SECTION 8

PLANNED DECOMMISSIONING ACTIVITIES

Mallinckrodt Inc.

C-T Phase II Decomissioning Plan
May 15, 2003

NRC Docket: 40-06563
NRC License: STB-401

8. PLANNED DECOMMISSIONING ACTIVITIES

8.1. INTRODUCTION

C-T Process and support buildings and all other affected above-ground areas at the site were or will be demolished or decontaminated in accordance with the C-T Phase I Decommissioning Plan (Phase I Plan). Activities in the Phase I Plan are authorized under license STB-401, as amended May 3, 2002. Under the C-T Phase II Decommissioning Plan (Phase II Plan), authorization to perform activities described in this section 8 is being sought. The Phase II Plan addresses remediation of C-T Process and Support Building floor slabs, subsurface sewer system, contaminated soils, and the wastewater neutralization basins.

Most of the activities required to decommission the C-T project site will take place within Plant 5. However, wastewater neutralization basins outside Plant 5 supported C-T operations and will also be decommissioned. Within Plant 5, the C-T Project remediation area boundaries have been defined as:

- everything south of the south edge of Destrehan Street,
- everything north of a line drawn along the south sides of Buildings 200 and 260,
- everything west of a line drawn on the east side of Bldgs. 222 and 223, and
- everything east of a line drawn along the west sides of Buildings 240 and 250.

Certain Plant 5 areas outside of these limits contain residues of uranium processing under MED/AEC and are the responsibility of USACE under the FUSRAP. The FUSRAP is responsible for evaluation and remediation of all areas containing MED/AEC residues, including any areas where such residues are commingled with other radioactive materials such as C-T materials.[1]

The following C-T support areas outside of Plant 5 will be remediated during Phase II:

- Building 91 sewers (if contamination of drains is identified in Phase I),
- Wastewater basins in Plant 7.
- Figures 14-1A, 14-1B, and 14-2 are maps of the St. Louis Plant C-T process and support areas to be addressed in Phase II.

An Occupational Dose Evaluation was performed to provide a conservative estimate of the radiological dose to a worker under normal conditions. This evaluation is included as Attachment 1.

An Accident Analysis was performed to assess the radiological dose to a worker under the maximum credible accident conditions. This analysis is included as Attachment 2.

During the planning stages, Mallinckrodt has evaluated several alternative methods for decommissioning the C-T project site including, but not limited to various options for decontaminating or demolishing pavement and building slabs, excavation of subsurface

[1] USDOE and USEPA. *DOE FUSRAP Sites, St. Louis and Hazelwood, Missouri Federal Facilities Agreement,* EPA Docket No. VII-90-F-0005. June 26, 1990.

sewerage, and excavation of contaminated soils. Phase II activities are complicated by the fact that the facility will continue to perform routine manufacturing while decontamination and remediation are performed. After careful review of site and facility characterization data, research program results, and engineering cost analyses, Mallinckrodt selected the following decommissioning strategy. During Phase I, Mallinckrodt contractor(s):

(a) demolished C-T process buildings (Buildings 238, 246B, 247, 248) and immediately adjacent support buildings (Buildings 213, 214, 246A), and
(b) surveyed and decontaminated other C-T support areas.

During Phase II, Mallinckrodt will, as may be necessary

(a) remediate remaining floor slabs and subsurface soils and systems by decontamination or excavation and disposal followed by a final survey,
(b) remediate former wastewater neutralization basins by decontamination or demolition and disposal followed by final surveys where appropriate, and
(c) Remediate sewerage.

Decontamination and volume reduction methods were selected to minimize the volume and cost of radioactive waste requiring disposal. Mallinckrodt and its contractor(s) will determine whether decontamination and final survey of individual materials is preferred over excavation and disposal. The Phase II Plan is based on the following preferences:

- excavation or demolition and disposal when it is cost-effective,
- decontamination when it is judged to be cost-effective compared to disposal, and
- decontamination or removal of selected contaminated areas of pavement and subsurface material to reduce the average mass concentration activities below release limits and therefore minimize the cost of disposal.

The general technical approach for decommissioning during Phase II is as follows:

- decontamination, if necessary, or removal of remaining C-T building floor slabs and foundations,
- removal or plugging of contaminated sewers and soils;
- packaging and shipping of contaminated materials for transfer to an appropriate facility,
- final radiation status survey,
- backfilling and compaction of remediated areas, and
- final grading and paving.

The activities to be performed during Phase II decommissioning are grouped below in several categories of similar work.

8.2. STRUCTURES

C-T process and support buildings, above-grade structures, were subject to the Phase I Plan.

8.3. PAVEMENT AND SLABS

8.3.1. Street Pavement

Plant 5 is paved with macadam or concrete. In compliance with the Phase I Plan, floor slabs of process and support building that were removed have been sealed.[2] A seal-coat of macadam was applied.

8.3.2. Building Slabs and Foundations

C-T process and support building floor slab and foundation surfaces exposed above grade that are subject to decommissioning include the floor slabs of former Buildings 213, 213A, 213B, 214, 238, 246, 246B, 247A, 247B, and 248. If a floor slab or foundation surface were to fail a final status survey, it would either be decontaminated, *e.g.*, by scabbling, and be subject to survey again in accordance with section 14 of this Plan or would be removed. In the event a floor slab or foundation were removed, its debris would be characterized for disposal and would be managed in accordance with provisions of section 12.1 of this Plan.

If access to contaminated subsoil is necessary, pavement or floor slab would be removed. Otherwise, if pavement or a floor slab passes a final status survey, it may be left in place. Where gross removal is necessary, it will be completed using standard construction equipment such as excavators, bulldozers, front-end loaders, dump trucks, compactors, water trucks, forktrucks, and miscellaneous small tools. Debris size reduction will be performed during excavation as required for transportation and disposal. Excavated pavement and associated soil and debris will either be loaded into shipping containers at the excavation site or will be transported to the soil handling area for characterization, segregation, staging and shipment.

8.3.3. Wastewater Neutralization Basins

The former wastewater neutralization basins will remain after completion of Phase I decommissioning. During Phase II, the basins may either be removed and disposed by NRC-authorized transfer to a disposal facility off-site or be decontaminated if necessary, left in place, and subjected to a final status survey. The wastewater neutralization basins and surrounding areas will be remediated by the remediation contractor(s) as follows:

- Basin liners will be removed and packaged for shipment and disposal.
- Exposed concrete surfaces will be surveyed either for the purpose of establishing cost-effective disposal or final radiation status to compare with DCGL.
- Exposed surfaces of concrete structures may be decontaminated as appropriate by scabbling, grit blasting or similar techniques, broken into appropriate size pieces, and loaded into transport containers using conventional demolition equipment and techniques.

[2] C-T Phase I Decommissioning Plan, §2.3.1

8.3.4. General

In the event of pavement, building slab, foundation, or basin decontamination and/or demolition, it will be performed in accordance with administrative controls and programs described in Sections 9 through 14 of this Plan.

Decontamination and demolition of the pavement, building slab, foundation, or wastewater neutralization basins does not entail unique construction or remediation safety issues. Mallinckrodt has safely and effectively performed such activities during the ongoing operation and maintenance of the facility.

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.

Mallinckrodt has procedures developed for Phase I decommissioning activities. Pertinent ones of these procedures will be used during Phase II, with appropriate revisions.

8.4. SEWERAGE SYSTEMS

8.4.1. Description and History

Above-grade C-T process systems and equipment have been decontaminated and disposed of through implementation of the Phase I Plan. C-T process buildings and some support areas were served by subsurface sewer systems that are addressed in this Phase II Plan.

Prior to December 1970, all site wastewater was discharged to the Mississippi River through a combined (wet and dry weather) sewer system. Sewerage serving Plant 5 discharged to the Mississippi River through the Destrehan Street outfall structure. This structure was constructed by MED/AEC to support the Destrehan Street Plant and was located at the foot of Destrehan Street east of the plant.

Wastewater from the MED/AEC Destrehan Street Plant was discharged to the MSD Salisbury Street Sewer and the Destrehan Street outfall. The U.S. Army Corps of Engineers is addressing radioactivity contamination in these sewer systems under the FUSRAP program.[3]

8.4.2. Drains and Subsurface Sewerage That Served C-T Process Buildings

These drains and sewers are the most likely to contain C-T residues of licensed radioactive material. Drains and sewerage that served C-T process buildings (238, 246B, 247A&B, 248) will either be plugged to prevent use or will be removed during removal of building floor slabs and shallow soil, if any.

Main sewer lines immediately to the west and north of Building 238 will be removed or plugged in the process of remediation of subsurface soils beneath Building 238. If they are removed, the sewers and the sludge in them will be treated as radioactive waste, as described in Section 12 of the Phase II Plan. Else, if plugged, they may be released for unrestricted use if warranted by a

[3] USACE. *Record of Decision for the St. Louis Downtown Site.* p. 12. July 1998.

Final Status Survey as described in Section 14 of the Phase II Plan. It is anticipated that sewers remaining downstream of Building 238, beginning about even with west ends of Buildings 236 and 245 and extending to the Waste Water Treatment Basin area, will remain in service after a Final Status Survey as described in Section 14 of the Phase II Plan and release for unrestricted use.

8.4.3. Drains and Subsurface Sewerage That Served C-T Support Buildings

Mallinckrodt does not anticipate that drains and subsurface sewerage that served C-T support buildings will contain C-T related contamination in excess of sewerage contamination criteria. Drains and other at-grade locations that may have been exposed to C-T materials will be identified and surveyed for radioactivity. Downstream sewerage will reasonably be assumed to be uncontaminated if surveys of drains and other at-grade locations do not identify the presence of radioactivity above criteria. If these surveys identify contamination, interior surveys, *i.e.*, sediment sampling, will be performed.

8.4.4. Drains and Subsurface Sewerage That Served C-T Yard Areas

Drains and subsurface sewerage that served C-T yard areas will be addressed in a manner similar to that employed for drains and subsurface sewerage that served C-T support buildings.

