag. The ores and processing byproduct materials contained uranium and thorium isotopes. Products from this C-T process included tantalum oxide, potassium fluotantalate, and columbium oxide. C-T processing was shut down from 1985 through early 1987, when Mallinckrodt performed a two- month pilot production run. In July 1993, NRC amended Mallinckrodt's license to a possession only license for decommissioning and license termination.

MED-AEC activities resulted in radioactive contamination on some areas of Mallinckrodt's St. Louis Plant site and adjacent properties. The MED-AEC contamination consists of uranium series, thorium series, and actinium (U^{235}) series radionuclides, including Th^{230} and radium, from refining uranium ore and concentrate. Remediation of radioactive residues remaining from MED-AEC activity in other areas of the St. Louis Plant has previously been performed by the U.S. Department of Energy (DOE) and is currently being performed by the U.S. Army Corps of Engineers (USACE) under the Formerly Utilized Sites Remedial Action Program (FUSRAP). Plant 6W, in which the URO is buried, is subject to the FUSRAP.

3. SAFETY EVALUATION

3.1. DECOMMISSIONING OBJECTIVE

Decommissioning Goals. The goal of C-T decommissioning is to remediate the regulated radioactive constituents associated with C-T production to the extent required to terminate license STB-401. License STB-401 was most recently amended on May 3, 2002 to incorporate the approved C-T Phase I Decommissioning Plan, authorizing decommissioning of the C-T processing buildings. That has been accomplished. Phase II of decommissioning will remediate C-T processing building slabs, sewerage, wastewater neutralization basins, pavement, and soil affected by C-T processing.

Source Removal Goals. In a separate source removal action, Mallinckrodt intends to remove URO buried in trenches 1 through 9 and immediately adjacent soil within defined geographic boundary in Plant 6W and to dispose of it by NRC-authorized transfer to a disposal facility. Thereby, Mallinckrodt plans to remove the URO source to help assure that the potential radiological dose to people on the site will be less than 25 mrem/yr without necessity for post-remediation activity.

Delineation of responsibility for remediation in Plant 6W within the St. Louis Plant has been decided between Mallinckrodt and the U.S. Army Corps of Engineers. Mallinckrodt's intent remove URO that is buried in Plant 6W is being addressed in a license amendment request to remove that source material.

3.2. SOURCE REMOVAL

Radionuclides of interest in this plan have been identified in the review of C-T process history and in the evaluation of radiological characterization of the site. They are:

- U-238, U-235, and U-234, all from naturally occurring uranium (and their progeny Th-230, Ra-226, and other short-lived isotopes); and
- Th-232 from naturally occurring thorium, and its progeny (Ra-228, Th-228, and other short-lived isotopes).

Mallinckrodt has committed to dispose of URO that contains more than the exempted quantity of source material as defined in 10 CFR Part 40.13 at a regulated disposal facility. URO and immediately adjacent soil containing source material concentration exceeding the unrestricted release limits, but less than the exempted quantity of source material will be disposed of by NRC-authorized transfer to a disposal facility subject to approval of the cognizant state regulatory agencies. Materials potentially contaminated on surfaces meeting the requirements of NRC FC 83-23 can be released in accordance with license condition 16 or under the provisions of 10 CFR Part 20.2002.

The proposed source reduction action will remove this URO source of potential exposure from the property to safe disposal off-site. By removing all material within a defined physical boundary, verification may be physical. A residual radioactivity concentration criterion will not be needed.

3.3. CHARACTERIZATION.

An extensive radiation survey designed to characterize the radioactivity status of the site has been conducted in accordance with an NRC-approved plan[1] and results have been reported in detail.[2] A discussion of portions this effort pertaining to C-T Phase II decommissioning, including a general description of methodologies employed and a summary of results obtained, were provided.[3]

Residual radioactive sources from C-T processing are the naturally-occurring thorium series, the uranium series, and the actinium (U^{235}) series. The existing distributions of residual source material in soil and on pavement in Plant 5 are described in C-T Phase II DP § 4, Radiological Status of the Facility.

Characterization survey results of interest in the Phase II Plan are those related to surfaces of pavement, building floor slabs, and subsurface materials, including soil. The measurements of primary importance for pavement and building slabs were direct beta/gamma measurements using large-area detectors in both scan and static mode. The measurements of

1 Mallinckrodt Chemical, Inc., C-T Plant Characterization Plan, January 1994. Supplement May 1994.

2 "Radiological Characterization Data Set For The Mallinckrodt Chemical C-T Plant, Thermo NUtech, Oak Ridge, TN, Revised October, 1998.

3 Mallinckrodt, C-T Phase II Decommissioning Plan, section 4.

primary interest for subsurface materials were laboratory analyses of key radionuclides in samples collected from boreholes.

Buried URO. URO was buried in Plant 6W in approximately a two-foot layer in ten excavated trenches. Each burial trench has about 3 to 4 feet of clean cover consisting of compacted soil. In addition, trenches 1 thru 9 are covered by 3 to 5 inches of asphalt while trench 10 is covered by 5 to 10 inches of concrete floor slab.

During the time when unreacted ore (URO) was produced that is buried in Plant 6, C-T feed material was primarily tin slag with a lesser fraction of columbite ore. Thus, URO is comprised of tin slag ore and columbite that did not dissolve by acid leaching and include insoluble compounds UF_4 and ThF_4. The best estimate is that URO contains about 1.8 wt% thorium and about 0.1 as much uranium, or about 0.15 wt% U.

3.4. AFFECTED AREAS

Site Description. The St. Louis Plant site is in an urban industrial area, zoned and developed for industrial use. The St. Louis Plant currently contains more than 50 manufacturing and support buildings in an area of approximately twelve city blocks. Open areas of the St. Louis Plant site is typically paved with asphalt or concrete. Mallinckrodt currently produces a variety of products for the food, drug, cosmetic, pharmaceutical, and specialty chemical industries. A city block area designated as Plant 5 where C-T facilities are being decommissioned includes only Mallinckrodt facilities. Details are described in CT Phase II DP §3 Facility Description.

Buried URO.

Unreacted ore (URO) was buried in Plant 6W in ten excavated trenches. URO is comprised of columbite ore and tin slag that did not dissolve by acid leaching and portions that precipitated as insoluble flouride. Approximately 290 cubic yards of URO was packaged in 305 thirty-gallon steel drums before burial. Mallinckrodt proposes to remove all of the URO in burials 1 through 9 within defined boundaries, surrounded by land subject to the FUSRAP. URO burial trenches 1 through 9 occupy an area about 400 yd^2. Allowing for sloping excavation side walls increases the prospectively affected area to about 970 yd^2 and a total volume of about 2550 yd^3.

3.5. ORGANIZATION AND ADMINISTRATION

Mallinckrodt will be responsible for overall project direction and ensuring that NRC requirements are met. The remediation contractor will be required to implement the programs, including radiological, occupational, and environmental protection and quality assurance, with oversight by Mallinckrodt staff. The contractor will be responsible for providing trained personnel to conduct URO removal. Mallinckrodt's application for license amendment to remove the URO describes an organization structure and administrative controls to manage URO removal.

Mallinckrodt developed and implemented procedures while conducting Phase I of its decommissioning plan. Pertinent ones of them will be applied to URO removal, augmented by ones specific to URO removal. Alternatively, contractor-developed and approved procedures may be used. Implementing procedures and practices during buried URO removal will be subject to NRC inspection.

3.6. APPROACH TO URO REMOVAL

Buried URO. Removal of unreacted ore is to be approached as removal of a source within specified geographical bounds. Surrounding land outside those bounds is subject to the FUSRAP. URO is to be removed as generally described:

- Utility lines, including water, electricity, gas, *etc.*, will be located and marked prior to initiation of remediation activities and will be relocated as necessary to perform this work.
- Macadam pavement atop URO burials 1 through 9 will be removed.
- The soil covering the buried URO will be removed by excavation.
- Water misting or similarly effective dust control methods will be used as necessary to prevent the release of airborne dust during excavation and materials handling activities.
- Because a finished goods warehouse exists above burial trench 10, URO buried in trench 10 is inaccessible and is not a subject of this URO removal action.
- Extent of the removal is to be verified by visual inspection and, where necessary, confirmed by appropriate radiation measurements.
- URO contents will be transported to the rail loading facility on site for loading and delivery to a carrier for transport.
- Excavated soil and URO may be mixed in order to satisfy disposal site criteria.
- Backfill will be specified to ensure no subsidence or, by agreement with the USACE, excavation cavities may be left to facilitate FUSRAP remediation nearby.

Mallinckrodt has procedures developed for Phase I decommissioning activities. Pertinent ones of those procedures, with appropriate revisions, additional ones as needed, or contractor-developed procedures will be used during URO removal.

3.7. RADIATION CONTROL

Mallinckrodt has committed to radiation safety and environmental protection programs to protect against ionizing radiation.

An estimate of occupational radiation dose to a worker participating in the URO removal is summarized in Attachment 1. The evaluation considers an hypothetical situation, likely a bounding scenario, which is conjectured to occur during URO handling. A remediation worker is assumed to be exposed to URO during excavation or handling. Modeling performed using the RESRAD computer code and site-specific information or estimates yielded an estimate of 83 mrem radiological dose to a representative construction worker. Based upon an estimate of 10 workers on the project, the collective dose was estimated as 0.83 person-rem. The evaluation provides justification that the activities to be performed during the URO source removal will maintain occupational exposure to source material as low as reasonably achievable (ALARA).

3.8. ALARA

A principle of radiological protection is that reasonable effort should be made to **A**chieve exposure to ionizing radiation that is **A**s **L**ow **A**s is **R**easonable. Action planned to make radiation exposure ALARA may be judged to be sufficient when the expected benefit from additional collective dose averted becomes less than the expected cost of achieving it.

Potential for causing more than 25 mrem/yr radiological dose makes it necessary to remove the URO. Exposure to workers while removing the URO will be maintained ALARA by health physics practices specified by the radiation protection program. Removing the source URO from the site will eliminate potential exposure from it otherwise. Thereby, the ALARA principle will be implemented.

4. CONCLUSIONS

In order to coordinate schedules for remediation of Plant 6W with the USACE under the FUSRAP, Mallinckrodt proposes to remove URO buried in Plant 6W that originated from C-T processing. Removing the source URO from the site will eliminate potential exposure to it in the future.

This source removal within a geographical boundary will not require a radioactivity concentration criterion nor a final radiation status survey. Verification of removal may be by visual or physical survey. Surrounding land in Plant 6W is within FUSRAP domain.

Potential radiological dose to a remediation worker during the URO removal project is estimated to be 83 mrem and collective dose is estimated to be about 0.83 person-rem. Exposure to workers while removing the URO will be maintained ALARA by health physics practices specified by the radiation protection program.

URO and adjacent soil that is removed will be disposed off-site at a regulated disposal site or by NRC-authorized transfer to a suitable disposal site.

5. REFERENCES

1. Mallinckrodt, Inc. *Phase I Plan for C-T Decommissioning.* NRC Docket 040-06563. NRC License STB-401. Jan. 9, 2002.
2. Mallinckrodt, Inc. *Phase II Plan for C-T Decommissioning.* NRC Docket 040-06563. NRC License STB-401. May 14, 2003.
3. NRC. "Use or Termination of Facilities and Equipment Prior to Release for Unrestricted Use or Termination of Licenses for Byproduct, Source, or Special Nuclear Material," NRC Materials License STB-401, condition 16.
4. Mallinckrodt Chemical, Inc., C-T Plant Characterization Plan, January 1994. supplement May 1994.
5. Thermo Nutech. *Radiological Characterization Data Set For The Mallinckrodt Chemical C-T Plant*, Oak Ridge, TN, rev. October, 1998.
6. MARSSIM. *Multi-Agency Radiation Survey and Site Investigation Manual(MARSSIM).* NUREG-1575. EPA 402-R-97-016, Dec. 1997.

ATTACHMENT 1 TO APPENDIX 1

OCCUPATIONAL DOSE EVALUATION

1.1. INTRODUCTION

This attachment describes an estimate and evaluation of the occupational radiation dose to a worker participating in the URO removal project. The estimate of dose considers a hypothetical situation, likely a bounding scenario, during excavation of unreacted C-T ore (URO) from burial. The evaluation provides justification that the activities to be performed during the URO removal project will maintain occupational exposure to source material as low as reasonably achievable (ALARA).

1.2. HYPOTHETICAL OCCUPATIONAL EXPOSURE SCENARIO

Unreacted C-T ore was put into steel drums, deposited in trenches, and covered with about four feet of cinder-soil fill in Plant 6 West. Eventually, the area was paved. The scope of the URO removal project includes removal of the pavement, contaminated subsurface soils (cinder/fill), and URO-soil in burials 1 through 9 in Plant 6W. Workmen will excavate these 9 burial trenches, may temporarily stockpile the excavated material, and will load the subsurface soils and URO-soil into shipping containers or gondola rail cars. This exposure scenario assumes a typical construction worker may be exposed about one-half of the time to subsurface soils covering the buried URO and one-half of the time exposed to the URO-soil mixture.

The dominant exposure would be the proximity of construction workers with the URO-soils. The exposure pathways of concern are those associated with the chronic (occupational) exposure scenario of construction activities during the URO removal project, which will be external irradiation from contaminated soil, inhalation of suspended contaminated soil, and inadvertent ingestion of contaminated soil from hands and clothing, all while out-of-doors.

The occupational exposure scenario assumptions below are conservative and are expected to simulate upper range of exposure potential.

1.3. SCENARIO ASSUMPTIONS

The occupational exposure scenario is modeled with the RESRAD computer code. Default values of parameters have been developed and described.[1] Unless described herein, default parameters in RESRAD have been retained in the assessment of occupational dose. The influence of parameters most pertinent to the scenario has been considered for appropriateness of value.

1. (Soil) Nuclide concentration = radionuclide concentration in URO-soil was estimated for each of the key, long-lived radionuclides in the uranium series, the actinium series, and the thorium series. Characterization surveys in the C-T projects find that uranium series to thorium series ratio to average about 2.5 U series to 1 Th series. The concentration in buried URO with intermingled soil is estimated not to exceed 500 pCi U^{238} or 200 pCi Th^{232} per gram URO-soil mixture.

[1] Biwer, B.M., et. al., "Parameter Distributions for Use in RESRAD and RESRAD-BUILD Computer Codes." In *Development of Probabilistic RESRAD 6.0 and RESRAD-BUILD 3.0 Computer Codes.* NUREG/CR-6697. Dec 2000.

The input soil concentrations are thus:

Nuclide	Concentration (pCi/g)
U-238	500
U-235	22.75
U-234	500
Th-230	500
Ra-226	500
Th-232	200
Ra-228	200
Th-228	200
Ac-227	22.75
Pa-231	22.75

2. Basic Radiation Dose Limit = The radiation dose limit for a radiation worker is 5000 mrem/yr.[2]
3. Area of contaminated zone = The active working area of an individual construction worker was assumed to be 1000 m^2.
4. Wind speed = The average wind speed reported for St. Louis is 4.3 m/s (9.5 mph).[3]
5. Inhalation rate = An estimate of the volume of air inhaled by a worker while in an area on-site that is contaminated is needed to estimate potential radiological dose to the construction worker during decommissioning activities. That volume is the product of occupancy time and inhalation rate.

   Construction worker activity would seem to be most nearly similar to gardening, for which the recommended default inhalation rate is 1.7 m^3/h.[4] This would correspond to an outdoor worker whose activity is 0.8 moderate exertion at 1.5 m^3/h breathing rate and 0.2 heavy exertion at 2.5 m^3/h breathing rate.[5] Since construction workers are assumed to work out-of-doors entirely, the inhalation rate of this critical group is estimated to be 1.7 m^3/h without adjustment for any time indoors. The annual equivalent entry = 14900 m^3/yr.
6. Mass loading for inhalation = Estimation of intake by inhalation depends on the airborne concentration of contaminated airborne particulate matter. Airborne dust in the vicinity of the excavation may be reasonably assumed maintained less than the OSHA limit[6] for fugitive dust of 1 mg/m^3.
7. Exposure duration = The exposure duration must be entered in the RESRAD code at a minimum value of one year or 8766 hours.
8. Indoor time fraction = The construction worker is assumed to be indoors during work breaks. The indoor area is assumed to not be in the contaminated areas. The fraction of time the construction worker spends indoors in the contaminated area is assumed to be zero.

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[2] 10 CFR Part 20.1201.
[3] C-T Phase II Decommissioning Plan, Section 3.4, Table 3-2.
[4] Biwer, B.M., et. al., p. 5-4, Table 5.1-3.
[5] Biwer, B.M., et. al., p. 5-4, Table 5.1-2.
[6] 29 CFR Part 1926.

9. Outdoor time fraction = The outdoor time fraction is the fraction of the exposure duration spent outdoors in the contaminated area.

   The estimated volume of contaminated soil is 1840 yd^3. It is also estimated that about 100 yd^3 of soil can be excavated per workday. Then the contaminated soil could be excavated in about 20 workdays. About 4 feet of minimally-contaminated cover soil, followed by 3 or 4 feet of URO-soil mixture will be excavated. The outdoor time in the work area is assumed comprised of 8 hours per workday, 5 days per workweek, for 4 work weeks, or 160 work-hours. About ½ of that time is estimated to be subject to exposure to the source URO-soil mixture. The fraction of time per year that the construction worker spends outside in the contaminated area is then 80 work hours / 8766 total hours = 0.00915

10. Soil ingestion rate = The quantity of contaminated soil ingested incidentally from outdoor activities annually is estimated to range from 0 to 36.5 g/yr.[7] To account for the aggressive nature of excavation activities, the inadvertent soil ingestion rate will be assumed to be 36.5 g/yr.

11. Number of construction workers = This parameter is not a RESRAD input. This parameter will be used to complete an ALARA evaluation for the occupational dose scenario. This parameter describes the number of construction workers that will be subject to the occupational dose scenario evaluated here. The number of construction workers estimated for the URO removal project is 10.

1.4. Calculations

Results of the RESRAD modeling are provided in worksheets included with this attachment. In summary, the results reflect the dominant exposure pathway to be external gamma and Ra^{226} to be the primary contributor of this pathway. The annual dose to the construction worker, estimated from the aforementioned conservative input parameters, is 83 mrem per year.

1.5. Comparison with the Basic Radiation Dose Limit

The basic radiation dose limit is the maximum radiation dose allowed in a year to a radiation worker. The estimated annual dose to the construction worker is less than 10% of the basic radiation dose limit.

1.6. ALARA Evaluation

NUREG/BR-0058, Revision 2 (November, 1995) recommends a value of $2,000 per person-rem averted as a criterion for determining whether additional funds should be expended to reduce risk. Applying this criterion to the URO removal project, the expenditure that would be justifiable if all radiological dose to workers who perform the URO removal could be averted would be about:

> Occupational Dose = 83 mrem per construction worker.
> Collective dose = 0.083 rem/worker x 10 workers = 0.83 person-rem.
> Justifiable expenditure = $2,000/person-rem x 0.83 person-rem = $1660.

Mallinckrodt has incorporated ALARA practices into its radiation protection program through the use of plans, procedures, training, safety work permits, and oversight. The funds spent to avert dose for the URO removal project already far exceed $1660. Therefore, the project meets

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[7] Biwer, *et.al.*, atch C, pp. c5-19 thru c5-25 in NUREG/CR-6697.

the definition of ALARA and should not require measures beyond good health physics practices to avert dose. Therefore, the intent of the regulations has been met with respect to ALARA.

1.7. Conclusions

An occupational dose evaluation was performed for decommissioning work associated with the C-T URO removal project. Modeling performed using the RESRAD computer code and site-specific information or estimates yielded an estimate of 83 mrem per year for a representative construction worker. Based upon an estimate of 10 workers on the project, the collective dose was estimated as 0.83 person-rem.

An ALARA evaluation was performed to assess defensible cost-benefit balance for averting dose. Based upon the evaluation, routine health physics measures already planned for the project should be acceptable to maintain doses ALARA during the URO removal project. Additional measures such as a formal ALARA program, or ALARA Committee, are not warranted.

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	Base Case*	Parameter Name
B-1	Dose conversion factors for inhalation, mrem/pCi:			
B-1	Ac-227+D	6.724E+00	6.700E+00	DCF2(1)
B-1	Pa-231	1.280E+00	1.280E+00	DCF2(2)
B-1	Pb-210+D	2.320E-02	1.360E-02	DCF2(3)
B-1	Ra-226+D	8.594E-03	8.580E-03	DCF2(4)
B-1	Ra-228+D	5.078E-03	4.770E-03	DCF2(5)
B-1	Th-228+D	3.454E-01	3.420E-01	DCF2(6)
B-1	Th-230	3.260E-01	3.260E-01	DCF2(7)
B-1	Th-232	1.640E+00	1.640E+00	DCF2(8)
B-1	U-234	1.320E-01	1.320E-01	DCF2(9)
B-1	U-235+D	1.230E-01	1.230E-01	DCF2(10)
B-1	U-238	1.180E-01	1.180E-01	DCF2(11)
B-1	U-238+D	1.180E-01	1.180E-01	DCF2(12)
D-1	Dose conversion factors for ingestion, mrem/pCi:			
D-1	Ac-227+D	1.480E-02	1.410E-02	DCF3(1)
D-1	Pa-231	1.060E-02	1.060E-02	DCF3(2)
D-1	Pb-210+D	7.276E-03	5.370E-03	DCF3(3)
D-1	Ra-226+D	1.321E-03	1.320E-03	DCF3(4)
D-1	Ra-228+D	1.442E-03	1.440E-03	DCF3(5)
D-1	Th-228+D	8.086E-04	3.960E-04	DCF3(6)
D-1	Th-230	5.480E-04	5.480E-04	DCF3(7)
D-1	Th-232	2.730E-03	2.730E-03	DCF3(8)
D-1	U-234	2.830E-04	2.830E-04	DCF3(9)
D-1	U-235+D	2.673E-04	2.660E-04	DCF3(10)
D-1	U-238	2.550E-04	2.550E-04	DCF3(11)
D-1	U-238+D	2.687E-04	2.550E-04	DCF3(12)
D-34	Food transfer factors:			
D-34	Ac-227+D , plant/soil concentration ratio, dimensionless	2.500E-03	2.500E-03	RTF(1,1)
D-34	Ac-227+D , beef/livestock-intake ratio, (pCi/kg)/(pCi/d)	2.000E-05	2.000E-05	RTF(1,2)
D-34	Ac-227+D , milk/livestock-intake ratio, (pCi/L)/(pCi/d)	2.000E-05	2.000E-05	RTF(1,3)
D-34				
D-34	Pa-231 , plant/soil concentration ratio, dimensionless	1.000E-02	1.000E-02	RTF(2,1)
D-34	Pa-231 , beef/livestock-intake ratio, (pCi/kg)/(pCi/d)	5.000E-03	5.000E-03	RTF(2,2)
D-34	Pa-231 , milk/livestock-intake ratio, (pCi/L)/(pCi/d)	5.000E-06	5.000E-06	RTF(2,3)
D-34				
D-34	Pb-210+D , plant/soil concentration ratio, dimensionless	1.000E-02	1.000E-02	RTF(3,1)
D-34	Pb-210+D , beef/livestock-intake ratio, (pCi/kg)/(pCi/d)	8.000E-04	8.000E-04	RTF(3,2)
D-34	Pb-210+D , milk/livestock-intake ratio, (pCi/L)/(pCi/d)	3.000E-04	3.000E-04	RTF(3,3)
D-34				
D-34	Ra-226+D , plant/soil concentration ratio, dimensionless	4.000E-02	4.000E-02	RTF(4,1)
D-34	Ra-226+D , beef/livestock-intake ratio, (pCi/kg)/(pCi/d)	1.000E-03	1.000E-03	RTF(4,2)
D-34	Ra-226+D , milk/livestock-intake ratio, (pCi/L)/(pCi/d)	1.000E-03	1.000E-03	RTF(4,3)
D-34				
D-34	Ra-228+D , plant/soil concentration ratio, dimensionless	4.000E-02	4.000E-02	RTF(5,1)
D-34	Ra-228+D , beef/livestock-intake ratio, (pCi/kg)/(pCi/d)	1.000E-03	1.000E-03	RTF(5,2)
D-34	Ra-228+D , milk/livestock-intake ratio, (pCi/L)/(pCi/d)	1.000E-03	1.000E-03	RTF(5,3)
D-34				

Dose Conversion Factor (and Related) Parameter Summary (continued)
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Menu	Parameter	Current Value	Base Case*	Parameter Name
D-34	Th-228+D , plant/soil concentration ratio, dimensionless	1.000E-03	1.000E-03	RTF(6,1)
D-34	Th-228+D , beef/livestock-intake ratio, (pCi/kg)/(pCi/d)	1.000E-04	1.000E-04	RTF(6,2)
D-34	Th-228+D , milk/livestock-intake ratio, (pCi/L)/(pCi/d)	5.000E-06	5.000E-06	RTF(6,3)
D-34				
D-34	Th-230 , plant/soil concentration ratio, dimensionless	1.000E-03	1.000E-03	RTF(7,1)
D-34	Th-230 , beef/livestock-intake ratio, (pCi/kg)/(pCi/d)	1.000E-04	1.000E-04	RTF(7,2)
D-34	Th-230 , milk/livestock-intake ratio, (pCi/L)/(pCi/d)	5.000E-06	5.000E-06	RTF(7,3)
D-34				
D-34	Th-232 , plant/soil concentration ratio, dimensionless	1.000E-03	1.000E-03	RTF(8,1)
D-34	Th-232 , beef/livestock-intake ratio, (pCi/kg)/(pCi/d)	1.000E-04	1.000E-04	RTF(8,2)
D-34	Th-232 , milk/livestock-intake ratio, (pCi/L)/(pCi/d)	5.000E-06	5.000E-06	RTF(8,3)
D-34				
D-34	U-234 , plant/soil concentration ratio, dimensionless	2.500E-03	2.500E-03	RTF(9,1)
D-34	U-234 , beef/livestock-intake ratio, (pCi/kg)/(pCi/d)	3.400E-04	3.400E-04	RTF(9,2)
D-34	U-234 , milk/livestock-intake ratio, (pCi/L)/(pCi/d)	6.000E-04	6.000E-04	RTF(9,3)
D-34				
D-34	U-235+D , plant/soil concentration ratio, dimensionless	2.500E-03	2.500E-03	RTF(10,1)
D-34	U-235+D , beef/livestock-intake ratio, (pCi/kg)/(pCi/d)	3.400E-04	3.400E-04	RTF(10,2)
D-34	U-235+D , milk/livestock-intake ratio, (pCi/L)/(pCi/d)	6.000E-04	6.000E-04	RTF(10,3)
D-34				
D-34	U-238 , plant/soil concentration ratio, dimensionless	2.500E-03	2.500E-03	RTF(11,1)
D-34	U-238 , beef/livestock-intake ratio, (pCi/kg)/(pCi/d)	3.400E-04	3.400E-04	RTF(11,2)
D-34	U-238 , milk/livestock-intake ratio, (pCi/L)/(pCi/d)	6.000E-04	6.000E-04	RTF(11,3)
D-34				
D-34	U-238+D , plant/soil concentration ratio, dimensionless	2.500E-03	2.500E-03	RTF(12,1)
D-34	U-238+D , beef/livestock-intake ratio, (pCi/kg)/(pCi/d)	3.400E-04	3.400E-04	RTF(12,2)
D-34	U-238+D , milk/livestock-intake ratio, (pCi/L)/(pCi/d)	6.000E-04	6.000E-04	RTF(12,3)
D-5	Bioaccumulation factors, fresh water, L/kg:			
D-5	Ac-227+D , fish	1.500E+01	1.500E+01	BIOFAC(1,1)
D-5	Ac-227+D , crustacea and mollusks	1.000E+03	1.000E+03	BIOFAC(1,2)
D-5				
D-5	Pa-231 , fish	1.000E+01	1.000E+01	BIOFAC(2,1)
D-5	Pa-231 , crustacea and mollusks	1.100E+02	1.100E+02	BIOFAC(2,2)
D-5				
D-5	Pb-210+D , fish	3.000E+02	3.000E+02	BIOFAC(3,1)
D-5	Pb-210+D , crustacea and mollusks	1.000E+02	1.000E+02	BIOFAC(3,2)
D-5				
D-5	Ra-226+D , fish	5.000E+01	5.000E+01	BIOFAC(4,1)
D-5	Ra-226+D , crustacea and mollusks	2.500E+02	2.500E+02	BIOFAC(4,2)
D-5				
D-5	Ra-228+D , fish	5.000E+01	5.000E+01	BIOFAC(5,1)
D-5	Ra-228+D , crustacea and mollusks	2.500E+02	2.500E+02	BIOFAC(5,2)
D-5				
D-5	Th-228+D , fish	1.000E+02	1.000E+02	BIOFAC(6,1)
D-5	Th-228+D , crustacea and mollusks	5.000E+02	5.000E+02	BIOFAC(6,2)
D-5				
D-5	Th-230 , fish	1.000E+02	1.000E+02	BIOFAC(7,1)
D-5	Th-230 , crustacea and mollusks	5.000E+02	5.000E+02	BIOFAC(7,2)
D-5				

Dose Conversion Factor (and Related) Parameter Summary (continued)
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Menu	Parameter	Current Value	Base Case*	Parameter Name
D-5	Th-232 , fish	1.000E+02	1.000E+02	BIOFAC(8,1)
D-5	Th-232 , crustacea and mollusks	5.000E+02	5.000E+02	BIOFAC(8,2)
D-5				
D-5	U-234 , fish	1.000E+01	1.000E+01	BIOFAC(9,1)
D-5	U-234 , crustacea and mollusks	6.000E+01	6.000E+01	BIOFAC(9,2)
D-5				
D-5	U-235+D , fish	1.000E+01	1.000E+01	BIOFAC(10,1)
D-5	U-235+D , crustacea and mollusks	6.000E+01	6.000E+01	BIOFAC(10,2)
D-5				
D-5	U-238 , fish	1.000E+01	1.000E+01	BIOFAC(11,1)
D-5	U-238 , crustacea and mollusks	6.000E+01	6.000E+01	BIOFAC(11,2)
D-5				
D-5	U-238+D , fish	1.000E+01	1.000E+01	BIOFAC(12,1)
D-5	U-238+D , crustacea and mollusks	6.000E+01	6.000E+01	BIOFAC(12,2)

*Base Case means Default.Lib w/o Associate Nuclide contributions.