8.4.5. Plant 7 Lift Station

The Plant 7 Neutralization basin is described in Section 8.4.3 above. Lift station interior surfaces will be surveyed for radioactivity contamination, including any exposed joints. Areas exceeding the DCGL for pavement, stated in DP Section 5 will be decontaminated using scabbling, grit blasting, or other techniques or will be removed. A final status survey will be performed on surfaces that are left in place.

8.4.6. Sewerage That Served MED/AEC Operations

USACE is addressing sewerage serving MED/AEC operations under the FUSRAP program, including sewerage that may contain commingled C-T residue. Those sewers are not subject to this Phase II Decommissioning Plan.

8.4.7. Sewerage That Served Neither C-T Nor MED/AEC Operations.

No decommissioning activity will be performed in other sewers as they cannot reasonably be expected to contain C-T contamination in excess of criteria.

8.4.8. Other Sewerage Remediation Issues

Sewer decontamination and/or excavation will be performed in accordance with administrative controls and programs described in Sections 9 through 14 of this Plan. Mallinckrodt has procedures developed for Phase I decommissioning activities. Pertinent ones of these procedures will be used during Phase II, with appropriate revisions.

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.

Surveying, decontamination, excavation, and removal of drains and subsurface sewerage does not entail unique construction or remediation safety issues. Mallinckrodt has safely and effectively performed such activities during the ongoing operation and maintenance of the facility.

8.5. SOIL

The estimated radioactivity concentration profile observed by characterization survey that exceeds the $DCGL_W$ in soil in Plant 5 is described in Section 4 of the Phase II Plan. Characterization data indicate that radioactive residue in some soils beneath and adjacent C-T process Building 238 exceeds criteria. Demolition of the above-grade portions of C-T process and support buildings was accomplished during Phase I. Contaminated building floor slabs, foundations, and contaminated soils exceeding the DCGL will be addressed during Phase II.

8.5.1. Soil Remediation

Soil remediation will generally be performed as follows:

- Three-dimensional modeling of characterization data will define the gross outline of areas exceeding soil criteria.
- The areas where criteria are exceeded will be excavated using conventional construction equipment.
- Radiation measurements will be employed to guide remedial excavation.
- Excavated soils will be loaded into trucks or containers at the site of remediation and moved to the material handling area or shipped in accordance with NRC-authorized transfer to a state-regulated disposal facility.
- A final radiation status survey will be performed in each remediated area.
- Excavated soil demonstrated to contain lower radioactivity concentration than the DCGL by radioactivity survey performed to specifications in section 14 may be returned into an excavation pit.
- Remediated areas will be backfilled, compacted, graded, and resurfaced as appropriate.

8.5.2. Soils and Materials Management

Solid waste, including soil and pavement, slab, and foundation debris, will be managed as specified in Section 12.1.

8.5.3. General Information

Soil radioactivity surveys will be performed as appropriate during excavation and soil management to minimize the intermixing of contaminated and uncontaminated soils and debris. However, some incidental intermixing of contaminated and uncontaminated soils is unavoidable because of the heterogeneity of the contamination and the nature of excavation operations.

Techniques such as water misting and tarps may be used to minimize dust emissions during soil excavation, loading, transport, and handling.

Soil remediation and removal will be performed using standard construction equipment such as excavators, bulldozers, front-end loaders, dump trucks, compactors, water trucks, forktrucks, and miscellaneous small tools.

Slope stability will typically be maintained using conventional excavation sloping techniques. Shoring will be used when required to minimize the excavation area or maintain the stability of adjacent structures or other critical areas.

The excavation and remediation activities described above do not entail unique safety or remediation issues. Mallinckrodt has safely and effectively performed such activities as part of the ongoing operation, maintenance, and expansion of the facility.

Activities will be performed in accordance with administrative controls and programs described in Sections 9 through 14 of this Plan. Mallinckrodt has procedures developed for Phase I decommissioning activities. Pertinent ones of these procedures will be used during Phase II, with appropriate revisions.

Water misting of other similar techniques will be used as appropriate to prevent the release of airborne dust during excavation and materials handling activities.

8.6. SURFACE AND GROUNDWATER

No surface water groundwater remediation is warranted or will be performed. Surface water and groundwater monitoring has been performed at the site by Mallinckrodt, DOE and USACE and is described in Appendix A. There is not a complete groundwater exposure pathway at the site. As indicated previously, the City of St. Louis operates and maintains a municipal water system and there are no groundwater withdrawal wells in the site vicinity. Furthermore, a City ordinance[4] prohibits installation of drinking water wells in areas such as the Mallinckrodt site, and groundwater discharges to the Mississippi River immediately downgradient of the site.

8.7. FINAL RADIATION SURVEY

Section 14 describes specifications for the final radiation survey that will be performed after soil remediation tasks are completed. Following successful completion of the final radiation survey of a survey unit, soil replacement, compaction, and grading will be performed. Minimal time is planned for the NRC response following final survey because of the increased risk to worker health and safety of leaving excavations unfilled for extended periods of time. If timely NRC response is not received, excavations may be surveyed or otherwise delineated (*e.g.*,with a marker layer) and backfilled.

8.8. SITE RESTORATION

At completion of excavation activities, the site grade will be reestablished and remediated areas other than where the basins are will be paved. The site will continue to be an active and expanding industrial facility for the foreseeable future. New manufacturing or support operations may be constructed on previously remediated areas.

[4] St. Louis City Ordinance 13,272, Section 3. March 25, 1885.

8.9. SCHEDULE

Because the C-T production and support areas are located within an active manufacturing facility, completion of decommissioning activity within a 24-month period is technically infeasible without causing serious disruption to ongoing manufacturing operations. For this reason, Mallinckrodt has proposed and the NRC has approved use of a two phase decommissioning approach with the assurance that Mallinckrodt will plan, implement, and complete decommissioning as quickly as practicable.

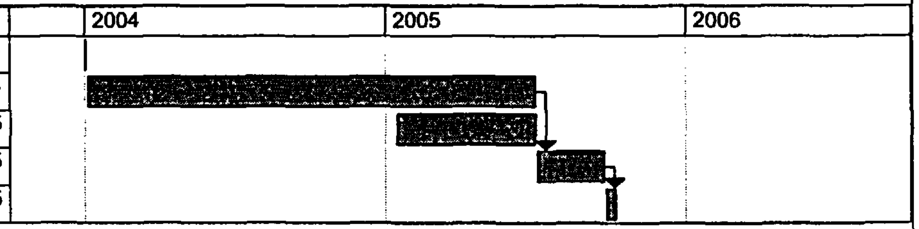
A preliminary schedule for Phase II decommissioning activities is presented in Figure 8-1 and is described below. The project schedule references project milestones and other dates to receipt of NRC approval of the decommissioning plan (Project Start Date = 0). The key elements forming the bases for the schedule are:

- Removal or decontamination of pavement and building slabs will take approximately 3 months,
- Removal of contaminated subsurface material will take approximately 10 months,
- Demolition of the waste water basins, if necessary, will take approximately 4 months,
- Relocation of water utility and site refurbishment will take place after the remediation, and
- Completion of final radiation surveys and NRC verification that the residual radioactivity limits have been met will occur concurrently with other activities and not impact the length of the Phase II schedule.

The project schedule is based on information available during plan preparation. Mallinckrodt will provide an updated schedule to NRC if it is determined that decommissioning cannot be completed as outlined in the schedule.

Figure 8-1
Conceptual Decommissioning Schedule for CT Phase II

ID	Task Name	Duration	Start
1	NRC Approval of Decommissioning Plan (See Note)	1 day	Fri 01/02/04
2	Remediate Floor Slabs and Subsurface Soils	13 mons	Mon 01/05/04
3	Remediate Former Wastewater Neutralization Basin	4 mons	Fri 01/14/05
4	Final Staus Survey/Sampling & Analysis (FSS)	2 mons	Mon 07/04/05
5	Complete FSS Report for CT Phase II	2 wks	Mon 09/26/05



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Date: Mon 05/12/03

Task		Milestone		External Tasks	
Split		Summary		External Milestone	
Progress		Project Summary		Deadline	

NOTE: The actual start date and subsequent dates are dependent on the NRC approval date.

SECTION 9

PROJECT MANAGEMENT AND ORGANIZATION

Mallinckrodt Inc.

C-T Phase II Decomissioning Plan
May 15, 2003

NRC Docket: 40-06563
NRC License: STB-401

9. PROJECT MANAGEMENT AND ORGANIZATION

This section describes the project organization that will become effective upon NRC approval of the C-T Phase II Decommissioning Plan (Phase II Plan). As the project moves forward, changes to the project organization may be justified in response to the varying level of site activities. Effective with NRC approval of this plan, 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 the educational and experience qualifications in provided below.

9.1. DECOMMISSIONING MANAGEMENT ORGANIZATION

9.1.1. Organization

Implementation of the Phase II Plan will be managed by a team comprised of management, radiation safety, and occupational safety personnel from the Mallinckrodt and decommissioning contractor organizations. The C-T project decommissioning organization is illustrated in Figure 9-1.

While Mallinckrodt is responsible for ensuring overall successful implementation of the Phase II Plan, it will contract the services of a remediation contractor to perform the decommissioning tasks required by the Plan.

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

Mallinckrodt will use various project management and decommissioning consultants to assist in the management of decommissioning 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, and project engineering and 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 9-1.

The responsibilities of the primary managers and the minimum qualifications for managers with safety-related responsibilities are provided below.

9.1.2. Mallinckrodt C-T Project Manager

The Mallinckrodt C-T Project Manager will provide overall leadership and management of C-T project decommissioning. He or she reports to the Site General Manager. The Radiation Safety Officer (RSO), Site Safety Manager, and project management and decommissioning consultants will support the Project Manager.