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+03	1.000E+04	---	AREA
R011	Thickness of contaminated zone (m)	2.000E+00	2.000E+00	---	THICK0
R011	Length parallel to aquifer flow (m)	not used	1.000E+02	---	LCZPAQ
R011	Basic radiation dose limit (mrem/yr)	5.000E+03	3.000E+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)	not used	3.000E+02	---	T(7)
R011	Times for calculations (yr)	not used	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): Ac-227	2.275E+01	0.000E+00	---	S1(1)
R012	Initial principal radionuclide (pCi/g): Pa-231	2.275E+01	0.000E+00	---	S1(2)
R012	Initial principal radionuclide (pCi/g): Pb-210	5.000E+02	0.000E+00	---	S1(3)
R012	Initial principal radionuclide (pCi/g): Ra-226	5.000E+02	0.000E+00	---	S1(4)
R012	Initial principal radionuclide (pCi/g): Ra-228	2.000E+02	0.000E+00	---	S1(5)
R012	Initial principal radionuclide (pCi/g): Th-228	2.000E+02	0.000E+00	---	S1(6)
R012	Initial principal radionuclide (pCi/g): Th-230	5.000E+02	0.000E+00	---	S1(7)
R012	Initial principal radionuclide (pCi/g): Th-232	2.000E+02	0.000E+00	---	S1(8)
R012	Initial principal radionuclide (pCi/g): U-234	5.000E+02	0.000E+00	---	S1(9)
R012	Initial principal radionuclide (pCi/g): U-235	2.275E+01	0.000E+00	---	S1(10)
R012	Initial principal radionuclide (pCi/g): U-238	5.000E+02	0.000E+00	---	S1(11)
R012	Concentration in groundwater (pCi/L): Ac-227	not used	0.000E+00	---	W1(1)
R012	Concentration in groundwater (pCi/L): Pa-231	not used	0.000E+00	---	W1(2)
R012	Concentration in groundwater (pCi/L): Pb-210	not used	0.000E+00	---	W1(3)
R012	Concentration in groundwater (pCi/L): Ra-226	not used	0.000E+00	---	W1(4)
R012	Concentration in groundwater (pCi/L): Ra-228	not used	0.000E+00	---	W1(5)
R012	Concentration in groundwater (pCi/L): Th-228	not used	0.000E+00	---	W1(6)
R012	Concentration in groundwater (pCi/L): Th-230	not used	0.000E+00	---	W1(7)
R012	Concentration in groundwater (pCi/L): Th-232	not used	0.000E+00	---	W1(8)
R012	Concentration in groundwater (pCi/L): U-234	not used	0.000E+00	---	W1(9)
R012	Concentration in groundwater (pCi/L): U-235	not used	0.000E+00	---	W1(10)
R012	Concentration in groundwater (pCi/L): U-238	not used	0.000E+00	---	W1(11)
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)	0.000E+00	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)	4.300E+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

Site-Specific Parameter Summary (continued)

Menu	Parameter	User Input	Default	Used by RESRAD (If different from user input)	Parameter Name
R013	Irrigation (m/yr)	0.000E+00	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)	not used	1.000E+06	---	WAREA
R013	Accuracy for water/soil computations	not used	1.000E-03	---	EPS
R014	Density of saturated zone (g/cm**3)	not used	1.500E+00	---	DENSAQ
R014	Saturated zone total porosity	not used	4.000E-01	---	TPSZ
R014	Saturated zone effective porosity	not used	2.000E-01	---	EPSZ
R014	Saturated zone field capacity	not used	2.000E-01	---	FCSZ
R014	Saturated zone hydraulic conductivity (m/yr)	not used	1.000E+02	---	HCSZ
R014	Saturated zone hydraulic gradient	not used	2.000E-02	---	HGWT
R014	Saturated zone b parameter	not used	5.300E+00	---	BSZ
R014	Water table drop rate (m/yr)	not used	1.000E-03	---	VWT
R014	Well pump intake depth (m below water table)	not used	1.000E+01	---	DWIBWT
R014	Model: Nondispersion (ND) or Mass-Balance (MB)	not used	ND	---	MODEL
R014	Well pumping rate (m**3/yr)	not used	2.500E+02	---	UW
R015	Number of unsaturated zone strata	not used	1	---	NS
R015	Unsat. zone 1, thickness (m)	not used	4.000E+00	---	H(1)
R015	Unsat. zone 1, soil density (g/cm**3)	not used	1.500E+00	---	DENSUZ(1)
R015	Unsat. zone 1, total porosity	not used	4.000E-01	---	TPUZ(1)
R015	Unsat. zone 1, effective porosity	not used	2.000E-01	---	EPUZ(1)
R015	Unsat. zone 1, field capacity	not used	2.000E-01	---	FCUZ(1)
R015	Unsat. zone 1, soil-specific b parameter	not used	5.300E+00	---	BUZ(1)
R015	Unsat. zone 1, hydraulic conductivity (m/yr)	not used	1.000E+01	---	HCUZ(1)
R016	Distribution coefficients for Ac-227				
R016	Contaminated zone (cm**3/g)	2.000E+01	2.000E+01	---	DCNUCC(1)
R016	Unsaturated zone 1 (cm**3/g)	not used	2.000E+01	---	DCNUCU(1,1)
R016	Saturated zone (cm**3/g)	not used	2.000E+01	---	DCNUCS(1)
R016	Leach rate (/yr)	0.000E+00	0.000E+00	6.597E-03	ALEACH(1)
R016	Solubility constant	0.000E+00	0.000E+00	not used	SOLUBK(1)
R016	Distribution coefficients for Pa-231				
R016	Contaminated zone (cm**3/g)	5.000E+01	5.000E+01	---	DCNUCC(2)
R016	Unsaturated zone 1 (cm**3/g)	not used	5.000E+01	---	DCNUCU(2,1)
R016	Saturated zone (cm**3/g)	not used	5.000E+01	---	DCNUCS(2)
R016	Leach rate (/yr)	0.000E+00	0.000E+00	2.655E-03	ALEACH(2)
R016	Solubility constant	0.000E+00	0.000E+00	not used	SOLUBK(2)
R016	Distribution coefficients for Pb-210				
R016	Contaminated zone (cm**3/g)	1.000E+02	1.000E+02	---	DCNUCC(3)
R016	Unsaturated zone 1 (cm**3/g)	not used	1.000E+02	---	DCNUCU(3,1)
R016	Saturated zone (cm**3/g)	not used	1.000E+02	---	DCNUCS(3)
R016	Leach rate (/yr)	0.000E+00	0.000E+00	1.331E-03	ALEACH(3)
R016	Solubility constant	0.000E+00	0.000E+00	not used	SOLUBK(3)

Site-Specific Parameter Summary (continued)

Menu	Parameter	User Input	Default	Used by RESRAD (If different from user input)	Parameter Name
R016	Distribution coefficients for Ra-226				
R016	Contaminated zone (cm**3/g)	7.000E+01	7.000E+01	---	DCNUCC(4)
R016	Unsaturated zone 1 (cm**3/g)	not used	7.000E+01	---	DCNUCU(4,1)
R016	Saturated zone (cm**3/g)	not used	7.000E+01	---	DCNUCS(4)
R016	Leach rate (/yr)	0.000E+00	0.000E+00	1.899E-03	ALEACH(4)
R016	Solubility constant	0.000E+00	0.000E+00	not used	SOLUBK(4)
R016	Distribution coefficients for Ra-228				
R016	Contaminated zone (cm**3/g)	7.000E+01	7.000E+01	---	DCNUCC(5)
R016	Unsaturated zone 1 (cm**3/g)	not used	7.000E+01	---	DCNUCU(5,1)
R016	Saturated zone (cm**3/g)	not used	7.000E+01	---	DCNUCS(5)
R016	Leach rate (/yr)	0.000E+00	0.000E+00	1.899E-03	ALEACH(5)
R016	Solubility constant	0.000E+00	0.000E+00	not used	SOLUBK(5)
R016	Distribution coefficients for Th-228				
R016	Contaminated zone (cm**3/g)	6.000E+04	6.000E+04	---	DCNUCC(6)
R016	Unsaturated zone 1 (cm**3/g)	not used	6.000E+04	---	DCNUCU(6,1)
R016	Saturated zone (cm**3/g)	not used	6.000E+04	---	DCNUCS(6)
R016	Leach rate (/yr)	0.000E+00	0.000E+00	2.222E-06	ALEACH(6)
R016	Solubility constant	0.000E+00	0.000E+00	not used	SOLUBK(6)
R016	Distribution coefficients for Th-230				
R016	Contaminated zone (cm**3/g)	6.000E+04	6.000E+04	---	DCNUCC(7)
R016	Unsaturated zone 1 (cm**3/g)	not used	6.000E+04	---	DCNUCU(7,1)
R016	Saturated zone (cm**3/g)	not used	6.000E+04	---	DCNUCS(7)
R016	Leach rate (/yr)	0.000E+00	0.000E+00	2.222E-06	ALEACH(7)
R016	Solubility constant	0.000E+00	0.000E+00	not used	SOLUBK(7)
R016	Distribution coefficients for Th-232				
R016	Contaminated zone (cm**3/g)	6.000E+04	6.000E+04	---	DCNUCC(8)
R016	Unsaturated zone 1 (cm**3/g)	not used	6.000E+04	---	DCNUCU(8,1)
R016	Saturated zone (cm**3/g)	not used	6.000E+04	---	DCNUCS(8)
R016	Leach rate (/yr)	0.000E+00	0.000E+00	2.222E-06	ALEACH(8)
R016	Solubility constant	0.000E+00	0.000E+00	not used	SOLUBK(8)
R016	Distribution coefficients for U-234				
R016	Contaminated zone (cm**3/g)	5.000E+01	5.000E+01	---	DCNUCC(9)
R016	Unsaturated zone 1 (cm**3/g)	not used	5.000E+01	---	DCNUCU(9,1)
R016	Saturated zone (cm**3/g)	not used	5.000E+01	---	DCNUCS(9)
R016	Leach rate (/yr)	0.000E+00	0.000E+00	2.655E-03	ALEACH(9)
R016	Solubility constant	0.000E+00	0.000E+00	not used	SOLUBK(9)
R016	Distribution coefficients for U-235				
R016	Contaminated zone (cm**3/g)	5.000E+01	5.000E+01	---	DCNUCC(10)
R016	Unsaturated zone 1 (cm**3/g)	not used	5.000E+01	---	DCNUCU(10,1)
R016	Saturated zone (cm**3/g)	not used	5.000E+01	---	DCNUCS(10)
R016	Leach rate (/yr)	0.000E+00	0.000E+00	2.655E-03	ALEACH(10)
R016	Solubility constant	0.000E+00	0.000E+00	not used	SOLUBK(10)

Site-Specific Parameter Summary (continued)

Menu	Parameter	User Input	Default	Used by RESRAD (If different from user input)	Parameter Name
R016	Distribution coefficients for U-238				
R016	Contaminated zone (cm**3/g)	5.000E+01	5.000E+01	---	DCNUCC(11)
R016	Unsaturated zone 1 (cm**3/g)	not used	5.000E+01	---	DCNUCU(11,1)
R016	Saturated zone (cm**3/g)	not used	5.000E+01	---	DCNUCS(11)
R016	Leach rate (/yr)	0.000E+00	0.000E+00	2.655E-03	ALEACH(11)
R016	Solubility constant	0.000E+00	0.000E+00	not used	SOLUBK(11)
R017	Inhalation rate (m**3/yr)	1.490E+04	8.400E+03	---	INHALR
R017	Mass loading for inhalation (g/m**3)	1.000E-03	1.000E-04	---	MLINH
R017	Exposure duration	1.000E+00	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	0.000E+00	5.000E-01	---	FIND
R017	Fraction of time spent outdoors (on site)	9.100E-03	2.500E-01	---	FOTD
R017	Shape factor flag, external gamma	1.000E+00	1.000E+00	>0 shows circular AREA.	FS
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)	not used	1.600E+02	---	DIET(1)
R018	Leafy vegetable consumption (kg/yr)	not used	1.400E+01	---	DIET(2)
R018	Milk consumption (L/yr)	not used	9.200E+01	---	DIET(3)
R018	Meat and poultry consumption (kg/yr)	not used	6.300E+01	---	DIET(4)
R018	Fish consumption (kg/yr)	not used	5.400E+00	---	DIET(5)
R018	Other seafood consumption (kg/yr)	not used	9.000E-01	---	DIET(6)
R018	Soil ingestion rate (g/yr)	3.650E+01	3.650E+01	---	SOIL
R018	Drinking water intake (L/yr)	not used	5.100E+02	---	DWI

Site-Specific Parameter Summary (continued)

Menu	Parameter	User Input	Default	Used by RESRAD (If different from user input)	Parameter Name
R018	Contamination fraction of drinking water	not used	1.000E+00	---	FDW
R018	Contamination fraction of household water	not used	1.000E+00	---	FHHW
R018	Contamination fraction of livestock water	not used	1.000E+00	---	FLW
R018	Contamination fraction of irrigation water	not used	1.000E+00	---	FIRW
R018	Contamination fraction of aquatic food	not used	5.000E-01	---	FR9
R018	Contamination fraction of plant food	not used	-1	---	FPLANT
R018	Contamination fraction of meat	not used	-1	---	FMEAT
R018	Contamination fraction of milk	not used	-1	---	FMILK
R019	Livestock fodder intake for meat (kg/day)	not used	6.800E+01	---	LFI5
R019	Livestock fodder intake for milk (kg/day)	not used	5.500E+01	---	LFI6
R019	Livestock water intake for meat (L/day)	not used	5.000E+01	---	LWI5
R019	Livestock water intake for milk (L/day)	not used	1.600E+02	---	LWI6
R019	Livestock soil intake (kg/day)	not used	5.000E-01	---	LSI
R019	Mass loading for foliar deposition (g/m**3)	not used	1.000E-04	---	MLFD
R019	Depth of soil mixing layer (m)	1.500E-01	1.500E-01	---	DM
R019	Depth of roots (m)	not used	9.000E-01	---	DROOT
R019	Drinking water fraction from ground water	not used	1.000E+00	---	FGWDW
R019	Household water fraction from ground water	not used	1.000E+00	---	FGWHH
R019	Livestock water fraction from ground water	not used	1.000E+00	---	FGWLW
R019	Irrigation fraction from ground water	not used	1.000E+00	---	FGWIR
R19B	Wet weight crop yield for Non-Leafy (kg/m**2)	not used	7.000E-01	---	YV(1)
R19B	Wet weight crop yield for Leafy (kg/m**2)	not used	1.500E+00	---	YV(2)
R19B	Wet weight crop yield for Fodder (kg/m**2)	not used	1.100E+00	---	YV(3)
R19B	Growing Season for Non-Leafy (years)	not used	1.700E-01	---	TE(1)
R19B	Growing Season for Leafy (years)	not used	2.500E-01	---	TE(2)
R19B	Growing Season for Fodder (years)	not used	8.000E-02	---	TE(3)
R19B	Translocation Factor for Non-Leafy	not used	1.000E-01	---	TIV(1)
R19B	Translocation Factor for Leafy	not used	1.000E+00	---	TIV(2)
R19B	Translocation Factor for Fodder	not used	1.000E+00	---	TIV(3)
R19B	Dry Foliar Interception Fraction for Non-Leafy	not used	2.500E-01	---	RDRY(1)
R19B	Dry Foliar Interception Fraction for Leafy	not used	2.500E-01	---	RDRY(2)
R19B	Dry Foliar Interception Fraction for Fodder	not used	2.500E-01	---	RDRY(3)
R19B	Wet Foliar Interception Fraction for Non-Leafy	not used	2.500E-01	---	RWET(1)
R19B	Wet Foliar Interception Fraction for Leafy	not used	2.500E-01	---	RWET(2)
R19B	Wet Foliar Interception Fraction for Fodder	not used	2.500E-01	---	RWET(3)
R19B	Weathering Removal Constant for Vegetation	not used	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	0.000E+00	---	CO2F
STOR	Storage times of contaminated foodstuffs (days):				

Site-Specific Parameter Summary (continued)

Menu	Parameter	User Input	Default	Used by RESRAD (If different from user input)	Parameter Name
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
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	suppressed
4 -- meat ingestion	suppressed
5 -- milk ingestion	suppressed
6 -- aquatic foods	suppressed
7 -- drinking water	suppressed
8 -- soil ingestion	active
9 -- radon	suppressed
Find peak pathway doses	active

Contaminated Zone Dimensions	
Area:	1000.00 square meters
Thickness:	2.00 meters
Cover Depth:	0.00 meters

Initial Soil Concentrations, pCi/g	
Ac-227	2.275E+01
Pa-231	2.275E+01
Pb-210	5.000E+02
Ra-226	5.000E+02
Ra-228	2.000E+02
Th-228	2.000E+02
Th-230	5.000E+02
Th-232	2.000E+02
U-234	5.000E+02
U-235	2.275E+01
U-238	5.000E+02

Total Dose TDOSE(t), mrem/yr
Basic Radiation Dose Limit = 5.000E+03 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
TDOSE(t):	8.279E+01	8.266E+01	8.239E+01	8.149E+01	7.938E+01	7.331E+01
M(t):	1.656E-02	1.653E-02	1.648E-02	1.630E-02	1.588E-02	1.466E-02

Maximum TDOSE(t): 8.279E+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	frac
Ac-227	3.695E-01	0.0045	1.265E+00	0.0153	0.000E+00	0.0000	0.000E+00	0.0000	0.000E+00	0.0000	0.000E+00	0.0000	1.097E-01	0.0C
Pa-231	4.144E-02	0.0005	2.654E-01	0.0032	0.000E+00	0.0000	0.000E+00	0.0000	0.000E+00	0.0000	0.000E+00	0.0000	8.175E-02	0.0C
Pb-210	2.490E-02	0.0003	9.621E-02	0.0012	0.000E+00	0.0000	0.000E+00	0.0000	0.000E+00	0.0000	0.000E+00	0.0000	1.189E+00	0.01
Ra-226	4.555E+01	0.5502	3.769E-02	0.0005	0.000E+00	0.0000	0.000E+00	0.0000	0.000E+00	0.0000	0.000E+00	0.0000	2.377E-01	0.0C
Ra-228	1.175E+01	0.1420	9.806E-02	0.0012	0.000E+00	0.0000	0.000E+00	0.0000	0.000E+00	0.0000	0.000E+00	0.0000	9.847E-02	0.0C
Th-228	1.399E+01	0.1690	4.885E-01	0.0059	0.000E+00	0.0000	0.000E+00	0.0000	0.000E+00	0.0000	0.000E+00	0.0000	4.506E-02	0.0C
Th-230	1.492E-02	0.0002	1.374E+00	0.0166	0.000E+00	0.0000	0.000E+00	0.0000	0.000E+00	0.0000	0.000E+00	0.0000	9.106E-02	0.0C
Th-232	6.729E-01	0.0081	2.769E+00	0.0335	0.000E+00	0.0000	0.000E+00	0.0000	0.000E+00	0.0000	0.000E+00	0.0000	1.872E-01	0.0C
U-234	1.694E-03	0.0000	5.557E-01	0.0067	0.000E+00	0.0000	0.000E+00	0.0000	0.000E+00	0.0000	0.000E+00	0.0000	4.694E-02	0.0C
U-235	1.433E-01	0.0017	2.356E-02	0.0003	0.000E+00	0.0000	0.000E+00	0.0000	0.000E+00	0.0000	0.000E+00	0.0000	2.018E-03	0.0C
U-238	6.191E-01	0.0075	4.969E-01	0.0060	0.000E+00	0.0000	0.000E+00	0.0000	0.000E+00	0.0000	0.000E+00	0.0000	4.457E-02	0.0C
Total	7.319E+01	0.8840	7.471E+00	0.0902	0.000E+00	0.0000	0.000E+00	0.0000	0.000E+00	0.0000	0.000E+00	0.0000	2.134E+00	0.02

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	frac
Ac-227	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	1.744E+00	0.02
Pa-231	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	3.886E-01	0.0C
Pb-210	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	1.310E+00	0.01
Ra-226	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	4.583E+01	0.55
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	1.195E+01	0.14
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	1.452E+01	0.17
Th-230	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+00	0.01
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	3.630E+00	0.04
U-234	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	6.043E-01	0.0C
U-235	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	1.689E-01	0.0C
U-238	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	1.161E+00	0.01
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	8.279E+01	1.0C

*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	frac
Ac-227	3.556E-01	0.0043	1.217E+00	0.0147	0.000E+00	0.0000	0.000E+00	0.0000	0.000E+00	0.0000	0.000E+00	0.0000	1.056E-01	0.00
Pa-231	5.285E-02	0.0006	3.042E-01	0.0037	0.000E+00	0.0000	0.000E+00	0.0000	0.000E+00	0.0000	0.000E+00	0.0000	8.495E-02	0.00
Pb-210	2.411E-02	0.0003	9.314E-02	0.0011	0.000E+00	0.0000	0.000E+00	0.0000	0.000E+00	0.0000	0.000E+00	0.0000	1.151E+00	0.01
Ra-226	4.545E+01	0.5498	4.054E-02	0.0005	0.000E+00	0.0000	0.000E+00	0.0000	0.000E+00	0.0000	0.000E+00	0.0000	2.734E-01	0.00
Ra-228	1.439E+01	0.1740	2.260E-01	0.0027	0.000E+00	0.0000	0.000E+00	0.0000	0.000E+00	0.0000	0.000E+00	0.0000	9.997E-02	0.00
Th-228	9.739E+00	0.1178	3.400E-01	0.0041	0.000E+00	0.0000	0.000E+00	0.0000	0.000E+00	0.0000	0.000E+00	0.0000	3.136E-02	0.00
Th-230	3.463E-02	0.0004	1.374E+00	0.0166	0.000E+00	0.0000	0.000E+00	0.0000	0.000E+00	0.0000	0.000E+00	0.0000	9.117E-02	0.00
Th-232	2.267E+00	0.0274	2.790E+00	0.0337	0.000E+00	0.0000	0.000E+00	0.0000	0.000E+00	0.0000	0.000E+00	0.0000	1.993E-01	0.00
U-234	1.689E-03	0.0000	5.542E-01	0.0067	0.000E+00	0.0000	0.000E+00	0.0000	0.000E+00	0.0000	0.000E+00	0.0000	4.681E-02	0.00
U-235	1.430E-01	0.0017	2.351E-02	0.0003	0.000E+00	0.0000	0.000E+00	0.0000	0.000E+00	0.0000	0.000E+00	0.0000	2.015E-03	0.00
U-238	6.175E-01	0.0075	4.956E-01	0.0060	0.000E+00	0.0000	0.000E+00	0.0000	0.000E+00	0.0000	0.000E+00	0.0000	4.445E-02	0.00
Total	7.307E+01	0.8840	7.458E+00	0.0902	0.000E+00	0.0000	0.000E+00	0.0000	0.000E+00	0.0000	0.000E+00	0.0000	2.130E+00	0.02

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	frac
Ac-227	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	1.679E+00	0.02
Pa-231	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	4.420E-01	0.00
Pb-210	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	1.268E+00	0.01
Ra-226	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	4.576E+01	0.55
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	1.471E+01	0.17
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	1.011E+01	0.12
Th-230	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+00	0.01
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	5.256E+00	0.06
U-234	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	6.027E-01	0.00
U-235	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	1.685E-01	0.00
U-238	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	1.158E+00	0.01
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	8.266E+01	1.00

*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	frac
Ac-227	3.293E-01	0.0040	1.127E+00	0.0137	0.000E+00	0.0000	0.000E+00	0.0000	0.000E+00	0.0000	0.000E+00	0.0000	9.775E-02	0.0C
Pa-231	7.430E-02	0.0009	3.769E-01	0.0046	0.000E+00	0.0000	0.000E+00	0.0000	0.000E+00	0.0000	0.000E+00	0.0000	9.095E-02	0.0C
Pb-210	2.259E-02	0.0003	8.729E-02	0.0011	0.000E+00	0.0000	0.000E+00	0.0000	0.000E+00	0.0000	0.000E+00	0.0000	1.079E+00	0.01
Ra-226	4.524E+01	0.5491	4.594E-02	0.0006	0.000E+00	0.0000	0.000E+00	0.0000	0.000E+00	0.0000	0.000E+00	0.0000	3.413E-01	0.0C
Ra-228	1.565E+01	0.1899	3.301E-01	0.0040	0.000E+00	0.0000	0.000E+00	0.0000	0.000E+00	0.0000	0.000E+00	0.0000	9.238E-02	0.0C
Th-228	4.718E+00	0.0573	1.647E-01	0.0020	0.000E+00	0.0000	0.000E+00	0.0000	0.000E+00	0.0000	0.000E+00	0.0000	1.520E-02	0.0C
Th-230	7.392E-02	0.0009	1.374E+00	0.0167	0.000E+00	0.0000	0.000E+00	0.0000	0.000E+00	0.0000	0.000E+00	0.0000	9.143E-02	0.0C
Th-232	5.966E+00	0.0724	2.860E+00	0.0347	0.000E+00	0.0000	0.000E+00	0.0000	0.000E+00	0.0000	0.000E+00	0.0000	2.226E-01	0.0C
U-234	1.681E-03	0.0000	5.513E-01	0.0067	0.000E+00	0.0000	0.000E+00	0.0000	0.000E+00	0.0000	0.000E+00	0.0000	4.657E-02	0.0C
U-235	1.422E-01	0.0017	2.340E-02	0.0003	0.000E+00	0.0000	0.000E+00	0.0000	0.000E+00	0.0000	0.000E+00	0.0000	2.008E-03	0.0C
U-238	6.142E-01	0.0075	4.930E-01	0.0060	0.000E+00	0.0000	0.000E+00	0.0000	0.000E+00	0.0000	0.000E+00	0.0000	4.421E-02	0.0C
Total	7.283E+01	0.8840	7.434E+00	0.0902	0.000E+00	0.0000	0.000E+00	0.0000	0.000E+00	0.0000	0.000E+00	0.0000	2.123E+00	0.02

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	frac
Ac-227	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	1.554E+00	0.01
Pa-231	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	5.422E-01	0.0C
Pb-210	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	1.189E+00	0.01
Ra-226	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	4.563E+01	0.55
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	1.607E+01	0.19
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	4.898E+00	0.05
Th-230	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	1.540E+00	0.01
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	9.048E+00	0.1C
U-234	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	5.996E-01	0.0C
U-235	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	1.676E-01	0.0C
U-238	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	1.151E+00	0.01
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	8.239E+01	1.0C

*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	frac
Ac-227	2.516E-01	0.0031	8.614E-01	0.0106	0.000E+00	0.0000	0.000E+00	0.0000	0.000E+00	0.0000	0.000E+00	0.0000	7.469E-02	0.0C
Pa-231	1.366E-01	0.0017	5.881E-01	0.0072	0.000E+00	0.0000	0.000E+00	0.0000	0.000E+00	0.0000	0.000E+00	0.0000	1.082E-01	0.0C
Pb-210	1.801E-02	0.0002	6.957E-02	0.0009	0.000E+00	0.0000	0.000E+00	0.0000	0.000E+00	0.0000	0.000E+00	0.0000	8.599E-01	0.01
Ra-226	4.451E+01	0.5462	6.205E-02	0.0008	0.000E+00	0.0000	0.000E+00	0.0000	0.000E+00	0.0000	0.000E+00	0.0000	5.440E-01	0.0C
Ra-228	9.101E+00	0.1117	2.260E-01	0.0028	0.000E+00	0.0000	0.000E+00	0.0000	0.000E+00	0.0000	0.000E+00	0.0000	4.713E-02	0.0C
Th-228	3.735E-01	0.0046	1.304E-02	0.0002	0.000E+00	0.0000	0.000E+00	0.0000	0.000E+00	0.0000	0.000E+00	0.0000	1.203E-03	0.0C
Th-230	2.100E-01	0.0026	1.374E+00	0.0169	0.000E+00	0.0000	0.000E+00	0.0000	0.000E+00	0.0000	0.000E+00	0.0000	9.278E-02	0.0C
Th-232	1.669E+01	0.2048	3.112E+00	0.0382	0.000E+00	0.0000	0.000E+00	0.0000	0.000E+00	0.0000	0.000E+00	0.0000	2.810E-01	0.0C
U-234	1.659E-03	0.0000	5.412E-01	0.0066	0.000E+00	0.0000	0.000E+00	0.0000	0.000E+00	0.0000	0.000E+00	0.0000	4.571E-02	0.0C
U-235	1.396E-01	0.0017	2.304E-02	0.0003	0.000E+00	0.0000	0.000E+00	0.0000	0.000E+00	0.0000	0.000E+00	0.0000	1.986E-03	0.0C
U-238	6.029E-01	0.0074	4.839E-01	0.0059	0.000E+00	0.0000	0.000E+00	0.0000	0.000E+00	0.0000	0.000E+00	0.0000	4.340E-02	0.0C
Total	7.203E+01	0.8840	7.354E+00	0.0902	0.000E+00	0.0000	0.000E+00	0.0000	0.000E+00	0.0000	0.000E+00	0.0000	2.100E+00	0.02

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	frac
Ac-227	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	1.188E+00	0.01
Pa-231	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	8.329E-01	0.01
Pb-210	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	9.474E-01	0.01
Ra-226	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	4.512E+01	0.55
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	9.374E+00	0.11
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	3.878E-01	0.0C
Th-230	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	1.677E+00	0.02
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	2.008E+01	0.24
U-234	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	5.886E-01	0.0C
U-235	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	1.646E-01	0.0C
U-238	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	1.130E+00	0.01
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	8.149E+01	1.0C

*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	frac
Ac-227	1.166E-01	0.0015	3.994E-01	0.0050	0.000E+00	0.0000	0.000E+00	0.0000	0.000E+00	0.0000	0.000E+00	0.0000	3.463E-02	0.0C
Pa-231	2.380E-01	0.0030	9.288E-01	0.0117	0.000E+00	0.0000	0.000E+00	0.0000	0.000E+00	0.0000	0.000E+00	0.0000	1.347E-01	0.0C
Pb-210	9.417E-03	0.0001	3.638E-02	0.0005	0.000E+00	0.0000	0.000E+00	0.0000	0.000E+00	0.0000	0.000E+00	0.0000	4.497E-01	0.0C
Ra-226	4.249E+01	0.5353	9.024E-02	0.0011	0.000E+00	0.0000	0.000E+00	0.0000	0.000E+00	0.0000	0.000E+00	0.0000	9.026E-01	0.01
Ra-228	8.346E-01	0.0105	2.121E-02	0.0003	0.000E+00	0.0000	0.000E+00	0.0000	0.000E+00	0.0000	0.000E+00	0.0000	4.227E-03	0.0C
Th-228	2.662E-04	0.0000	9.295E-06	0.0000	0.000E+00	0.0000	0.000E+00	0.0000	0.000E+00	0.0000	0.000E+00	0.0000	8.574E-07	0.0C
Th-230	5.867E-01	0.0074	1.375E+00	0.0173	0.000E+00	0.0000	0.000E+00	0.0000	0.000E+00	0.0000	0.000E+00	0.0000	9.922E-02	0.0C
Th-232	2.519E+01	0.3174	3.326E+00	0.0419	0.000E+00	0.0000	0.000E+00	0.0000	0.000E+00	0.0000	0.000E+00	0.0000	3.244E-01	0.0C
U-234	1.644E-03	0.0000	5.134E-01	0.0065	0.000E+00	0.0000	0.000E+00	0.0000	0.000E+00	0.0000	0.000E+00	0.0000	4.336E-02	0.0C
U-235	1.325E-01	0.0017	2.217E-02	0.0003	0.000E+00	0.0000	0.000E+00	0.0000	0.000E+00	0.0000	0.000E+00	0.0000	1.934E-03	0.0C
U-238	5.717E-01	0.0072	4.589E-01	0.0058	0.000E+00	0.0000	0.000E+00	0.0000	0.000E+00	0.0000	0.000E+00	0.0000	4.116E-02	0.0C
Total	7.018E+01	0.8840	7.171E+00	0.0903	0.000E+00	0.0000	0.000E+00	0.0000	0.000E+00	0.0000	0.000E+00	0.0000	2.036E+00	0.02