The C-T Project Manager is responsible for ensuring that the overall C-T decommissioning project, including the work performed by contractors and subcontractors, is accomplished in conformance with this Phase II Plan and with applicable health, safety, quality, technical, and contractual requirements. The Mallinckrodt Project Manager is responsible for assuring that NRC requirements are met. He or she also is responsible for coordinating activities between plant operations and the decommissioning contractor. He or she will use other Mallinckrodt staff or consultants as appropriate to perform this coordination. The Mallinckrodt Project Manager 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 this Phase II plan, 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 C-T Project Manager is the designated contact with the NRC.

9.1.3. Mallinckrodt Radiation Safety Officer

The Mallinckrodt Radiation Safety Officer (RSO) is 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 advises the Mallinckrodt Project Manager on matters pertaining to radiation safety. The RSO reports to the Site Environmental Manager. The Mallinckrodt RSO has the authority to halt any operation which he believes has the potential to threaten the health and safety of personnel, the public, or the environment.

9.1.4. Mallinckrodt Site Safety Manager

The Site Safety Manager is responsible for ensuring that the C-T Phase II occupational safety program is in conformance with applicable and relevant laws, regulations, and NRC requirements. He or she will also audit contractor performance to ensure compliance with this Phase II Plan and other generally applicable requirements. The Site Safety Manager reports to the Site Environmental Manager. The Site Safety Manager advises the Mallinckrodt C-T Project Manager on matters pertaining to occupational safety. The Site Safety 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.

9.1.5. Contractor Project Manager

The contractor's Project Manager is responsible for the execution of all of the Phase II Plan decommissioning activities. He is the primary interface with the Mallinckrodt C-T Project Manager. 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.

9.1.6. Contractor Radiation Protection, Health, & Safety Manager

The contractor Radiation Protection, Health & Safety Manager (RPHS Mgr), alternatively referred to as the contractor ES&H Representative, is responsible for implementation of safety and environmental protection, including radiation protection, environmental protection, and occupational health and safety in the Phase II Decommissioning. The contractor RPHS Manager reports directly to the contractor Project Manager and is functionally independent of decommissioning Operations, thus assuring independence of action in matters pertaining to decommissioning radiation and environmental protection, health, and safety. The contractor RPHS 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.

9.1.7. 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 decontamination and decommissioning activities for the implementation of Phase II decommissioning project. The Operations Manager will ensure that all personnel are properly trained to perform assigned decommissioning 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.

9.1.8. 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 Project Manager with copies of audits provided to the contractor's Project Manager.

9.2. DECOMMISSIONING TASK MANAGEMENT

Decommissioning activities for the C-T Project will be performed in accordance with written instructions. There will be four general types of written instructions in use for the C-T Project: Plans, Procedures, work plans, Safety Work Permits (e.g., Hot Work Permits, Excavation Permits, etc.). These written instructions and their approval are described below.

9.2.1. Administrative Control Plan

The project will develop and implement an Administrative Control Plan that establishes guidelines for creation, use, and control of these administrative controls to ensure that C-T decommissioning is performed safely and in conformance with governing regulations, the NRC license, and the Phase II Plan.

Specific procedures and safety work permits, as discussed below, will be implement under this Decommissioning Plan and the Administrative Control Plan.

9.2.2. Procedures

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, calibrate instruments, or other routine work activities. Procedures are typically prepared by the contractor and issued by the contractor project manager. All Procedures will be reviewed and approved by the Mallinckrodt Project Manager. Procedures addressing radiation safety issues with be reviewed and approved by the SSRO. Procedures addressing occupational or construction/remediation safety will be reviewed and approved by the Site Safety Manager. In the event that existing Mallinckrodt Procedures are used in Phase II activity, they will be reviewed and their use approved by the contractor and Mallinckrodt Project Managers and, as appropriate, by the RSO and Site Safety Manager.

9.2.3. Work Plan

A Work Plan is a plan to guide decommissioning work activities requiring a disciplined approach. It provides logical guidance without necessarily being procedural. Work Plans are typically prepared and issued by the contractor Operations Manager. A Work Plan depends on associated safety work permits for safety specifications that apply to the work activity covered. Each Work Plan will be prepared, reviewed, and approved in accordance with the Administrative Control Plan. Safety Work Permits and Daily Safety Permits (see below) required to perform the work will be identified. Each work plan will be reviewed and approved by the contractor Project Manager and/or the RPHS Manager, as appropriate depending upon the subject of the Work Plan. ny revision or termination will be communicated to decommissioning personnel in accordance with theAdministrative Control Plan.

9.2.4. Safety Work Permits

Safety Work Permits (SWP) specify industrial and radiation safety controls, including personnel monitoring, monitoring devices, protective clothing, respiratory protection equipment, special air sampling, and additional precautionary measures required to be used when performing decommissioning tasks. SWP are prepared in conformance with the SWP Procedure and are typically prepared in concert with a work plan. SWP 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. Safety Work Permits will be reviewed and approved by the contractor RSO or contractor environmental health and safety representative as appropriate. SWP will remain in force until they are revised or terminated by the Operations Manager. Any revisions or terminations will be communicated to decommissioning personnel in accordance with the Project Communications Procedure.

9.2.5. Daily Safety Permits

Daily Safety Permits check for hazardous conditions, allow use of spark-generating tools and equipment, ensure adequate ventilation, etc. The Daily Safety Permit procedure describes the conditions under which a Daily Safety Permit must be issued prior to the initiation of work. The contractor environmental health and safety representative will issue Daily Safety Permits. Daily Safety Permits expire eight hours after issuance and must be reissued prior to continuation of work.

9.2.6. Operations and Safety Communications

The Mallinckrodt and contractor decommissioning organizations will be small. Mallinckrodt and contractor management teams will have routinely scheduled meetings to review project status, decommissioning performance, safety performance, and issues for which action is required. Project teams may be established as deemed appropriate by the Mallinckrodt or Contractor Project Managers. The Contractor Project Manager will be responsible for establishing project teams, monitoring their performance, and ensuring timely completion and reporting of findings and recommendations.

9.3. DECOMMISSIONING MANAGEMENT POSITIONS AND QUALIFICATIONS

9.3.1. Mallinckrodt CT Project Manager

Minimum qualifications for C-T decommissioning management positions are specified hereafter. In the event a person having equivalent although not exact qualifications were to occupy one of these positions Mallinckrodt would inform the NRC. This person must hold a baccalaureate degree in science or engineering and have a minimum of five years of project management experience.

9.3.2. Mallinckrodt Radiation Safety Officer

This person must have completed a basic health physics course, must have a minimum of five years experience in health physics and radiation safety, and must be familiar with NRC radiation protection standards.

9.3.3. Mallinckrodt Safety Manager

This person must hold a baccalaureate degree in science or engineering and have a minimum of five years experience in nuclear safety, health physics, industrial safety, or environmental protection.

9.3.4. Contractor Project Manager

This person must hold (a) a baccalaureate degree in science or engineering and have a minimum of five years of experience in the nuclear industry, including five years of project management experience or (b) a baccalaureate degree in science or engineering and have a minimum of five years of construction experience with at least five years of experience in nuclear activities as well as five years of project management experience.

9.3.5. Contractor Radiation Protection, Health, and Safety Manager

This person must have a baccalaureate degree in science or engineering, must have completed a basic health physics course, must have a minimum of five years experience in occupational and environmental radiationprotection industrial safety, and decommissioning, and must be familiar with NRC radiation protection standards.

9.3.6. Contractor Quality Assurance Manager

This person must hold a baccalaureate degree in engineering, chemistry, or the physical sciences with at least two years experience in quality assurance or quality control.

9.3.7. Contractor Operations Manager

This person must have a minimum of five years construction management experience with a minimum of two years radioactivity or chemical remediation management experience.

9.4. TRAINING

All decommissioning activity will be performed in accordance with license STB-401, the C-T Phase II Decommissioning Plan, and the Administrative Control Plan. With the exception of the Mallinckrodt site-wide industrial safety training program described in Section 9.4.1 below, all required training will be provided by the contractor. Training subcontractors will be used as appropriate to provide timely and cost-effective training.

9.4.1. Industrial Safety Training

All decommissioning personnel will be required to successfully complete the existing Mallinckrodt St. Louis Plant site-wide industrial safety training program before starting physical activity or unescorted access to the site. 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 routine and frequent basis.

Personnel involved in the C-T 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 person uses that equipment. Credit may be given for applicable training received off-site.

The primary objectives of the C-T Project industrial safety training program are to:

- provide information on the industrial safety and hygiene hazards associated with working at the St. Louis Plant and on the C-T Project and the steps to be taken to provide a safe work environment, including those hazards unique to excavation and management of soil and debris;
- enable each person to comply with plant rules and respond properly to warnings and alarms under normal and accidental conditions; and,
- enable persons 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 person will be documented to verify that each worker is adequately trained for each job he will perform.

9.4.2. Radiation Safety Training

All unescorted persons involved in decommissioning activities for the C-T 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 decommissioning, 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 ES&H personnel, will be used to complement the formal radiation safety training.

Each person will be trained before entering a controlled area to perform work. The safety performance of each person will be reviewed annually, and workers will be retrained every two years. Credit may be given for applicable training received off-site, but plant-specific training is required for all decommissioning personnel. Training and examination results will be formally documented.

The primary objective of the radiation safety training program is to enable workers to work safely and 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 decommissioning work - potential radiological problems;
- radiological work planning - integrating radiation safety and operational requirements to ensure safe conduct of work;
- application, use, and maintenance of personal protective equipment and devices;

- emergency procedures and systems - work related information and actions;
- biological effects of radiation - basic understanding of biological effects and methods of assessment; and,
- the Radiation Protection Program.
- workers rights and responsibilities
- radiation exposure reports which workers may request pursuant to 10 CFR 19.13
- ALARA

9.4.3. Training Documentation

Training will be documented in each person's training record, including Mallinckrodt, contractor, and subcontractor personnel. Training received prior to employment on the C-T project, *e.g.*, initial or annual HAZWOPER training, will be verified and included in the person's record before physical work is performed. All classroom training and initial on-the-job training on decommissioning procedures or the use of specialized tools, equipment, or methods will be documented. General safety awareness discussions such as daily tailgate meetings and jobsite discussions prior to or during the performance of a given task will not be documented.