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	frac
Ac-227	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	5.507E-01	0.0C
Pa-231	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	1.302E+00	0.01
Pb-210	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	4.955E-01	0.0C
Ra-226	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	4.348E+01	0.54
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	8.600E-01	0.01
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	2.764E-04	0.0C
Th-230	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	2.061E+00	0.02
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	2.884E+01	0.36
U-234	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	5.585E-01	0.0C
U-235	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	1.566E-01	0.0C
U-238	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	1.072E+00	0.01
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	7.938E+01	1.0C

*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-	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	frac
Ac-227	7.916E-03	0.0001	2.710E-02	0.0004	0.000E+00	0.0000	0.000E+00	0.0000	0.000E+00	0.0000	0.000E+00	0.0000	2.350E-03	0.0C
Pa-231	2.764E-01	0.0038	1.041E+00	0.0142	0.000E+00	0.0000	0.000E+00	0.0000	0.000E+00	0.0000	0.000E+00	0.0000	1.352E-01	0.0C
Pb-210	9.739E-04	0.0000	3.763E-03	0.0001	0.000E+00	0.0000	0.000E+00	0.0000	0.000E+00	0.0000	0.000E+00	0.0000	4.651E-02	0.0C
Ra-226	3.610E+01	0.4924	1.047E-01	0.0014	0.000E+00	0.0000	0.000E+00	0.0000	0.000E+00	0.0000	0.000E+00	0.0000	1.113E+00	0.01
Ra-228	1.582E-04	0.0000	4.021E-06	0.0000	0.000E+00	0.0000	0.000E+00	0.0000	0.000E+00	0.0000	0.000E+00	0.0000	8.011E-07	0.0C
Th-228	2.574E-15	0.0000	8.986E-17	0.0000	0.000E+00	0.0000	0.000E+00	0.0000	0.000E+00	0.0000	0.000E+00	0.0000	8.289E-18	0.0C
Th-230	1.775E+00	0.0242	1.377E+00	0.0188	0.000E+00	0.0000	0.000E+00	0.0000	0.000E+00	0.0000	0.000E+00	0.0000	1.318E-01	0.0C
Th-232	2.601E+01	0.3548	3.346E+00	0.0456	0.000E+00	0.0000	0.000E+00	0.0000	0.000E+00	0.0000	0.000E+00	0.0000	3.285E-01	0.0C
U-234	2.064E-03	0.0000	4.271E-01	0.0058	0.000E+00	0.0000	0.000E+00	0.0000	0.000E+00	0.0000	0.000E+00	0.0000	3.607E-02	0.0C
U-235	1.104E-01	0.0015	1.983E-02	0.0003	0.000E+00	0.0000	0.000E+00	0.0000	0.000E+00	0.0000	0.000E+00	0.0000	1.795E-03	0.0C
U-238	4.747E-01	0.0065	3.811E-01	0.0052	0.000E+00	0.0000	0.000E+00	0.0000	0.000E+00	0.0000	0.000E+00	0.0000	3.418E-02	0.0C
Total	6.476E+01	0.8833	6.727E+00	0.0918	0.000E+00	0.0000	0.000E+00	0.0000	0.000E+00	0.0000	0.000E+00	0.0000	1.830E+00	0.02

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	frac
Ac-227	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	3.737E-02	0.0C
Pa-231	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	1.452E+00	0.01
Pb-210	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	5.124E-02	0.0C
Ra-226	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	3.732E+01	0.5C
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	1.630E-04	0.0C
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	2.672E-15	0.0C
Th-230	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	3.283E+00	0.04
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	2.969E+01	0.4C
U-234	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	4.652E-01	0.0C
U-235	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	1.320E-01	0.0C
U-238	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	8.901E-01	0.01
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	7.331E+01	1.0C

*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)	Thread Fraction	DSR(j,t) At Time in Years (mrem/yr)/(pCi/g) 0.000E+00	1.000E+00	3.000E+00	1.000E+01	3.000E+01	1.000E+02
Ac-227+D	Ac-227+D	1.000E+00	7.667E-02	7.378E-02	6.832E-02	5.221E-02	2.421E-02	1.643E-03
Pa-231	Pa-231	1.000E+00	1.585E-02	1.581E-02	1.573E-02	1.544E-02	1.463E-02	1.213E-02
Pa-231	Ac-227+D	1.000E+00	1.227E-03	3.615E-03	8.105E-03	2.117E-02	4.258E-02	5.171E-02
Pa-231	∑DSR(j)		1.708E-02	1.943E-02	2.383E-02	3.661E-02	5.721E-02	6.384E-02
Pb-210+D	Pb-210+D	1.000E+00	2.620E-03	2.537E-03	2.378E-03	1.895E-03	9.909E-04	1.025E-04
Ra-226+D	Ra-226+D	1.000E+00	9.162E-02	9.141E-02	9.098E-02	8.951E-02	8.543E-02	7.256E-02
Ra-226+D	Pb-210+D	1.000E+00	4.091E-05	1.209E-04	2.726E-04	7.271E-04	1.539E-03	2.071E-03
Ra-226+D	∑DSR(j)		9.166E-02	9.153E-02	9.125E-02	9.023E-02	8.697E-02	7.463E-02
Ra-228+D	Ra-228+D	1.000E+00	4.636E-02	4.102E-02	3.211E-02	1.363E-02	1.177E-03	2.230E-07
Ra-228+D	Th-228+D	1.000E+00	1.338E-02	3.254E-02	4.825E-02	3.325E-02	3.123E-03	5.921E-07
Ra-228+D	∑DSR(j)		5.974E-02	7.356E-02	8.036E-02	4.687E-02	4.300E-03	8.151E-07
Th-228+D	Th-228+D	1.000E+00	7.262E-02	5.055E-02	2.449E-02	1.939E-03	1.382E-06	1.336E-17
Th-230	Th-230	1.000E+00	2.940E-03	2.940E-03	2.940E-03	2.940E-03	2.939E-03	2.937E-03
Th-230	Ra-226+D	1.000E+00	1.985E-05	5.950E-05	1.385E-04	4.121E-04	1.170E-03	3.558E-03
Th-230	Pb-210+D	1.000E+00	5.925E-09	4.107E-08	2.123E-07	1.757E-06	1.200E-05	7.140E-05
Th-230	∑DSR(j)		2.960E-03	3.000E-03	3.079E-03	3.354E-03	4.121E-03	6.567E-03
Th-232	Th-232	1.000E+00	1.474E-02	1.474E-02	1.474E-02	1.474E-02	1.474E-02	1.473E-02
Th-232	Ra-228+D	1.000E+00	2.852E-03	8.112E-03	1.688E-02	3.508E-02	4.733E-02	4.849E-02
Th-232	Th-228+D	1.000E+00	5.595E-04	3.431E-03	1.362E-02	5.059E-02	8.215E-02	8.521E-02
Th-232	∑DSR(j)		1.815E-02	2.628E-02	4.524E-02	1.004E-01	1.442E-01	1.484E-01
U-234	U-234	1.000E+00	1.209E-03	1.205E-03	1.199E-03	1.177E-03	1.116E-03	9.265E-04
U-234	Th-230	1.000E+00	1.322E-08	3.962E-08	9.221E-08	2.741E-07	7.753E-07	2.333E-06
U-234	Ra-226+D	1.000E+00	5.954E-11	4.162E-10	2.193E-09	1.939E-08	1.582E-07	1.531E-06
U-234	Pb-210+D	1.000E+00	1.335E-14	1.987E-13	2.277E-12	5.668E-11	1.166E-09	2.482E-08
U-234	∑DSR(j)		1.209E-03	1.205E-03	1.199E-03	1.177E-03	1.117E-03	9.304E-04
U-235+D	U-235+D	1.000E+00	7.425E-03	7.405E-03	7.366E-03	7.230E-03	6.856E-03	5.693E-03
U-235+D	Pa-231	1.000E+00	1.677E-07	5.018E-07	1.165E-06	3.429E-06	9.445E-06	2.582E-05
U-235+D	Ac-227+D	1.000E+00	8.679E-09	6.000E-08	3.084E-07	2.501E-06	1.619E-05	8.254E-05
U-235+D	∑DSR(j)		7.425E-03	7.405E-03	7.367E-03	7.236E-03	6.882E-03	5.801E-03
U-238	U-238	5.400E-05	5.826E-08	5.811E-08	5.780E-08	5.674E-08	5.380E-08	4.468E-08
U-238+D	U-238+D	9.999E-01	2.321E-03	2.315E-03	2.303E-03	2.260E-03	2.143E-03	1.780E-03
U-238+D	U-234	9.999E-01	1.712E-09	5.125E-09	1.190E-08	3.503E-08	9.649E-08	2.640E-07
U-238+D	Th-230	9.999E-01	1.249E-14	8.729E-14	4.598E-13	4.063E-12	3.307E-11	3.177E-10
U-238+D	Ra-226+D	9.999E-01	4.219E-17	6.318E-16	7.344E-15	1.922E-13	4.525E-12	1.417E-10
U-238+D	Pb-210+D	9.999E-01	7.576E-21	2.332E-19	5.788E-18	4.285E-16	2.614E-14	1.933E-12
U-238+D	∑DSR(j)		2.321E-03	2.315E-03	2.303E-03	2.260E-03	2.143E-03	1.780E-03

The DSR includes contributions from associated (half-life ≤ 180 days) daughters.

Single Radionuclide Soil Guidelines G(i,t) in pCi/g
Basic Radiation Dose Limit = 5.000E+03 mrem/yr

Nuclide (i)	t= 0.000E+00	1.000E+00	3.000E+00	1.000E+01	3.000E+01	1.000E+02
Ac-227	6.521E+04	6.777E+04	7.318E+04	9.577E+04	2.066E+05	3.044E+06
Pa-231	2.927E+05	2.574E+05	2.098E+05	1.366E+05	8.740E+04	7.832E+04
Pb-210	1.908E+06	1.971E+06	2.103E+06	2.639E+06	5.046E+06	4.879E+07
Ra-226	5.455E+04	5.463E+04	5.479E+04	5.541E+04	5.749E+04	6.700E+04
Ra-228	8.369E+04	6.797E+04	6.222E+04	1.067E+05	1.163E+06	6.134E+09
Th-228	6.885E+04	9.891E+04	2.042E+05	2.579E+06	3.618E+09	*8.195E+14
Th-230	1.689E+06	1.667E+06	1.624E+06	1.491E+06	1.213E+06	7.614E+05
Th-232	*1.097E+05	*1.097E+05	*1.097E+05	4.980E+04	3.467E+04	3.369E+04
U-234	4.137E+06	4.148E+06	4.170E+06	4.247E+06	4.477E+06	5.374E+06
U-235	6.734E+05	6.752E+05	6.787E+05	6.910E+05	7.266E+05	8.619E+05
U-238	*3.361E+05	*3.361E+05	*3.361E+05	*3.361E+05	*3.361E+05	*3.361E+05

*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)
Ac-227	2.275E+01	0.000E+00	7.667E-02	6.521E+04	7.667E-02	6.521E+04
Pa-231	2.275E+01	68.2 ± 0.1	6.614E-02	7.560E+04	1.708E-02	2.927E+05
Pb-210	5.000E+02	0.000E+00	2.620E-03	1.908E+06	2.620E-03	1.908E+06
Ra-226	5.000E+02	0.000E+00	9.166E-02	5.455E+04	9.166E-02	5.455E+04
Ra-228	2.000E+02	2.711 ± 0.005	8.050E-02	6.211E+04	5.974E-02	8.369E+04
Th-228	2.000E+02	0.000E+00	7.262E-02	6.885E+04	7.262E-02	6.885E+04
Th-230	5.000E+02	1.000E+02	6.567E-03	7.614E+05	2.960E-03	1.689E+06
Th-232	2.000E+02	90.5 ± 0.2	1.484E-01	3.369E+04	1.815E-02	*1.097E+05
U-234	5.000E+02	0.000E+00	1.209E-03	4.137E+06	1.209E-03	4.137E+06
U-235	2.275E+01	0.000E+00	7.425E-03	6.734E+05	7.425E-03	6.734E+05
U-238	5.000E+02	0.000E+00	2.321E-03	*3.361E+05	2.321E-03	*3.361E+05