9.5. ADJUSTMENTS TO THE DECOMMISSIONING PROCESS

Decommissioning is intended to remove 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 decommissioning process without filing an application for an amendment to the license to change the decommissioning plan when the following conditions are satisfied:

a. the change does not conflict with requirements specifically stated in license STB-401 nor 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 decommissioning plan for the activity being performed;
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 Assessment;
e. reasonable assurance that adequate funds will be available for decommissioning remains;
f. the coverage requirements for scan measurements and/or sample density will not be reduced;
g. the derived concentration guideline levels and related minimum detectable concentrations (for both scan and fixed measurements methods) will not be increased;
h. the radioactivity level, relative to the applicable derived concentration guideline level, at which an investigation occurs will not be increased;
i. the statistical test applied to a final status survey will not be other than approved section 14 herein, or a Sign test, a Wilcoxon Rank Sum test, or those described in NUREG-1505;

j. the Type I decision error will not be increased beyond what is authorized in section 14 herein; and
k. a final status survey area classification will not be decreased, *e.g.*, from impacted to non-impacted; Class 1 to Class 2; Class 2 to Class 3; or Class 1 to Class 3.

Persons having managerial responsibilities as identified in section 9 *Project Organization and Management*, including proponents of controlled documents, will be asked to report any change to the decommissioning process that would seem to violate either of conditions *a* through *k*. Determination of whether the conditions are met will be made by and each change shall require approval by Mallinckrodt's C-T Project Manager, and Radiation Safety Officer, the contractor's Project Manager, and its RPHS representative. Mallinckrodt's and the contractor's C-T Project Managers are responsible for ensuring that the project is conducted in accordance with applicable health, safety, quality, and technical requirements. Mallinckrodt's C-T Project Manager shall be responsible for approval of operational and engineering changes. The contractor's RPHS representative 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 §9.5 have been met. The records of each evaluation shall be retained until license termination.

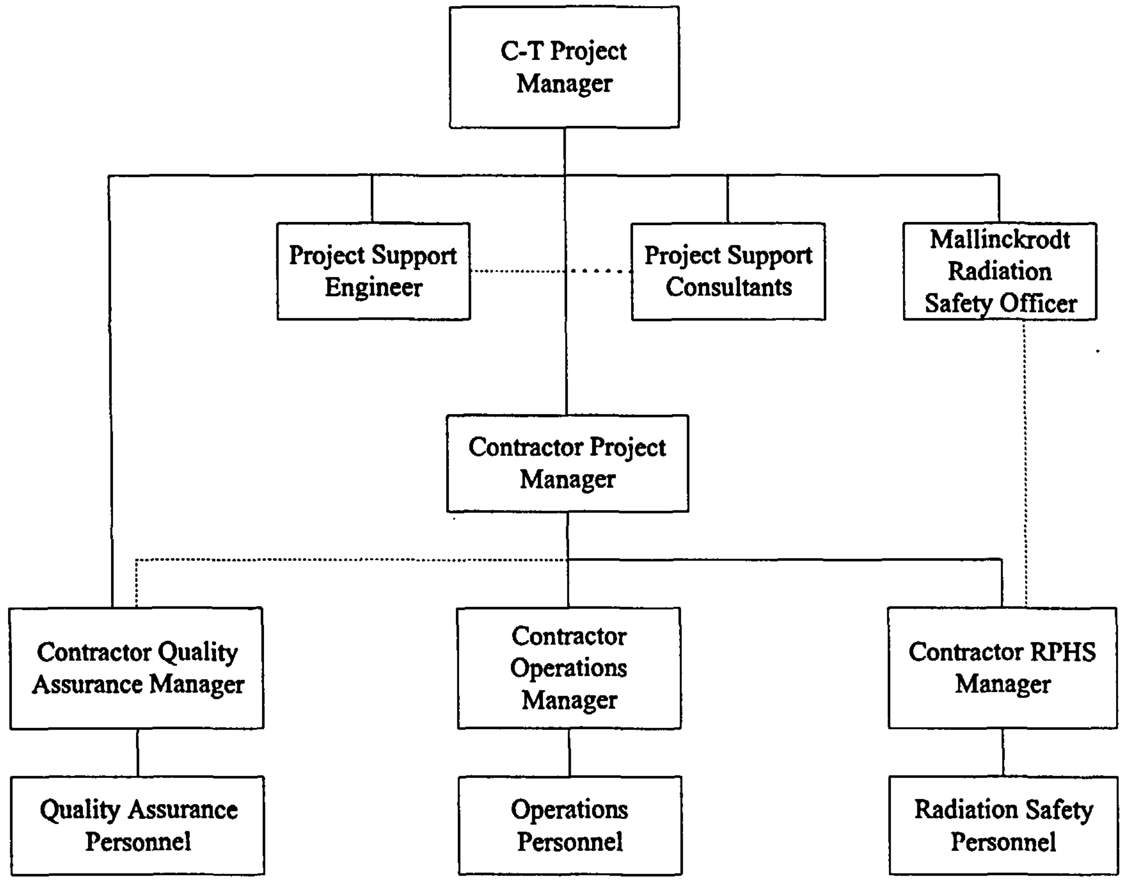

Figure 9-1. C-T Phase II Decommissioning Organization

SECTION 10

RADIATION SAFETY PROGRAM DURING DECOMMISSIONING

Mallinckrodt Inc.

C-T Phase II Decomissioning Plan
May 15, 2003

NRC Docket: 40-06563
NRC License: STB-401

10. RADIATION SAFETY PROGRAM DURING DECOMMISSIONING

This chapter describes the radiation safety program for the C-T Phase II Decommissioning Plan project to ensure the safety of all Mallinckrodt employees, contractors, and visitors during decommissioning. In recognition that the amount of radioactivity and therefore associated hazards will be reduced as the project progresses, the radiation safety program may be modified to be commensurate with the activities being performed. Mallinckrodt will review and approve implementation of the radiation safety program, and any revisions that are made during the project. Any such adjustment to the requirements of the radiation safety program shall be made in accordance with Section 9 Project Management and Organization.

10.1. RADIATION SAFETY CONTROLS AND MONITORING FOR WORKERS

The Radiation Safety Program will include procedures to protect workers, the public, and the environment from ionizing radiation. The contractor will be required to implement the program with oversight by the Site RSO.

10.1.1. Air Sampling Program

10.1.1.1. Collection

Concentrations of radioactive material in air will be determined by sampling the air. Air sampling shall be conducted in accordance with or equivalent to the guidance provided in U.S. NRC Regulatory Guide 8.25, "Air Sampling in the Workplace", July 1992. Breathing zone air samples will be the primary method of monitoring the worker's intake of radioactive material. The samples will be collected under known physical conditions (*e.g.*, filter type, sample time, flow rate). The flow meters of air samplers shall be calibrated at least annually. Calibration shall also be performed after repair or modification of the flow meter.

Air samples will also be collected of general and localized 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 warning of elevated concentrations for planning or response actions. In each case, the sampling point will be located in the airflow pathway near the known or suspected release point(s). As necessary, more than one air sample location may be used in order to provide a reasonable estimate of the general concentration of radioactive material in air.

Considering the low radioactivity concentration observed during characterization and during Phase 1 decommissioning, the ventilation rate in outdoor air, instrumentation having instant readout, annunciator, or alarm, is not proposed for the C-T Phase II Decommissioning Project.

10.1.1.2. Action Level and Limit

An administrative action level shall be established for breathing zone air samples of one DAC; air sample results greater than this administrative action level shall be reported to the RSO. An administrative limit shall be established for breathing zone air samples of 10 DAC-hours; individual exposure greater than this action level shall require the individual to be restricted from work involving potential exposure to airborne radioactive material unless approved by the Site RSO.

10.1.2. Respiratory Protection Program

The use of respiratory protection is not anticipated to be necessary during the C-T Phase II Decommissioning Project. However, if respiratory protection is determined to be necessary, it will be administered in accordance with the following requirements.

The respiratory protection program (RPP) provides guidance and instruction regarding protection of workers from occupational injury and illness due to exposure to airborne radioactive material. The RPP is implemented by written procedures. The RPP and implementing procedures are the primary means used to administratively establish safe respiratory protection practices and compliance with requirements of the NRC.

The RPP covers routine use of respiratory protection equipment. The functional areas of the RPP include medical evaluation, fit testing, selection, issue, inspection, cleaning, maintenance, storage, and training.

10.1.2.1. Medical Evaluation

Prior to the initial fit test, and at least every 12 months thereafter, an evaluation will be made of each worker required to wear respiratory protection equipment as part of the worker's duties as to whether or not the worker can wear the required respirator without physical risk. A worker will not be allowed to wear a particular type of respirator if, in the opinion of a physician, the worker might suffer physical harm due to wearing the respirator. A worker shall not be allowed to use a respirator without a current medical evaluation.

10.1.2.2. Fit Test

All workers required to wear respiratory protection equipment shall be required to successfully complete a fit test prior to initial use of the equipment. The fit test shall be repeated at least annually. A worker shall not be allowed to wear a respirator without a current successful fit test.

10.1.2.3. Selection

Respirators shall be selected from those approved by the National Institute for Occupational Safety and Health for the contaminant or situation to which the worker may be exposed. The Contractor's EH&S staff shall select the respirator type. Selection shall be based on the physical, chemical, and physiological properties of the contaminant, the contaminant concentration likely to be encountered, and the likely physical conditions of the workplace environment in which the respirator will be used.

10.1.2.4. Issue

Workers may be assigned respirators for their exclusive use or they shall otherwise be issued by the Contractor's EH&S staff. Respirators shall only be assigned or issued to workers qualified, with respect to the program, to use respiratory protection equipment. The type of respirator selected shall be documented on a Radiation Work Permit.

10.1.2.5. Inspection

Each respirator shall be inspected with regard to operability before, and routinely after, each use, and after cleaning.

10.1.2.6. Cleaning

Respiratory protection equipment that is used routinely shall be cleaned after each use. Respiratory protection equipment that is used by more than one worker shall be cleaned and disinfected after each use. The need for cleaning shall also be based on contamination surveys of the work area and of the respiratory protection equipment.

10.1.2.7. Maintenance

Respiratory protection equipment shall be maintained to retain its original effectiveness. Replacement or repair shall be done only by experienced persons, with parts designed for the respirator. No attempt shall be made to replace components or to make adjustments or repairs beyond the manufacturer's recommendations. Reducing valves or admission valves on regulators shall be returned to the manufacturer or equivalent for repair.

10.1.2.8. Storage

Respirators shall be stored to protect against dust, sunlight, heat, extreme cold, excessive moisture, or damaging chemicals. Respirators shall be stored in dedicated carrying cases or cartons that protect from dirt and damage.

10.1.2.9. Training

All workers required to use respiratory protection equipment shall be instructed in the content and applicability of the program and implementing procedures, and especially in the proper use of the equipment and its limitations. A worker shall not be allowed to use a respirator without current successful completion of training.

10.1.3. <u>Internal Exposure Determination</u>

Individual monitoring shall be provided for workers who require monitoring of the intake of radioactive material pursuant to 10 CFR 20.1502(b). Monitoring of intake shall normally be conducted by use of air samples, particularly of the breathing zone. Internal dose shall be determined by converting airborne concentrations to intakes in accordance with NRC Regulatory Guide 8.34 "Monitoring Criteria and Methods to Calculate Occupational Radiation Doses", July 1992.

When a potential or actual condition exists where the worker(s) could have received an unmonitored intake of radioactive material, and cannot otherwise be estimated, the intake shall be determined by measurements of quantities of radionuclides excreted from or retained in the body. These measurements shall be made consistent with the guidance provided in NRC Regulatory Guide 8.9 "Acceptable Concepts, Models, Equations, and Assumptions for a Bioassay Program", July 1993.

Determination of radiation dose to the embryo/fetus shall be performed in accordance with NRC Regulatory Guide 8.36 "Radiation Dose to the Embryo/Fetus", July 1992.

Work restrictions shall be implemented for any worker with an intake in excess of 50% of the applicable limit in 10 CFR 20. Work restrictions shall be implemented for any worker with an intake in excess of 50% of the chemical toxicity limit for soluble uranium.

10.1.4. External Exposure Determination

An individual monitoring device shall be provided to each worker who requires monitoring for external exposure pursuant to 10 CFR 10.1502(a). External monitoring shall be conducted in accordance with or equivalent to NRC Regulatory Guide 8.34, "Monitoring Criteria and Methods to Calculate Occupational Radiation Doses", July 1992.

External exposure monitoring, when required, shall be accomplished using a thermoluminescent dosimeter worn on the front of the upper torso. Radiological surveys may be performed to supplement personnel monitoring when work is being performed where workers are required to be monitored.

Dosimeters shall be processed at least quarterly by a vendor accredited by NVLAP.

Work restriction shall be implemented for any worker reaching 50% of the annual limits of 10 CFR 20.

10.1.5. Summation of Internal and External Exposures

Results of internal and external monitoring shall be used to calculate total organ dose equivalent and total effective dose equivalent to workers for which monitoring is required. Summation of internal and external doses shall be performed in accordance with NRC Regulatory Guide 8.34 "Monitoring Criteria and Methods to Calculate Occupational Radiation Doses", July 1992.

10.1.6. Contamination Control Program

Contamination control shall be managed by exposure control and monitored by radiation surveys.

10.1.6.1. Exposure Control

Personnel exposure to radioactive material will be controlled by application of engineering, administrative, and personnel protection provisions. The priority of application will be descending with respect to their order of description below.

Engineering. Engineering controls will be used, as practicable, to minimize or prevent the presence of uncontained radioactive material. Engineering controls will predominantly be comprised of containment, isolation, ventilation, and decontamination.

Administrative. Administrative controls will be used to control work conditions and work practices. Administrative controls will predominantly be comprised of the following:

Access control: Routine access to work areas will be limited to personnel necessary to accomplish tasks or activities. Access to work areas will also be controlled with respect to an individuals completed level of training, and requirements for use of personnel protection equipment.

Postings and barriers: Postings will be used to inform personnel of relevant hazards or conditions and associated access requirements. Barriers may be used to prevent unauthorized access.

Procedures: Written procedures may be used to describe specific radiation safety requirements necessary for tasks that involve radioactive material.

Safety Work Permit: The requirements for a Safety Work Permit (SWP) are described in Section 9.2. SWP will be used to describe specific or special worker protection requirements for activities involving radioactive material and not covered by a procedure. SWP may also be used in conjunction with a procedure.

Contamination Control: Action levels and limits for radiation surveys, described later in this section, will be used to control the levels of radioactivity on equipment and in areas.

Personal Protective Equipment. Personal protective equipment will be used to control personnel exposure to radioactive material when administrative controls are not sufficient and engineering controls are not practicable. Personal protective equipment may include head covering, eye protection, respiratory protection, impervious outerwear, gloves, and/or protective shoes or shoe covers.

10.1.6.2. Radiation Surveys

Radiation surveys will be performed to describe the radiation types and levels in an area or during a task, to identify or quantify radioactive material, and to evaluate potential and known radiological hazards.

The types of radiation surveys and their frequency are described in the following subsections.

Contamination Measurements. Measurements will be made of removable alpha and/or beta-gamma. The measurements will be made by wiping an area with cloth, paper, or tape. The radiation levels will be measured on the wipe. Contamination surveys shall be performed at the end of each workday where invasive demolition of contaminated material was performed.

Radiation. Exposure rate measurements will be performed using an ion chamber or equivalent. Measurements will be made at 30 centimeters. Measurements may also be made at contact.

Personnel. Personnel will be frisked prior to leaving an access controlled area.

Action Levels. Action levels are established to inform facility personnel when a situation needs to be evaluated so that corrective action can be taken. Action levels are set so that corrective actions can be made before a regulatory limit is exceeded.

Exceedance of an action level requires investigation including evaluation of preventative and/or corrective action. The investigation, and documentation of such, is completed commensurate with the significance of the condition.

Radiation levels exceeding the values described in the following subsections will be reduced below the respective levels as soon as practicable.

Removable: The action level for removable alpha or beta-gamma radiation on a surface is 1000 αpm/100 cm^2 or 1000 βpm/100 cm^2.

Exposure Rate: The action level for exposure rate is two millirem per hour at 30 centimeters.

Personnel: The action level for personnel and their personal effects is three times the background count rate of the survey instrument.

Limits. Items that are 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.

The limits are administered such that, when exceeded, action must be taken to reduce the level or additional control must be applied.

Items will not be released for unrestricted use until the relevant limits are satisfied.

Accessible surfaces and areas outside of an access-controlled area that exceed the respective limits will be decontaminated on a timely basis. In no case will the delay to initiate control exceed one normal workday. In the case of personnel contamination, there will be no delay to initiate decontamination.

10.1.7. Instrumentation Program

Instrumentation utilized for personnel monitoring will be calibrated and maintained in accordance with radiation safety procedures. Instrument calibration will be performed by the manufacturer, or by a contractor subject to equivalent calibration requirements. Portable instruments are calibrated on a semi-annual basis or as required due to maintenance. Specific requirements for instrumentation include traceability to NIST 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) for health physics application is given in Table 10-1. Typical personnel monitoring equipment is shown in Table 10-2.

In the event an instrument of the type listed in Table 10-1 is employed for the C-T Decommissioning Project, its background count rate or exposure rate and its lower limit of detection will be estimated for its application. Alternative instrumentation must also be able to measure adequately to assess compliance with radiological safety requirements.

Table 10-1. Typical Instruments for Performing Radiation Surveys

Instrument Type	Radiation Detected	Scale Range	BKG	Typical MDA 95% confidence Level
Scintillation (Ludlum 2224) Scaler/Ratemeter	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 MDA are based upon static measurements, one minute count times unless otherwise noted.

2) Instrument MDA depend upon background.

Table 10-2. 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 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

10.2. NUCLEAR CRITICALITY SAFETY

This topic is not applicable to the C-T Decommissioning Project.

10.3. HEALTH PHYSICS AUDITS, INSPECTIONS, AND RECORD-KEEPING

The radiation safety program shall be subject to an annual audit and periodic inspections. Each is performed to determine whether radiological safety activities are conducted in accordance with regulations, license conditions, and written procedures.

An audit of the radiation safety program shall be conducted annually. The audit shall be conducted by the Site RSO or designee. The audit will consider the basic functional areas of the radiation safety program; *e.g.*, Safety Work Permits, radiation safety procedures, radiological surveys and air monitoring, ALARA emphasis, individual and area monitoring results, access controls, respiratory protection program, training, *etc.*

The audit shall be conducted in accordance with a specific audit plan developed by the auditor. A written report shall be generated upon completion of the audit describing the results. The report shall be distributed to site management. As necessary, a written corrective action plan shall be prepared to address non-compliance issues. All corrective actions shall be tracked to completion. Once corrective actions have been completed, a written closure report shall be distributed to management documenting the completion of corrective actions.

Periodic inspections shall be conducted by the Contractor's EH&S staff. These inspections shall be routine reviews performed of operations and activities. The inspections shall normally be completed against a pre-established checklist. Checklists may be developed independently for differing periods; e.g. daily, weekly, monthly, etc. The checklist items shall usually be comprised of routine procedural requirements. Any findings discovered during the routine inspection shall be recorded on a tracking log. The log shall be maintained by the Contractor's EH&S Representative. The log shall include a description of planned corrective action and date of completion of corrective action.

SECTION 11

ENVIRONMENTAL MONITORING AND CONTROL PROGRAM

Mallinckrodt Inc.