*At specific activity limit

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

Nuclide (j)	Parent (i)	THF(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
Ac-227	Ac-227	1.000E+00	1.744E+00	1.679E+00	1.554E+00	1.188E+00	5.507E-01	3.737E-02
Ac-227	Pa-231	1.000E+00	2.792E-02	8.225E-02	1.844E-01	4.817E-01	9.687E-01	1.176E+00
Ac-227	U-235	1.000E+00	1.974E-07	1.365E-06	7.016E-06	5.689E-05	3.684E-04	1.878E-03
Ac-227	∑DOSE(j)		1.772E+00	1.761E+00	1.739E+00	1.669E+00	1.520E+00	1.216E+00
Pa-231	Pa-231	1.000E+00	3.607E-01	3.597E-01	3.578E-01	3.512E-01	3.329E-01	2.760E-01
Pa-231	U-235	1.000E+00	3.814E-06	1.142E-05	2.650E-05	7.802E-05	2.149E-04	5.875E-04
Pa-231	∑DOSE(j)		3.607E-01	3.597E-01	3.578E-01	3.512E-01	3.331E-01	2.766E-01
Pb-210	Pb-210	1.000E+00	1.310E+00	1.268E+00	1.189E+00	9.474E-01	4.955E-01	5.124E-02
Pb-210	Ra-226	1.000E+00	2.046E-02	6.043E-02	1.363E-01	3.636E-01	7.694E-01	1.035E+00
Pb-210	Th-230	1.000E+00	2.962E-06	2.053E-05	1.062E-04	8.783E-04	6.001E-03	3.570E-02
Pb-210	U-234	1.000E+00	6.675E-12	9.933E-11	1.138E-09	2.834E-08	5.830E-07	1.241E-05
Pb-210	U-238	9.999E-01	3.788E-18	1.166E-16	2.894E-15	2.142E-13	1.307E-11	9.667E-10
Pb-210	∑DOSE(j)		1.331E+00	1.329E+00	1.325E+00	1.312E+00	1.271E+00	1.122E+00
Ra-226	Ra-226	1.000E+00	4.581E+01	4.570E+01	4.549E+01	4.475E+01	4.271E+01	3.628E+01
Ra-226	Th-230	1.000E+00	9.927E-03	2.975E-02	6.925E-02	2.061E-01	5.848E-01	1.779E+00
Ra-226	U-234	1.000E+00	2.977E-08	2.081E-07	1.096E-06	9.696E-06	7.908E-05	7.653E-04
Ra-226	U-238	9.999E-01	2.109E-14	3.159E-13	3.672E-12	9.609E-11	2.262E-09	7.086E-08
Ra-226	∑DOSE(j)		4.582E+01	4.573E+01	4.556E+01	4.496E+01	4.330E+01	3.806E+01
Ra-228	Ra-228	1.000E+00	9.273E+00	8.204E+00	6.422E+00	2.728E+00	2.354E-01	4.461E-05
Ra-228	Th-232	1.000E+00	5.703E-01	1.622E+00	3.377E+00	7.016E+00	9.467E+00	9.697E+00
Ra-228	∑DOSE(j)		9.843E+00	9.826E+00	9.799E+00	9.741E+00	9.702E+00	9.697E+00
Th-228	Ra-228	1.000E+00	2.676E+00	6.507E+00	9.649E+00	6.649E+00	6.246E-01	1.184E-04
Th-228	Th-228	1.000E+00	1.452E+01	1.011E+01	4.898E+00	3.878E-01	2.764E-04	2.672E-15
Th-228	Th-232	1.000E+00	1.119E-01	6.862E-01	2.724E+00	1.012E+01	1.643E+01	1.704E+01
Th-228	∑DOSE(j)		1.731E+01	1.730E+01	1.727E+01	1.715E+01	1.705E+01	1.704E+01
Th-230	Th-230	1.000E+00	1.470E+00	1.470E+00	1.470E+00	1.470E+00	1.470E+00	1.469E+00
Th-230	U-234	1.000E+00	6.612E-06	1.981E-05	4.610E-05	1.370E-04	3.877E-04	1.167E-03
Th-230	U-238	9.999E-01	6.245E-12	4.365E-11	2.299E-10	2.032E-09	1.654E-08	1.588E-07
Th-230	∑DOSE(j)		1.470E+00	1.470E+00	1.470E+00	1.470E+00	1.470E+00	1.470E+00
Th-232	Th-232	1.000E+00	2.947E+00	2.947E+00	2.947E+00	2.947E+00	2.947E+00	2.947E+00
U-234	U-234	1.000E+00	6.043E-01	6.027E-01	5.995E-01	5.885E-01	5.580E-01	4.632E-01
U-234	U-238	9.999E-01	8.562E-07	2.562E-06	5.948E-06	1.752E-05	4.825E-05	1.320E-04
U-234	∑DOSE(j)		6.043E-01	6.027E-01	5.995E-01	5.885E-01	5.580E-01	4.634E-01
U-235	U-235	1.000E+00	1.689E-01	1.685E-01	1.676E-01	1.645E-01	1.560E-01	1.295E-01
U-238	U-238	5.400E-05	2.913E-05	2.905E-05	2.890E-05	2.837E-05	2.690E-05	2.234E-05
U-238	U-238	9.999E-01	1.161E+00	1.157E+00	1.151E+00	1.130E+00	1.072E+00	8.899E-01
U-238	∑DOSE(j)		1.161E+00	1.158E+00	1.151E+00	1.130E+00	1.072E+00	8.899E-01

THF(i) is the thread fraction of the parent nuclide.

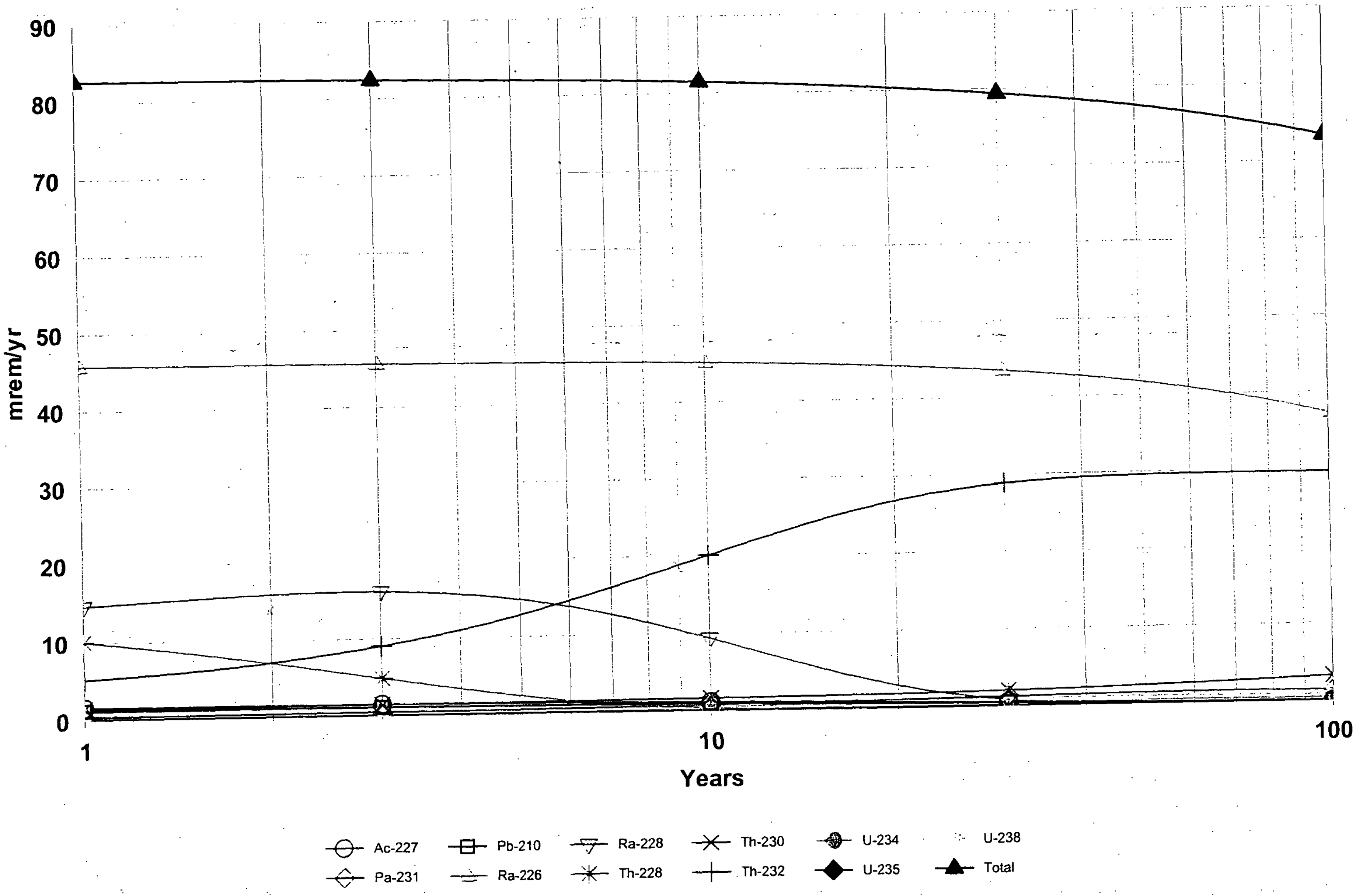
Individual Nuclide Soil Concentration
Parent Nuclide and Branch Fraction Indicated

Nuclide (j)	Parent (i)	THF(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
Ac-227	Ac-227	1.000E+00	2.275E+01	2.189E+01	2.027E+01	1.549E+01	7.182E+00	4.874E-01
Ac-227	Pa-231	1.000E+00	0.000E+00	7.096E-01	2.044E+00	5.928E+00	1.230E+01	1.506E+01
Ac-227	U-235	1.000E+00	0.000E+00	7.551E-06	6.603E-05	6.645E-04	4.589E-03	2.390E-02
Ac-227	∑S(j):		2.275E+01	2.260E+01	2.232E+01	2.142E+01	1.948E+01	1.558E+01
Pa-231	Pa-231	1.000E+00	2.275E+01	2.269E+01	2.257E+01	2.215E+01	2.099E+01	1.741E+01
Pa-231	U-235	1.000E+00	0.000E+00	4.801E-04	1.433E-03	4.687E-03	1.333E-02	3.687E-02
Pa-231	∑S(j):		2.275E+01	2.269E+01	2.257E+01	2.215E+01	2.101E+01	1.744E+01
Pb-210	Pb-210	1.000E+00	5.000E+02	4.841E+02	4.537E+02	3.616E+02	1.891E+02	1.956E+01
Pb-210	Ra-226	1.000E+00	0.000E+00	1.527E+01	4.427E+01	1.311E+02	2.864E+02	3.890E+02
Pb-210	Th-230	1.000E+00	0.000E+00	3.328E-03	2.927E-02	3.006E-01	2.191E+00	1.332E+01
Pb-210	U-234	1.000E+00	0.000E+00	1.001E-08	2.652E-07	9.215E-06	2.092E-04	4.605E-03
Pb-210	U-238	9.999E-01	0.000E+00	7.102E-15	5.662E-13	6.616E-11	4.608E-09	3.569E-07
Pb-210	∑S(j):		5.000E+02	4.993E+02	4.980E+02	4.930E+02	4.776E+02	4.218E+02
Ra-226	Ra-226	1.000E+00	5.000E+02	4.988E+02	4.965E+02	4.885E+02	4.662E+02	3.960E+02
Ra-226	Th-230	1.000E+00	0.000E+00	2.164E-01	6.475E-01	2.141E+00	6.275E+00	1.931E+01
Ra-226	U-234	1.000E+00	0.000E+00	9.733E-07	8.731E-06	9.588E-05	8.348E-04	8.267E-03
Ra-226	U-238	9.999E-01	0.000E+00	9.195E-13	2.473E-11	9.038E-10	2.349E-08	7.617E-07
Ra-226	∑S(j):		5.000E+02	4.991E+02	4.972E+02	4.906E+02	4.725E+02	4.153E+02
Ra-228	Ra-228	1.000E+00	2.000E+02	1.770E+02	1.385E+02	5.878E+01	5.078E+00	9.622E-04
Ra-228	Th-232	1.000E+00	0.000E+00	2.269E+01	6.053E+01	1.390E+02	1.919E+02	1.969E+02
Ra-228	∑S(j):		2.000E+02	1.996E+02	1.990E+02	1.978E+02	1.970E+02	1.969E+02
Th-228	Ra-228	1.000E+00	0.000E+00	5.700E+01	1.073E+02	8.072E+01	7.664E+00	1.453E-03
Th-228	Th-228	1.000E+00	2.000E+02	1.392E+02	6.745E+01	5.340E+00	3.806E-03	3.679E-14
Th-228	Th-232	1.000E+00	0.000E+00	3.726E+00	2.482E+01	1.122E+02	1.893E+02	1.969E+02
Th-228	∑S(j):		2.000E+02	1.999E+02	1.996E+02	1.982E+02	1.970E+02	1.969E+02
Th-230	Th-230	1.000E+00	5.000E+02	5.000E+02	5.000E+02	4.999E+02	4.998E+02	4.994E+02
Th-230	U-234	1.000E+00	0.000E+00	4.495E-03	1.345E-02	4.441E-02	1.298E-01	3.950E-01
Th-230	U-238	9.999E-01	0.000E+00	6.368E-09	5.711E-08	6.268E-07	5.445E-06	5.353E-05
Th-230	∑S(j):		5.000E+02	5.000E+02	5.000E+02	5.000E+02	5.000E+02	4.998E+02
Th-232	Th-232	1.000E+00	2.000E+02	2.000E+02	2.000E+02	2.000E+02	2.000E+02	2.000E+02
U-234	U-234	1.000E+00	5.000E+02	4.987E+02	4.960E+02	4.869E+02	4.617E+02	3.833E+02
U-234	U-238	9.999E-01	0.000E+00	1.414E-03	4.218E-03	1.380E-02	3.926E-02	1.087E-01
U-234	∑S(j):		5.000E+02	4.987E+02	4.960E+02	4.869E+02	4.617E+02	3.834E+02
U-235	U-235	1.000E+00	2.275E+01	2.269E+01	2.257E+01	2.215E+01	2.101E+01	1.744E+01
U-238	U-238	5.400E-05	2.700E-02	2.693E-02	2.679E-02	2.629E-02	2.493E-02	2.070E-02
U-238	U-238	9.999E-01	5.000E+02	4.986E+02	4.960E+02	4.869E+02	4.617E+02	3.834E+02
U-238	∑S(j):		5.000E+02	4.987E+02	4.960E+02	4.869E+02	4.617E+02	3.834E+02

THF(i) is the thread fraction of the parent nuclide.

RESCALC.EXE execution time = 6.41 seconds

DOSE: All Nuclides Summed, All Pathways Summed



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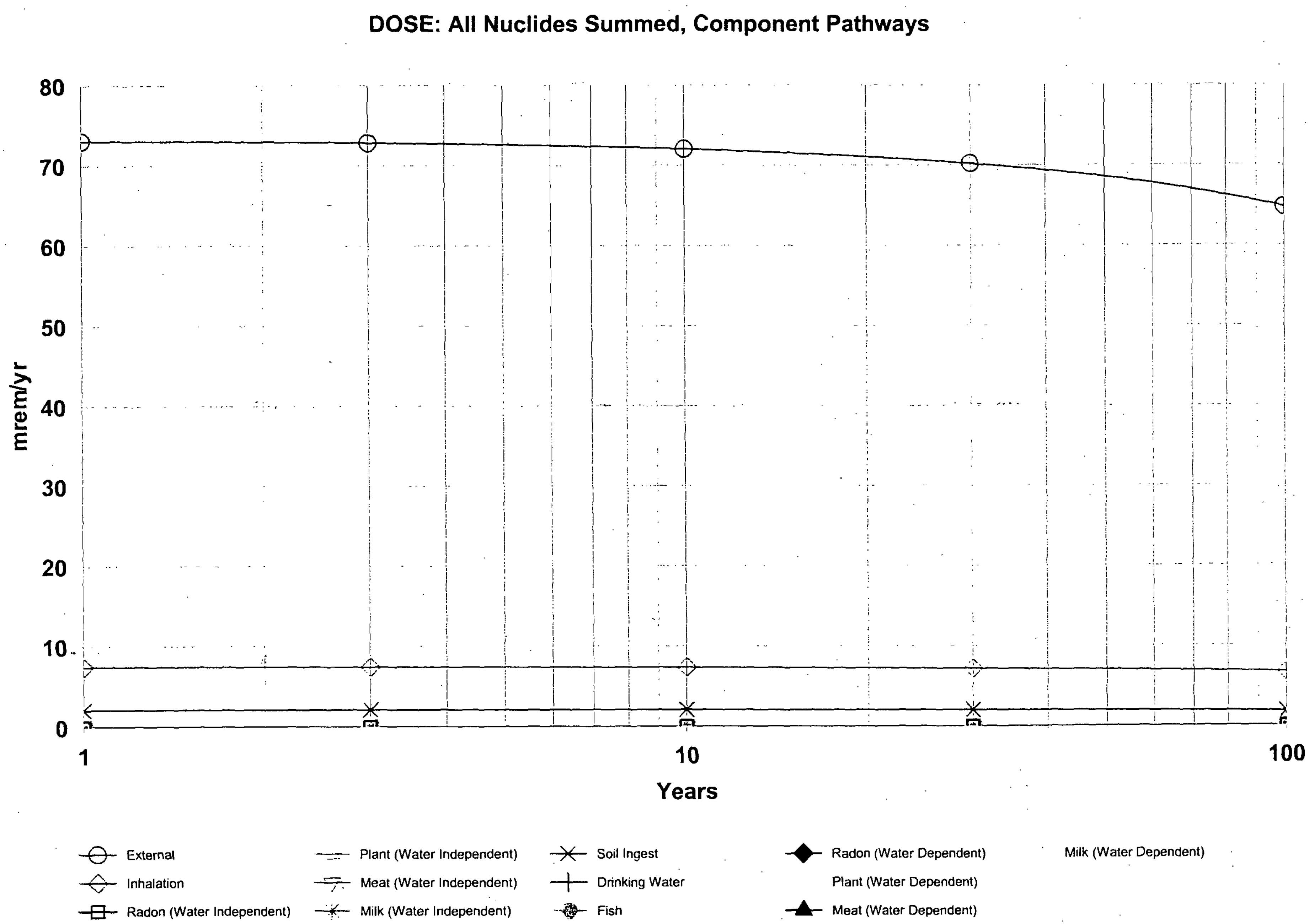

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APPENDIX 2

ENVIRONMENTAL REPORT OF BURIED URO REMOVAL

1. INTRODUCTION

1.1. BACKGROUND

Mallinckrodt has been operating at the St. Louis Plant since 1867 producing various products including metallic oxides and salts, ammonia, and organic chemicals. From 1942 to 1957, Mallinckrodt was under contract with the Manhattan Engineering District and the Atomic Energy Commission (MED-AEC) to process uranium ore to produce uranium for development of atomic weapons. From 1961 to 1985, Mallinckrodt extracted columbium and tantalum compounds from natural ores and tin slags.