C-T Phase II Decomissioning Plan
May 15, 2003

NRC Docket: 40-06563
NRC License: STB-401

11. ENVIRONMENTAL MONITORING AND CONTROL PROGRAM

This section describes an environmental safety program to monitor environmental radiation, air effluent, and water effluent discharged from the C-T Decommissioning Project. The program will be reviewed and approved by Mallinckrodt prior to implementation. 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 decommissioning progresses, the Environmental Safety Program can be modified to be commensurate with the activities being performed by following the procedure described in Section 13.2.6.

11.1. ENVIRONMENTAL ALARA EMPHASIS

11.1.1. ALARA Emphasis for Effluent Control

The project ALARA aim for effluents is 50% of the respective value in 10 CFR 20 Appendix B. The aim is not intended to set precedent or to be applied as a limit. The emphasis may be adjusted on the basis of review with regard to what may be ALARA for the particular circumstance.

The action levels for air and water effluents are based on the levels provided in 10 CFR 20, Appendix B, Tables 2 and 3. The action levels are 0.75 for environmental air, 0.6 for effluent water, and 0.6 for sewage effluent. If exceeded, an investigation will be initiated. The results of the investigation will include identification of appropriate corrective actions.

The site Radiation Safety Officer (RSO) will be responsible for setting and periodically reviewing the ALARA emphasis. The RSO shall be responsible for conducting investigations initiated due to exceeding an investigation level.

11.1.2. Engineering Controls and Processes

A description of practices, process controls, and engineering controls to maintain concentrations of radioactive material in effluents ALARA is provided in Section 11.3.

11.1.3. ALARA Reviews and Reports to Management

The effectiveness of the ALARA emphasis for the environmental monitoring and control of effluents is evaluated through the use of surveillances and audit(s).

11.1.3.1 Surveillance

The environmental monitoring and control program will be periodically subjected to surveillance. Surveillances are intended to verify that the objectives of the program are being satisfied and that the emphasis is generally effective. The surveillances may be limited in scope.

11.1.3.2 Audit

Environmental audits are scheduled and conducted under the Quality Assurance Program described in Section 13 of this Decommissioning Plan.

11.2 EFFLUENT MONITORING

11.2.1 Expected Concentrations

Concentrations of radionuclides in effluents are not expected to increase as a result of the activities conducted under this DP. The effluent controls described in Section 11.3 are intended to realize this condition.

11.2.2 Physical and Chemical Characteristics

The physical and chemical characteristics of radionuclides in any discharges from the activities conducted under this DP are expected to be representative of the source material characterization in DP Section 4.

11.2.3 Discharge Locations

Each area of remedial activity will have a known location(s) of discharge of storm water from the area. The location(s) will be identified in written procedures or work plans.

Emissions to air may occur from specific locations of activity and therefore will vary with the progress of the project. The emissions are expected to be ground-level or from inside a structure. No discharge from a stack is planned.

11.2.4 Sample Collection and Analysis

Water samples will be collected and analyzed in accordance with the requirements of the Industrial Wastewater Discharge Permit issued by the Metropolitan St. Louis Sewer District, which is designed to be representative of the effluent discharges.

11.2.5 Sample Collection and Analysis Procedures

11.2.5.1 Effluent Air Monitoring

No effluent air monitoring is anticipated, since no point source of effluent air is expected to exist. However, in the event a decontamination process exhaust ventilation or similar point discharge of potentially radioactive effluent air were employed, its effluent air would be sampled and analyzed for regulated radioactive particulate.

11.2.5.2 Environmental Air Monitoring

Environmental sampling stations will be provided during demolition or decontamination activities as required by 10 CFR Part 20 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 demolition 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).

11.2.5.3 Storm Water Monitoring

It will be the policy of Mallinckrodt during the C-T Decommissioning Project to minimize the production of contaminated aqueous liquids. There are three possible sources of contaminated aqueous liquids: sink and shower water, decontamination fluids, and water used for dust suppression. Mallinckrodt expects sink and shower water to contain an 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 rainwater 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.

11.2.6 Sample Collection Frequencies

Water samples will be collected in accordance with the requirements of the Industrial Wastewater Discharge Permit.

11.2.7 Environmental Monitoring Recording and Reporting Procedures

Water sample analyses will be recorded and reported in accordance with the requirements of the Industrial Wastewater Discharge Permit.

11.2.8 Quality Assurance Program

The Quality Assurance Program described in Section 13 is applicable to the implementation and conduct of the Environmental Monitoring and Control Program.

11.2.9 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.

11.3 EFFLUENT CONTROL

11.3.1 Practices, Process Controls, and Engineering Controls

Available process options will be considered to control the concentration of radioactive material in effluents to the environment. Examples of process controls include recycling, leakage reduction, and modification of facilities, operations, and/or procedures. If further reduction in effluent concentration is necessary, available engineering options will be considered. Examples of available engineering options include filtration, adsorption, containment, and storage.

Process and engineering options will be implemented unless a review indicates that a substantial reduction in effluent concentration would not result or costs are considered unreasonable. A determination of reasonableness may be based on a qualitative review requiring the exercise of professional judgment for factors difficult to quantify. These factors could include nonradiological social or environmental impacts, availability and practicality of alternative technologies, and potential for unnecessarily increasing occupational exposures.

Effluent controls will be described in a written procedure, work instruction, or safety permit. The primary effluent controls used are expected to be dust suppression and erosion control.

11.3.1.1 Dust Suppression

Administrative controls, such as use of less aggressive decontamination or demolition techniques, will be used to minimize generation of fugitive emissions. Engineering controls, such as water spray or filtration, will also be utilized to control fugitive emissions and minimize visible dust.

11.3.1.2 Erosion and Sediment Control

Erosion and sediment controls may be temporary or permanent, depending on the duration of the activity and any specific objectives. Controls will be provided in accordance with best management practices, regulatory guidance, manufacturer's specifications, and good engineering practices. Temporary controls serve to minimize erosion and restrict the transport of sediment within the project area. Permanent controls serve to stabilize the site with durable erosion control features to control sediment discharge, and protect nearby surface waters. Descriptions of erosion and sedimentation control practices that will be considered for use during the project include:

Stabilization Practices:

- Minimizing disturbance areas;
- Minimizing and controlling dust;
- Stabilizing surfaces after final grading; and
- Permanent vegetative cover for disturbed areas not intended for other cover.
- Pavement

Structural Features to Control Erosion and Sedimentation:

- Barriers to isolate areas of erosion and minimize sediment transport;
- Check dams in swale areas to minimize sediment transport;
- Erosion control blankets to minimize erosion due to concentrated flow prior to establishing vegetation;
- Construction of stabilized construction entrances to minimize the transport of sediment from project areas; and
- Stockpiles will be surrounded by sediment barriers.

Storm Water Management Practices

- Maintaining runoff flow patterns and discharge locations similar to existing conditions; and
- Maximizing overland flow through vegetated areas.

11.3.2 Action Levels

The action levels for implementation or revision of effluent controls are those described previously in Section 11.1.1.

11.3.3 Leak Detection Systems

Other than a pit from which contaminated soil was excavated, no impoundment is being planned for retention or processing of wastewater for the C-T Decommissioning Project. Processing systems use tanks, which can be visually inspected for leakage.

11.3.4 Release to Sewerage

Release to sewerage is described in Section 11.2.6.1.

11.3.5 Radiological Dose to Members of the Public

Based on the monitoring and controls described above, radiological dose to members of the public will be less than the applicable limits described in 10 CFR 20.

SECTION 12

RADIOACTIVE WASTE MANAGEMENT PROGRAM

Mallinckrodt Inc.

C-T Phase II Decomissioning Plan
May 15, 2003

NRC Docket: 40-06563
NRC License: STB-401

12. RADIOACTIVE WASTE MANAGEMENT PROGRAM

Radioactive waste from the C-T Decommissioning Project will be managed in accordance with the requirements of this C-T Radioactive Waste Management Plan. This plan ensures that radioactive waste from the C-T Decommissioning 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.

12.1. SOLID RADIOACTIVE WASTE

12.1.1. Solid Radioactive Waste Generation

Decommissioning activity will generate three general categories of solid waste: debris of pavement, concrete slabs, and subsurface material. Pavement includes macadam and concrete pavement removed to access subsurface materials. Concrete slabs include wastewater basin slabs and floor slabs from C-T process and support buildings demolished in Phase I. Subsurface materials will include but not be limited to soil, fill, sewer pipe, and building foundations not removed during Phase I. Subsurface foundations and other concrete, wood, or metal materials from buildings and equipment that previously occupied the site may also be encountered during Phase II. Soil and fill will be "volumetrically" contaminated. It is anticipated that sewer pipe, foundation material, and other non-soil materials will exhibit surface contamination only. In the discussions below, all subsurface material will generally be referred to as "soil".

Table 12-1 provides a summary of the type and estimated volume of radioactive wastes to be generated during Phase II. Table 12-2 provides estimates of the radionuclide activities in C-T radioactive waste. As indicated in the Table 12-2, Phase II solid wastes are projected to have average concentrations of natural uranium and natural thorium significantly below exempted quantities of source material as defined in 10 CFR 40.13.

C-T radioactive waste 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 C-T radioactive waste will therefore be Class A.

12.1.2. Solid Radioactive Waste Management

Pavement and excavated subsurface materials will be loaded into roll-off containers or dump trucks at the excavation site. As discussed in Section 8, water misting or similar technique will be used as appropriate to control emissions during excavation and loading. Containers or trucks will be covered prior to movement from the excavation area. 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 the excavation area on containers or vehicles.

As stated in Section 8.1, decontamination and volume reduction methods were selected to minimize the volume and cost of radioactive waste requiring disposal. Mallinckrodt and its contractor(s) will determine whether decontamination and final survey of individual materials is preferred over excavation and disposal. This Phase II Plan is based on the following preferences:

- excavation or demolition and disposal when it is cost-effective,
- decontamination when it is judged to be cost-effective compared to disposal, and
- decontamination or removal of selected contaminated areas of pavement and subsurface material to reduce the average mass concentration radioactivity below release limits and therefore minimize the cost of disposal.

12.1.3. Material Management Area

Soils and other materials that are not loaded directly into transport containers at the excavation site will be moved by truck or container to a Materials Management Area (MMA). Candidate MMA are:

1. the open area in Plant 5 would be within bounds of the
    - South side of Destrehan Street,
    - North side of Building 260,
    - East side of Buildings 240 and 250, and
    - West side of Buildings 236 and 245
2. the rail car loading area, and
3. where wastewater basins are located in Plant 7.

At either the excavation site or the MMA, radioactivity monitoring will be used to segregate solid wastes generated during Phase 2 into four categories, depending upon their radioactivity and chemical content:

- *non-impacted material*
- soils and materials that are < DCGL for soil and can be returned into an excavation on-site,
- soils and materials that contain unimportant quantities of radioactive material and can be managed by NRC-authorized transfer to a state-regulated disposal facility,
- soils and materials that must be managed at a NRC-licensed disposal facility, and
- soils and materials that contain above-background radioactivity and listed or characteristic hazardous wastes and must be managed as mixed waste as described in Section 12.3.

Soils and other waste materials generated during decontamination and remediation may be temporarily stored at the MMA for sampling and analysis, to accumulate sufficient quantities for economical shipment and disposal, or to coordinate shipments between the carrier and the disposal site. Soils and materials will be stored in covered containers or in piles. If needed to control dust or erosion by wind or rain, covers, surface coatings, or functionally similar techniques will be used. Stormwater run-on and run-off controls and monitoring will be used as appropriate.

Mallinckrodt anticipates that a maximum of approximately 20,000 cubic feet (approximately 750 cubic yards) of waste materials will be in temporary storage at any given time. Storage periods will be no longer than three months. In the event that additional area storage is needed, covered roll-off containers of C-T solid waste may be temporarily stored in MMA within the facility. Positive control over waste materials will be maintained in a two-fold manner: 1) An active 24-hour security system is in place for the entire Mallinckrodt facility, and 2) the temporary radioactive material storage area will be enclosed and/or roped-off and appropriately posted as required. 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.

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 will 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.

12.1.4. 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. Phase II contractor personnel will load C-T radioactive wastes that will be shipped in containers or trucks into transport containers in the MMA.

C-T radioactive wastes that will be shipped by rail gondola cars will be handled differently. To the extent practical, the existing FUSRAP rail car loading facility will be used. This facility was constructed specifically to load contaminated soil and debris into rail gondola cars. Soils will be loaded into containers or trucks at the excavation site or at the MMA and be taken to the FUSRAP soils management area. Contractor personnel, working under agreement with Mallinckrodt, will load the wastes into rail gondola cars. Contractor personnel will perform the work using their health and safety procedures and protocols. In the event that the FUSRAP facility is not available, the Phase II contractor will load C-T waste into rail gondola cars at a controlled location at the facility and in accordance with the health and safety requirements of this Phase II Plan.

12.1.5. 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, 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 requirements as appropriate. Mixed waste, if any, will also be managed in conformance with State and Federal hazardous waste regulations.

12.1.6. Waste Disposition

Contaminated materials will be disposed of by transfer to a licensed disposal facility, by transfer to a disposal facility authorized to receive an unimportant quantity of source material, or may be sorted or decontaminated, surveyed, and released under criteria specified in Section 14 of this Phase II Plan.

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

If equipment subject to surficial contamination that is generated during Phase II contains less regulated radioactivity than the criterion for unrestricted release specified in NRC Regulatory Guide 1.86 or in NRC Policy and Guidance Directive FC 83-23, it may be released without restriction. Before unrestricted release, that equipment or material would be subjected to a radiation survey.

Soil, debris, and or other material generated during Phase II whose radioactivity concentration is less than the DCGL specified in Section 5, thereby satisfying the criterion for unrestricted release, may be used for backfill in on-site excavations deeper than 4 feet below grade.

If waste material contains more than unrestricted release radioactivity concentration and less than the *unimportant quantity* of source material as defined in 10 CFR 40.13, it will be disposed in accordance with an NRC-authorized transfer to a disposal facility, subject to approval from the cognizant state regulatory agency(ies) in which the disposal facility is located. Waste Control Specialists in Texas or USEcology in Idaho are examples of facilities for the disposal of these materials.

If waste material contains greater than an *unimportant quantity* of source material, *i.e.*, concentration, of source material as defined in 10 CFR 40.13 it will be disposed at an NRC-regulated disposal facility authorized by radioactive materials license to receive it. Segregation from other material will be maintained.

12.2. LIQUID RADWASTE

Phase II operations will not involve use of significant quantities of liquid chemicals requiring treatment and/or 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.

Soil management and housekeeping activities will be designed to minimize the exposure of contaminated soils to stormwater. However, stormwater from active remediation areas, decontamination areas, and the Material Management Area may contain contaminated soil particles. Management of potentially contaminated soil is described in Section 12.1 above. Stormwater will be contained, collected, and stored in temporary, dedicated aboveground tankage located in the Material Management Area. Collected water will be used for dust control or be filtered or otherwise treated prior to discharge to the plant sewer system in accordance with the facility's wastewater permit. Used filters and treatment sludge, if any, will be solidified and or dewatered and managed as a solid radioactive waste.

Water removed from excavations will be managed in a manner similar to decontamination water and stormwater runoff.

As in the case of radioactive solid waste discussed above, any aqueous radioactive waste generated during Phase II will be Class A.

12.3. MIXED WASTE

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

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

12.4. RECORDS

Mallinckrodt will maintain records of waste material released from the C-T decommissioning area or controlled areas.

Table 12-1. Estimated Phase 2 Solid Radioactive Waste Volumes

Waste Type	Volume[a] (ft^3)
Pavement	4100
Building slabs	13000
Subsurface material	71000
TOTAL	88100

[a] Volume estimates are described in sections 4.8.2, 4.8.3, and 4.8.4.

Table 12-2. Estimated Solid Radioactive Waste Concentration and Activity

Radionuclide	Pavement[a]		Building slabs[b]		Subsurface Material[c]	
	Concentration (pCi/g)	Activity (Ci)	Concentration (pCi/g)	Activity (Ci)	Concentration (pCi/g)	Activity (Ci)
U-238	35	0.0005	18	0.0008	29	0.06
Th-230	26	0.0004	23	0.001	50	0.10
Ra-226	146	0.002	27	0.001	226	0.43
Th-232	15	0.0002	11	0.0005	11	0.02
Ra-228	16	0.0002	10	0.0004	38	0.07
Th-228	17	0.0003	15	0.0007	17	0.03

[a] The radionuclide concentrations for pavement are the respective average concentrations of scabble samples SC-07 through SC-18 (see Table 4-2). The radionuclide activity is estimated as the product of the radionuclide concentration, the area corresponding to Table 12-1 (assuming an average contamination depth of 1 cm and a density of 120 lb/ft^3).

[b] The radionuclide concentrations for building slabs are the respective average concentrations of scabble samples collected in support of the CT Phase 1 DP. The radionuclide activity is the product of the radionuclide concentration, the building slab area, 25000 ft^2, corresponding to Table 12-1, and assuming an average contamination depth of 1 cm and a density of 120 lb/ft^3.

[c] The radionuclide concentrations for subsurface material are the respective average concentrations of subsurface samples for which the sum-of-fractions value is greater than one. The radionuclide activity is the product of the radionuclide concentration and the subsurface material volume of Table 12-1, assuming an average density of 100 lb/ft^3.

SECTION 13

QUALITY ASSURANCE PROGRAM

Mallinckrodt Inc.

C-T Phase II Decomissioning Plan
May 15, 2003

NRC Docket: 40-06563
NRC License: STB-401

13. QUALITY ASSURANCE PROGRAM

The major aspects of the quality assurance program for the decommissioning activities are discussed in the following sections.

13.1. ORGANIZATION

13.1.1 QA Program Management Organization

The C-T decommissioning organizational structure will consist of a management team from Mallinckrodt and the decommissioning contractor.

The Mallinckrodt C-T Project Manager will provide overall direction for the C-T Decommissioning Project. The Project Manager will be supported by managers responsible for contract administration, environmental affairs, quality assurance, project engineering, and legal.

While Mallinckrodt will be responsible for ensuring that the NRC requirements are met, Mallinckrodt intends to contract services to perform decommissioning activities.

The contractor will implement the radiological, occupational, and environmental safety programs and the procedures to implement the program requirements. The contractor will also provide an independent quality assurance program, and provide and manage a trained, experienced labor force to perform the decommissioning activities.

The contractor's Project Manager will provide day-to-day direction for the C-T Decommissioning Project, but will report directly to the Mallinckrodt Project Manager. The contractor's Project Manager will be supported by operations, environmental, safety, and health personnel who will provide technical advice, resources, and day-to-day management of the C-T Decommissioning Project workers.

13.1.2 Duties and Responsibilities

Duties and responsibilities of responsible management positions are described in Section 9.1.

13.1.2.1 Contractor's Quality Assurance Manager

The contractor's Quality Assurance Manager is responsible for establishing and assuring implementation of the contractor quality assurance program. This function is independent of Operations and will report directly to the Mallinckrodt C-T Project Manager with copies of audits provided to the contractor's Project Manager. [ref. section 9.1.8]

13.1.3 Work Performance Evaluation

Work performance is evaluated through the Corrective Action Program and through the Audit and Surveillance Program.

13.1.4 Description of Authority

The authorities of the various groups within the C-T Decommissioning Project are described in Section 9.1.

13.1.5 Organization Chart

The C-T Decommissioning Project organization, including the Quality Assurance Manager, is illustrated in Figure 9-1.

13.2. QUALITY ASSURANCE PROGRAM

13.2.1. Quality Assurance Program

Decommissioning activities will be performed in a manner to ensure the results are accurate and that uncertainties have been adequately considered. The quality assurance program will operate in all stages of decommissioning through the final survey, 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 decommissioning 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.