Radioactive contamination at the site resulted from MED-AEC and C-T processing activities. MED-AEC contamination is being removed by the U.S. Army Corps of Engineers (USACE) under the Formerly Utilized Sites Remedial Action Program (FUSRAP). USACE developed a preferred cleanup approach for the MED-AEC contamination, based on the data and findings presented in four documents: (1) Remedial Investigation Report; (2) Baseline Risk Assessment; (3) Initial Screening of Alternatives; and (4) Feasibility Study.

Nuclear Regulatory Commission regulations[1] provide radiological criteria for decommissioning structures and land affected by NRC-licensed material. The purpose of those regulations is to ensure that decommissioning is executed without undue impact on public health and safety or on the environment.

Mallinckrodt proposes to decommission C-T facilities in order that the NRC may terminate Materials License No. STB-401. Before it can be terminated, NRC must be assured that the areas of the Mallinckrodt facility associated with the C-T project meet NRC's release criteria.

Mallinckrodt is planning to conduct the C-T decommissioning project in two phases. In Phase I, Mallinckrodt decommissioned buildings and equipment used during C-T production. C-T project buildings and equipment remaining on-site were cleaned and released for unrestricted use. Mallinckrodt submitted a plan to decommission buildings and equipment used during C-T production on January 10, 2002 and revisions on February 13, 2002 and March 8, 2002. The NRC approved the plan by amendment of License STB-401 on May 3, 2002 to add condition 18. Mallinckrodt is executing that plan. During Phase II, Mallinckrodt will remediate building slabs and foundations, paved surfaces, and contaminated soil. A plan has been submitted to do that.

Separately, in order to coordinate schedules for remediation of Plant 6W with the USACE under the FUSRAP, Mallinckrodt proposes to remove URO originating from C-T processing and now buried in trenches 1 through 9 in Plant 6W. This Environmental Assessment (EA) addresses removal of unreacted ore (URO) buried in Plant 6.

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1 NRC. "Radiological Criteria for License Termination." Fed. Reg. 62, no. 139, pp. 39058 - 39095. July 21, 1997.

1.2. OBJECTIVE.

This Environmental Assessment (EA) applies only to the URO removal activities.

Mallinckrodt intends to remove the buried URO and immediately adjacent soil within defined geographic boundary in Plant 6W and to dispose of it by NRC-authorized transfer to a disposal facility. Thereby, Mallinckrodt plans to remove the URO source to help assure that the potential radiological dose to people on the site will be less than 25 mrem/yr without necessity for post-remediation activity. This proposed action will remove a source of potential environmental impact, dispose of it safely at a facility off-site, and return affected land to usable status, while protecting the health and safety of remediation workers and of members of the public during the remedial action.

Unreacted Ore. The C-T process generated an unreacted ore (URO) residue that contained materials that were not dissolved in the initial C-T process steps. URO contained natural uranium, natural thorium, and their progeny in addition to non-radioactive constituents. Specific URO composition varied with raw material composition and process conditions.

In 1972 and 1973, approximately 300 cubic yards of drummed URO was buried in a series of 10 trenches located in Plant 6. Trenches were generally excavated to a depth of six feet. An approximate two-foot thick layer of URO in steel drums was placed in the trench and compacted. The trench was then backfilled with compacted excavated soil. A finished goods warehouse was subsequently constructed above one of the trenches, trench 10.

Mallinckrodt proposes to remove ore that was unreacted by C-T processing and that is buried in trenches 1 through 9 in Plant 6 West. Trench 10 is presentlyinaccessible. It proposes to dispose of the URO by shipping it to a regulated land burial facility. An application to the NRC for license amendment to authorize removal of the buried URO source is submitted separately from the C-T Phase II Decommissioning Plan.

The proposed source reduction action will remove this URO source of potential exposure from the property to safe disposal off-site. By removing all material within a defined physical boundary, verification may be by physical inspection. A residual radioactivity concentration criterion will not be needed.

2. PURPOSE AND NEED FOR THE PROPOSED ACTION

Mallinckrodt intends no further processing to extract columbium or tantalum (C-T) at its St. Louis downtown plant. Consequently, it wants to terminate NRC Materials License No. STB-401, which applies to the radioactive material of interest. Before the license can be terminated, the NRC must be assured that areas of the Mallinckrodt facility associated with the C-T project meet NRC's release criteria in 10 CFR Part 20, Subpart E. Thus, Mallinckrodt intends to decommission its C-T facilities to satisfy the NRC criteria.

Mallinckrodt is conducting C-T decommissioning in two phases. In Phase I, it decommissioned buildings and equipment used during C-T production. C-T-related buildings and equipment remaining on-site were cleaned, surveyed, and released for unrestricted use in accordance with an NRC-approved plan.

In Phase II, Mallinckrodt will remediate building slabs and foundations, paved surfaces, and subsurface materials. A two phase decommissioning approach has been proposed and is needed because:

- Mallinckrodt's St. Louis downtown plant is an operating facility with limited areas for staging decommissioning activities. Removal of buildings and equipment in Phase I will provide staging areas necessary for Phase II decommissioning.
- On-site workers have access to buildings containing residual contamination. Removal of buildings and equipment in Phase I reduced the potential that workers will be exposed to residual radioactive material. Further, some of the C-T process buildings were not used for several years, and the buildings began to deteriorate physically.

Unreacted Ore. Mallinckrodt proposes to remove unreacted ore from burial sites 1 through 9 in Plant 6W and dispose of it at an acceptable disposal facility offsite in accordance with Federal and State regulations. This action to remove this source of radioactive material from the site is proposed separately from the Phase II Decommissioning Plan in order to facilitate coordination with the USACE for its remedial action in Plant 6 under the FUSRAP.

3. THE PROPOSED ACTION

3.1. PLANNED PHASES AND ACTIVITIES

The ultimate goal of the C-T project decommissioning is to remediate those areas of the site associated with C-T production to the extent necessary to remove source material and to terminate License STB-401. Mallinckrodt decommissioned C-T process and support buildings and equipment in the first phase. In Phase II, Mallinckrodt proposes to decommission the C-T process and support building slabs and foundations, paved surfaces, and subsurface materials the C-T Project areas of the site to the extent necessary to meet NRC's unrestricted release criteria as presented in 10 CFR Part 20, Subpart E. Mallinckrodt submitted its Phase II Decommissioning Plan to the NRC for review and approval in May 2003 and has subsequently responded to all NRC requests for additional information.

Unreacted Ore. Unreacted ore is buried in the west area of Plant 6 in Mallinckrodt's St. Louis downtown site. Mallinckrodt proposes to remove that source of regulated radioactive material from burial trenches 1 through 9 in Plant 6W, thereby removing that source of potential radiological exposure. Burial 10, located beneath warehouse 101, isinaccessible. Removal will be performed by conventional excavation equipment, *e.g.*, backhoe or bucket loader; will be hauled by truck to a rail car station on-site; and will be loaded into rail cars to be transported off-site to an acceptable disposal facility. Remedial action to remove the URO is expected to be completed within one year from the date Mallinckrodt is authorized to perform the remediation.

4. ALTERNATIVES TO THE PROPOSED ACTION

4.1. NO ACTION ALTERNATIVE

An alternative supposing that no action be taken provides a baseline for comparison with other alternatives. Absent any action to decommission C-T process building slabs and nearby pavement, subsoil, and sewerage, it is possible that some residual source material might pose more than 25 mrem/yr potential radiological dose to workers on-site in the vicinity of the contamination in a postulated future scenario. That would not provide sufficient assurance of compliance with the NRC decommissioning regulation, 10 CFR Part 20, Subpart E. To compensate, future monitoring and possibly restriction on land use might be necessary.

Buried URO. Absent any action, the buried, unreacted ore might eventually be excavated inadvertently and might be spread without consideration of its radioactive quality. Alternatively, it would impede remediation of adjacent portions of Plant 6W to be done under the FUSRAP. In either prospect, it is not assured that the URO will remain buried in place. To compensate, future monitoring and possibly restriction on land use might be necessary.

5. AFFECTED ENVIRONMENT

The Mallinckrodt St. Louis Plant is a 43-acre (174,016 m^2) site located in an urban industrial area in the northeastern section of the City of St. Louis, Missouri 63147. The plant site occupies about 12 city blocks near the west bank of the Mississippi River in an area zoned and developed for industrial use. The site is located in an area of fill, alluvial deposits, and limestone bedrock, adjacent the west bank of the Mississippi River. The plant site is protected from flooding by a levee. Built on fill material and operated since 1867, Mallinckrodt's plant does not displace either farmland nor parkland.

MED-AEC contamination at Mallinckrodt facility is being removed by USACE under the FUSRAP. The USACE developed a preferred cleanup approach for the MED-AEC contamination that is based on the data and findings presented in four of its documents: Remedial Investigation Report, Baseline Risk Assessment, Initial Screening of Alternatives, and Feasibility Study.

The USACE Feasibility Study,[2] Section 2.2, provides an evaluation of the affected environment surrounding the Mallinckrodt facility. The following issues are addressed in that study: land use and recreational and aesthetic resources; climatology, meteorology, and air quality; geology and soils; water resources; biological resources; threatened and endangered species; wetlands and floodplains; population and socioeconomics; and historical, archeological, and cultural resources. The findings in the Feasibility Study also apply to remediation of the C-T process areas and to URO removal.

Buried URO. Unreacted ore from C-T processing (URO) is comprised of columbite ore

[2] USACE. *Feasibility Study for the St. Louis Downtown Site*. St. Louis, Missouri. April 1998.

and tin slag that did not dissolve by acid leaching and of portions precipitated as insoluble flouride. Approximately 290 cubic yards of URO, packaged in 305 thirty-gallon steel drums, was buried in Plant 6W in approximately a two-foot layer in ten excavated trenches. Each burial trench has about 3 to 4 feet of clean cover consisting of compacted soil. In addition, trenches 1 thru 9 are covered by 3 to 5 inches of asphalt while trench 10 is covered by 5 to 10 inches of concrete floor slab.

Mallinckrodt proposes to remove all of the URO in burials 1 through 9 within defined boundaries, surrounded by land subject to the FUSRAP. The URO burial trenches 1 through 9 occupy an area about 400 yd^2. Allowing a slope in adjacent soil increases the prospectively affected area to about 970 yd^2 and a total volume of about 2550 yd^3.

6. ENVIRONMENTAL IMPACTS

6.1. THE ENVIRONMENT

6.1.1. Occupancy

Mallinckrodt's St. Louis downtown site and its environmental setting are described in C-T Phase 2 Decommissioning Plan, section 3.[3] The site occupies 43 acres (about 12 city blocks) in an urban industrial area, built mainly on coal cinder fill near the west bank of the Mississippi River. Mallinckrodt has operated on the site since 1867. Manufacturing and support buildings occupy much of the site; practically all of the remainder is paved and is without resettlement vegetation.

The area of St. Louis where Mallinckrodt's plant is located is completely developed. Manufacturing and support buildings cover a large portion of the site, and the remainder of the area is typically paved with asphalt or concrete.

Land within one mile of the site is a mixture of commercial, industrial, and residential uses. This industrial zone allows all uses except new or converted dwellings. The long-term plans for this area are to retain the industrial uses, encourage the wholesale produce district, and phase out any junkyards, truck storage lots, and the remaining marginal residential uses.

6.1.2. Demographic

A total population of 1,997 in the contiguous census tract and a total of 12,904 including surrounding tracts was reported by the U.S. census in year 2000. Total population in these tracts decreased by 29% over the period 1990-2000.[4]

6.1.3. Cultural

A riverfront hiking and bicycle trail runs along the top of the levee located between Mallinckrodt and the Mississippi River. Otherwise, that city property is undeveloped and

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3 Mallinckrodt, Inc.. *C-T Phase II Decommissioning Plan*, §3.1 Site Location and Description, §3.2 Population Distribution, §3.3 Current & Future Land Use, & §3.8 Natural Resources. 2003.

4 U.S. Census Bureau. 1990 and 2000 Summary Files 1 (SF 1) 100-Percent Data

unfenced.

The nearest community facility is the Holy Trinity Catholic Church building located about 0.5 mile west of Mallinckrodt's plant site. Interstate 70 intervenes between them.

6.2. HISTORY

The St. Louis Plant has been in operation since 1867.

6.2.1. National Register of Historical Places

There is no historic building on Mallinckrodt's site that is listed with SHPO or the National Register of Historic Places.[5]

6.3. ARCHEOLOGY

Available data do not identify any archaeological site in the area. Although an archaeological survey has not been conducted on-site, it is unlikely that a significant archaeological site exists on-site, considering the intensive industrial use of the site.[6]

6.4. ECOLOGY

6.4.1. Natural Habitat

No commercially or recreationally important plant or terrestrial animal species are known to occur in the site area.

6.4.2. Wetland

No wetlands in the site area have been designated by USACE or the U.S. Fish and Wildlife Service.[7] The plant site is protected from flooding by a levee between it and the Mississippi River.

6.4.3. Endangered or Threatened Species

Federal and state designated endangered, or threatened species that may occur within the area are the pallid sturgeon, bald eagle, and peregrine falcon. The pallid sturgeon is found in both the Mississippi and Missouri rivers. Bald eagles are known to winter in the region. It is doubtful that they use the downtown area because of poor habitat quality (*i.e.*, sparse vegetation, significant noise and human activity).[8] A peregrine falcon pair has recently nested on the McKinley Bridge north of the site. The nest was established and maintained throughout an almost continuous period of site construction and demolition activity.

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5 USACE. Feasibility Study for the St. Louis Downtown Site. St. Louis, Missouri, April 1998, page 2-24.

6 USACE. Feasibility Study for the St. Louis Downtown Site, St. Louis, Missouri, April 1998, page 2-24.

7 USACE. Feasibility Study for the St. Louis Downtown Site, St. Louis, Missouri, April 1998, page 2-15.

8 USACE. Feasibility Study for the St. Louis Downtown Site, St. Louis, Missouri, April 1998, page 2-14.

6.5. SOCIOECONOMIC

6.5.1. Business Conditions

Approximately 1,100 employees work at Mallinckrodt's St. Louis downtown Plant. Due to the small number of workers required for URO removal, and the short duration of the project, this effort should have minimal incremental socioeconomic impact on the local community. Completion of URO removal and eventually of C-T decommissioning will enable the remediated land to be returned to productive use.

6.5.2. Population or Demographic Changes

Projections of population change in the St. Louis area are inconsistent. The state of Missouri projects continued decreases of 9 to 12% per year in the City of St. Louis population for the 2000 thru 2025 period.[9] The East-West Gateway Coordinating Council predicts an increase of approximately 0.4% per year over the same period.[10]

6.6. WATER QUALITY AND WATER SUPPLY

6.6.1. Surface Water.

Site wastewater, storm water, and all other surface drainage flow via site sewers and drains to a combined municipal sewer system and then to the Metropolitan St. Louis Sewer District (MSD) Bissell Point Treatment Plant, located approximately 1 km (0.7 mi.) north (upstream) of the site. Treated water is discharged to the Mississippi River.

The City of St. Louis operates the metropolitan municipal water supply system, which provides all the water required for domestic, industrial, and other uses within the City. The system intake and treatment plant are located upstream of the site and upstream of the MSD Bissell Point Plant discharge. The nearest municipal water intake downstream of the site is located on the east bank of the Mississippi River approximately 12 km (7.5 mi.) downstream.

6.6.2. Groundwater.

Groundwater in the St. Louis area is generally of poor quality and does not meet drinking water standards without treatment. Future use of groundwater at the SLDS is unexpected since the Mississippi and Missouri Rivers constitute high-quality, large-quantity, readily available sources.[11]

The quality of perched groundwater in fill historically placed along the riverfront in the St. Louis area and underlying the plant site is naturally poor due to the presence of brick, glass, concrete rubble, coal cinder, and slag, and associated metals and PAH compounds (DOE, 1990).

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9 State of Missouri, Office of Administration / Division of Budget and Planning, http://www.oa.state.mo.us/bp/projections/FinalComponentsOutput.htm, Accessed 4/5/02

10 East-West Gateway Coordinating Council, Our Region, Population, http://www.ewgateway.org/ourregion/trendicators/Pop/PopProj-2025/popproj-2025.htm, Accessed 4/5/02

11 USACE. Record of Decision for St. Louis Downtown Site. p. 6, July 1998.

The perched zone is intermittent in nature and limited in its lateral continuity, saturated thickness, and transmissivity, which results in low water producing quality. For these reasons, the perched zone is not a realistic source of potable groundwater even in the absence of any contamination derived from the Mallinckrodt facility.

Groundwater in the sandy alluvial unit beneath the fill is locally saline and generally very hard, with high iron and manganese content. Groundwater found in the underlying bedrock is generally saline and non-potable. Groundwater in the site area is not withdrawn for potable, industrial, or agricultural purposes, and groundwater use is not anticipated to change in the future. Considering these unfavorable groundwater characteristics and that St. Louis has a municipal water system that serves this region, installation of a domestic water well is not reasonably foreseeable. Since the land is unsuitable for agriculture because it is coal cinder fill, withdrawal of groundwater for agricultural irrigation also is not a reasonable expectation.

6.7. AIR QUALITY

If any, the main prospect for creating airborne dust would be a consequence of excavating and handling soil. Airborne radioactive particulate will be measured as an activity of environmental monitoring during solid waste excavation and handling. If dust suppression were needed, Mallinckrodt has committed to active measures to control it.

6.8. COMPETITION FOR RESOURCES

There are no mineral, fuel, or hydrocarbon resources on or near the site that could reasonably be exploited. There are no current or former mines or quarries on the site.

6.9. HEALTH

6.9.1. Health and Safety Program

Mallinckrodt has committed to perform URO removal activities in accordance with a health and safety program that will include an emphasis on industrial safety, radiation protection, and environmental protection. The program specifies the minimum requirements for radiological and environmental protection.[12]

Organization and administrative controls to manage the URO removal are described in the application for license amendment to remove the URO. Mallinckrodt will manage the tasks by using administrative procedures, work plans, and safety permits.

The URO removal plan requires that workers be adequately trained. Each unescorted person involved in URO removal is required to receive industrial safety training and radiation safety training. Each worker will receive radiation safety training before entering a controlled area to perform work.

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[12] C-T Phase I DP, §3.

6.9.2. Radioactivity Criteria

Unreacted Ore. Mallinckrodt's objective for URO buried in Plant 6 is to remove all unreacted ore (URO) in burials 1 through 9 and intermingled soil within specified geographic boundaries in Plant 6W. Adjacent soil is subject to remediation under the FUSRAP. Thereby, confirmation of URO source removal will be by physical inspection, *i.e.*, by visual observation and geographical survey in lieu of a final radiation status survey within the bounds of URO to be removed. The FUSRAP is responsible for remediation outside of the geographic boundaries of buried URO.

6.9.3. Environmental Protection

Mallinckrodt will have an environmental safety program to monitor environmental radiation, effluent air, and effluent water discharged from the URO removal project during decommissioning and during URO removal. Samples will be routinely collected or measurements routinely made on-site, at the Plant 6 boundary, or at the site boundary to determine the extent of environmental discharges during remediation.

6.9.3.1. Solid Waste

Non-impacted wastes that are indistinguishable from background radioactivity will be managed in accordance with applicable State and Federal solid and/or hazardous requirements as appropriate.

Mallinckrodt intends to dispose of solid material, objects, or equipment affected by source material by either transfer to a licensed disposal facility, NRC-authorized transfer of an unimportant concentration[13] to a disposal facility, or decontamination, survey, and release in compliance with NRC materials license specifications.[14]

6.9.3.2. Mixed Waste

Characterization efforts performed to date have not identified any mixed wastes in the soil or other materials to be remediated during URO removal. Mallinckrodt does not anticipate that mixed waste will be generated by URO removal efforts.

A small quantity of radioactive waste that exhibits a hazardous toxicity characteristic may be treated in a container to eliminate the characteristic. Neutralization, stabilization, fixation, and of solidification techniques may be used. Such treatment would typically be performed in the material management area.

In the event a substantial amount of mixed waste is identified during remediation activities, Mallinckrodt will characterize the wastes, identify a disposal method, assess the effect on the schedule, assess related disposal costs, modify handling procedures, as needed, and will notify the NRC. Mallinckrodt has a RCRA Part B permit authorizing on-site storage of hazardous and

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[13] Unimportant concentration as defined in 10 CFR Part 40.13.

[14] NRC. "Use or Termination of Facilities and Equipment Prior to Release for Unrestricted Use or Termination of Licenses for Byproduct, Source, or Special Nuclear Material," NRC Materials License STB-401, condition 16.

mixed waste. Other than the presence of hazardous chemicals, storage in Mallinckrodt's hazardous waste storage facility, and the labeling and transportation requirements of RCRA and state hazardous waste agencies, mixed wastes will have the same radioactive character and will be managed as solid radioactive wastes described above. That is, mixed waste, if any, will be managed in conformance with State and Federal hazardous waste regulations.

6.9.3.3. Aqueous Waste

Mallinckrodt has provisions for managing water that may accumulate in excavation pits. If removal is necessary, radioactivity monitoring and appropriate treatment to satisfy 10 CFR Part 20 aqueous effluent criteria would be performed before discharge.

6.9.3.4. Air Emission

Because the site is paved with asphalt or concrete, climatological events should have minimal impact on radionuclide migration except during the brief periods when soils are exposed during site activities. During remediation activity, Mallinckrodt will perform airborne particulate sampling and, if needed, will apply water spray to control dust.

6.9.4. Radiological Safety

Mallinckrodt will maintain a Radiation Safety Program, including measures to protect workers, the public, and the environment from ionizing radiation. The Radiation Safety Program incorporates the following elements;[15]

- health and safety protection measures and policies
- instrumentation, calibration and equipment
- use of air samplers, monitoring policy methods, frequency and procedures
- contamination control and personnel decontamination
- external exposure control
- airborne releases and monitoring
- radiation safety work permits
- engineering controls
- posting and labeling, and
- records and reports.

6.9.5. Occupational Exposure

Personnel exposure to radioactive material will be controlled by application of engineering, administrative, and personnel protection provisions.

Air samples will be collected in areas when and/or where there is potential for generation of airborne radioactive material. These samples will be used to verify that the confinement of radioactive material is effective and provide information concerning elevated concentrations for planning or response actions.

Individual monitoring shall be provided for workers who require monitoring of the intake of radioactive material. Monitoring of intake shall normally be conducted by use of air samples.

[15] C-T Phase I DP, §3.

6.9.6. Direct Radiation

An individual monitoring device shall be provided to each worker who requires monitoring for external exposure.

6.9.7. ALARA

The Radiation Protection Program will emphasize keeping exposures to radiation and radioactive material "**as** **l**ow **as** **r**easonably **a**chievable," or ALARA This will be done mainly in safety work permits and in training workers who work in a controlled area.

6.9.8. Final Radiation Status Survey

Unreacted Ore. Mallinckrodt's objective for URO will be to remove all unreacted ore (URO) in burials 1 through 9 and intermingled soil within specified geographic boundaries in Plant 6W. Adjacent soil is subject to remediation under the FUSRAP. Thereby, confirmation of source removal will be by visual observation and geographical survey in lieu of a final radiation status survey within the bounds of URO to be removed.

6.9.9. Radiological Impacts

Source Removal. Removal of buried URO from Mallinckrodt's site will remove that potential source and thereby eliminate potential radiological impact it might otherwise pose on the site in the future.

Remedial Action. Radiological safety of workers performing URO removal has been evaluated. An occupational dose evaluation was modeled using the RESRAD computer code and site-specific information or estimates of input parameters. The modeling yielded an estimate of 83 mrem for a representative remediation worker, which is less than 10% of the maximum tolerable radiological dose to a worker annually.

An ALARA evaluation was performed to assess defensible cost-benefit balance for averting dose. Based upon an estimate of 10 workers on the project, the prospective collective dose was estimated to be 0.83 person-rem. This evaluation suggests that routine health physics measures already planned for the project should be acceptable to maintain doses ALARA during the URO removal project.

The safety evaluation report for the URO removal project is provided as an appendix to the request for license amendment to remove the URO.

Disposal of Solid Waste. Radioactively contaminated solid wastes will be disposed of by transfer to a licensed disposal facility or by transfer to a disposal facility authorized to receive an unimportant quantity of source material.

In the event URO and associated soil that is removed from Plant 6W contains less than 0.05 wt% source material, it will be disposed at a regulated disposal facility off-site as an *unimportant quantity* as defined in 10 CFR Part 40.13(a). and subject to approval from the cognizant state regulatory agency(ies) in which the disposal facility is located. Potential radiological impact during transport, disposal operation, and buried in the depository afterward have been estimated for candidate disposal facilities.[16, 17] In both instances, at WCS in Texas and at USEcology in Idaho, potential radiological dose to the most exposed members of the public was estimated to be less than 25 mrem/yr. Alternatively, it may be disposed by transfer to an NRC-regulated or Agreement State-regulated disposal facility

In the event URO and associated soil that is removed from Plant 6W contains more than 0.05 wt% source material, it will be disposed by transfer to an NRC-regulated or Agreement State-regulated disposal facility. There, its handling and disposal will be subject to NRC or equivalent radiological criteria, thereby protecting site workers and members of the public.

6.9.10. Other Health-related Impacts

Hazardous Chemicals or Metals. Characterization efforts performed to date have not identified any hazardous chemical or hazardous metal that would become *mixed waste*[18] in the soil or other materials to be remediated during URO removal. Mallinckrodt does not anticipate that mixed waste will be generated by URO removal efforts. In the event mixed waste were to be identified during remediation activities, Mallinckrodt would characterize the wastes, modify handling procedures, as needed, and identify a disposal method. Mallinckrodt has a RCRA Part B permit authorizing on-site storage of hazardous and mixed waste. Other than the presence of hazardous chemicals, storage in Mallinckrodt's hazardous waste storage facility, and the labeling and transportation requirements of RCRA and State hazardous waste agencies, mixed wastes will have the same radioactive character and will be managed as solid radioactive wastes described above. Thereby environmental protection against health effects of hazardous chemicals or metals will be assured.

6.10. TRANSPORTATION

The St. Louis downtown plant site is served by commercial transportation routes. Three railroads cross, serve, or are adjacent the site: Burlington, Northern, and Santa Fe; Norfolk Southern; and the St. Louis Terminal Railroad Association. Interstate Highway 70 is within about 3 blocks west of the plant site.

6.10.1. Waste

Solid waste from the proposed project is expected to be transported from the site by rail. About 38 gondola-type rail cars can haul the 2550 yd^3 of URO and adjacent soil that is estimated to be removed. Otherwise, if shipped in 4 intermodal containers per rail car, about 64 rail cars would be used. That will not pose a significant increment to local rail traffic.

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16 "Disposal of Mallinckrodt 10 CFR Part 40 Section 40.13(a) Material at the USEcology Idaho Site." June 24, 2002. Submitted by Mallinckrodt to NRC on June 24, 2002.

17 "Analysis of Disposal of Unimportant Quantity of Source Material at WCS Andrews Facility." April 17, 2000. Submitted by Mallinckrodt to NRC on April 17, 2000.

18 *Mixed waste* would include radionuclides in excess of naturally-occurring background concentration and hazardous chemicals and or hazardous metals.

6.10.2. Personnel

Fewer than 20 workers are expected to be employed on the URO source removal project at a time. As a result, roadway traffic is not expected to be impacted by a significant amount.

6.11. ENVIRONMENTAL JUSTICE

Because C-T decommissioning and URO removal activities pose an insignificant risk to the public health and safety and to the human environment, while diminishing potential future radiological exposure. Thereby URO removal does not produce an environmental justice issue.

7. MITIGATION MEASURES

The purpose of URO removal is to diminish potential for adverse radiological impact relative to no action. Overall then, these proposed actions may be considered mitigation measures themselves. Section 6.9, Health, summarizes specific measures to be taken in health, safety, and environmental protection to control potential adverse effects of remedial actions to remove buried URO.

8. MONITORING

Health, safety, and environmental controls, including monitoring to assure remedial actions are conducted as intended, are summarized in section 6.9 herein. Mallinckrodt implements a quality assurance program, including quality controls and inspections to assure conformance with specifications for URO removal.

9. LIST OF REFERENCES

1. Mallinckrodt, Inc. *Phase I Plan for C-T Decommissioning.* NRC Docket 040-06563. NRC License STB-401. Jan. 9, 2002.
2. Mallinckrodt, Inc. *Phase II Plan for C-T Decommissioning.* NRC Docket 040-06563. NRC License STB-401. May 14, 2003.
3. NRC. "Radiological Criteria for License Termination." Fed. Reg. 62, no. 139, pp. 39058 - 39095. July 21, 1997.
4. USACE. *Feasibility Study for the St. Louis Downtown Site.* St. Louis, Missouri. April 1998.
5. U.S. Census Bureau. 1990 and 2000 Summary Files 1 (SF 1) 100-Percent Data.
6. State of Missouri, Office of Administration / Division of Budget and Planning, http://www.oa.state.mo.us/bp/projections/FinalComponentsOutput.htm, Accessed 4/5/02
7. East-West Gateway Coordinating Council, Our Region, Population, http://www.ewgateway.org/ourregion/trendicators/Pop/PopProj-2025/popproj-2025.htm, Accessed 4/5/02
8. USACE. *Record of Decision for St. Louis Downtown Site.* July 1998.
9. NRC. "Use or Termination of Facilities and Equipment Prior to Release for Unrestricted Use or Termination of Licenses for Byproduct, Source, or Special Nuclear Material," NRC Materials License STB-401, condition 16.5