13.2.2. QA Policies

It is the policy of Mallinckrodt C-T Decommissioning Project management to perform its decommissioning work professionally and consistently to achieve a level of quality which meets or exceeds facility license termination and unrestricted use requirements. As part of accomplishing this management requirement, all personnel are required to comply with the elements of this Quality Assurance Program (QAP), implementing directives and project specific addenda in the day-to-day performance of their work. Suggestions on improvements to the Quality Assurance Program and its elements are encouraged and should be directed to the C-T Project Manager or the Quality Assurance Manager.

The QAP and its sub-tier functional area directives are designed to implement applicable requirements of the NRC's radiation program regulations applicable to fuel cycle facilities and their decommissioning for license termination.

All employees of the C-T Decommissioning Project and its contractors are responsible for assuring the quality of the work that they perform and for compliance with the requirements of this plan and applicable regulation.

The C-T Decommissioning Project Manager has the overall responsibility for ensuring that the Quality Assurance Program is implemented and maintained. A Quality Assurance Manager is designated as the position responsible for implementing and assessing the scope, status, implementation and effectiveness of the Quality Assurance Program.

13.2.3. Procedures

Supporting Quality Implementing Procedures (QIP) will provide step-by-step details for complying with project QA requirements. The final radiation status survey, including development of sampling plans, direct measurements, sample analyses, 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.

13.2.4. Management Reviews

Management reviews are implemented through the Corrective Action program and the Audit and Surveillance program.

13.2.5. Notification of Changes

Changes to the key elements of this Quality Assurance Program will be submitted to the NRC for review and approval prior to implementation. [ref. Sections 9.5 and 9.6]

Editorial changes or personnel reassignments of a non-substantive nature do not require NRC notification.

13.2.6. Management Assessment

The effectiveness of the Quality Assurance Program will be monitored and assessed through the Audit and Surveillance Program and the Corrective Action Program. Audit findings and deficiencies identified through the Corrective Action Program will be tracked and trended through the commitment tracking system.

Audit findings and their responses, and Condition Reports and their resolutions will be reviewed by project management.

13.2.7. Self-Assessment Program

The Self-Assessment Program is implemented through the Audit and Surveillance Program and the Corrective Action Program. Results of audits and surveillances are forwarded to the cognizant Department Manager and to the Mallinckrodt C-T Decommissioning Project Manager.

13.2.8. Independence of QA Personnel

An organizational structure, functional responsibilities and qualifications, levels of authority, and lines of communication for activities affecting quality shall be established and documented. The management organization that is responsible for assuring that decommissioning and subsequent license termination requirements are met is described in Section 9.

13.2.9. Organizational Responsibilities

Personnel performing self-assessment shall be independent of the activities being observed, and shall be qualified by education, experience and training, as appropriate.

13.2.10. Acceptance Criteria

The Self-Assessment Program is implemented through the Audit and Surveillance Program and the Corrective Action Program. Results of audits and surveillances are forwarded to the cognizant Department Manager and to the Mallinckrodt C-T Decommissioning Project Manager.

13.3. DOCUMENT CONTROL

13.3.1 Documents Included in QA Program

Documents that generate materials or data essential to the quality of decommissioning are controlled to assure that they are current, correct, are properly evaluated and audited, cite validation back-ups, and are stored and available for inspection or use in generating final project license termination materials. Standardized document control procedures are defined in the Quality Assurance Procedures (QIP).

Functional groups, when generating directives, are to identify essential quality requirements and acceptance criteria in their respective directives. Back-up records are to accompany the final data set that is to be reviewed, stored, and relied upon for license termination use.

13.3.2 Control of Documents

Documents that specify quality-related requirements and instructions are identified, reviewed, approved, issued, distributed, and maintained as controlled documents in accordance with written procedures. A listing of the types of documents to be maintained as controlled documents is contained in a Controlled Document List. The Controlled Document List will be updated as needed, to ensure it is comprehensive, current, and complete.

Changes to controlled documents are reviewed and approved by the same organization that reviewed and approved the documents originally, or by other designated, qualified persons. Disposition of a superseded or modified document is controlled in accordance with written procedure. A master list of controlled documents is maintained to identify the current revision number of instructions, procedures, specifications, and drawings important to quality. The list is distributed periodically to those individuals or organizations responsible for maintaining the applicable controlled documents, to prevent the use of outdated or obsolete documents.

Appropriate controlled documents are available in the work area before initiation of and during the performance of activities affecting quality. This availability is verified periodically by Quality Assurance. Changes or revisions to controlled documents are verbally communicated to affected individuals and a required reading program assures awareness of the change.

13.4. CONTROL OF MEASURING AND TEST EQUIPMENT

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 or other recognized standards. 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.

13.5. CORRECTIVE ACTION

13.5.1 Corrective Action Procedures

Conditions adverse to the quality requirements of decommissioning are those conditions that if uncorrected, could violate safety and environmental regulations, and/or license commitments. Non-conformance shall be identified promptly and corrected as soon as practical. Corrective action shall be commensurate with the seriousness of the condition being corrected.

13.5.1.1 Implementation

To ensure that only correct and current documents are in use, a Quality Assurance Procedure applicable to all functional areas is required for notification of corrective actions. This quality requirement is implemented by procedures covering Corrective Action Requests and Stop Work Orders.

13.5.2 Documentation

The effectiveness of any corrective action shall be documented before the condition is considered corrected.

13.6. QUALITY ASSURANCE RECORDS

13.6.1. 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 building grid. Data management personnel will also ensure that chain-of-custody and data management procedures are followed for decommissioning-related samples. The decommissioning 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. Each element of the decommissioning process that is important to quality of outcome, 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.

13.6.2. Data Management

13.6.2.1. 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.

13.6.2.2. Field Survey Data

The generation, handling, computations, evaluation, and reporting of final radiation status survey data will be as specified in the decommissioning 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.

13.6.2.3. 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.

If sample data are rejected or data omissions are identified during the data validation, those 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 final status survey data are processed by computer, the application program[1] 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 will document the application program, including its algorithms and a listing or copy of the program.

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

The person responsible for sample collection will initiate a chain-of-custody record using a standard form provided by the decommissioning contractor. A copy of this form will accompany the samples throughout transportation and analyses; and any breach in custody or evidence of tampering will be documented.

13.7. AUDITS AND SURVEILLANCES

Periodic audits will be performed to verify that decommissioning activities comply with established procedures and other aspects of this QA Plan 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 semi-annual basis, in accordance with written guidelines or checklists. Health and safety personnel will also conduct semiannual audits in their area of concern or have them performed by qualified personnel. External program audits may 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.

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[1] An *application program* consists of instructions and or algorithms created specifically for processing data for the CT decommissioning 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.™

SECTION 14

FACILITY RADIATION SURVEYS

Mallinckrodt Inc.

C-T Phase II Decomissioning Plan
May 15, 2003

NRC Docket: 40-06563
NRC License: STB-401

14. FACILITY RADIATION SURVEYS

This section provides a summary of facility radiation surveys primarily focused on site investigation. These surveys include characterization surveys, remedial action support surveys, and the Final Status Survey (FSS). The FSS survey will demonstrate that areas of the site subject to this decommissioning plan meet the criteria for release.

As discussed in C-T Phase II Decommissioning Plan (Phase II Plan) Sections 1 and 4, the scope of this decommissioning plan includes two types of environmental media. The first is surface slab material, either concrete or asphalt pavement or building floor, slab, or basin surface. The second type is soil, fill, and similar bulk materials. These materials are almost entirely subsurface, because the surface of the area of interest is nearly entirely covered by either building floor slabs or pavement.[1, 2]

Information regarding the FSS is intended to satisfy Method 2 described in NUREG-1727 Section 14. That is, the decommissioning plan includes descriptions of release criteria, site characterization surveys (included by referring to the comprehensive characterization survey report), remedial action support surveys, the final status survey design principles, and Final Status Survey Report contents. The description of final status survey design principles includes a description of the method to determine the number and locations of sampling points to be used in the final radiological survey in accordance with the method described in MARSSIM. The FSS information provided here is intended to be the only information submitted for NRC approval prior to the Final Status Survey Report.

To the extent practical, guidance from the Multi-Agency Radiation Survey and Site Investigation Manual (MARSSIM), NUREG-1727 (Section 14 and Appendix E), and NUREG-1505 has been incorporated in this Section 14. Release criteria (denoted "derived concentration guideline level" or "DCGL" in MARSSIM) have been established, as discussed in Section 14.1. Site characterization surveys have been performed and reported earlier and are discussed briefly in Section 14.2. Remedial action support surveys are described in Section 14.3. The Final Status

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[1] The Phase II FSS will include certain surveys designed to confirm that the Phase II activities have not invalidated certain results of the Phase I FSS. Phase I applied to structures, including a number of structures to remain in use. After Phase II and before the license is terminated, Mallinckrodt will perform a confirmatory radiation survey to assess whether buildings in Area 5 previously released by the Phase I FSS might have been contaminated as a result of subsequent Phase II decommissioning activity. The confirmatory survey would emphasize floors near entrances since re-contamination would most likely be by tracking-in. The methodology to be used in this confirmatory survey will be the methodology applied in the Phase I FSS.

[2] An exposed surface of a building foundation expected to remain in place after license termination will be considered as part of the contiguous building slab for survey purposes. A subsurface building foundation will be considered part of the subsoil survey unit within which it is located. A subsurface building foundation within a soil survey unit that passes a FSS will also be assumed to pass FSS and will not be sampled. A subsurface building foundation within a soil survey unit that requires remedial action adjacent the foundation will be subject to measurement of radionuclide concentration in scabble samples from locations selected based on professional judgment. Results of those samples will be considered remedial action support survey data and will be evaluated to determine whether remedial action for the building foundation is necessary.

Survey design, based on Data Quality Objectives (DQO) is described in Section 14.4. The planned Final Status Survey Report is described in Section 14.5.

14.1. RELEASE CRITERIA

Release criteria (DCGL values) have been determined for each medium for each residual radionuclide of interest[3] regulated under the NRC license. These criteria do not apply to other radioactive material, such as background radioactivity, for example, or to unregulated radionuclides such as K-40.

Radionuclides of interest in this plan have been identified in the review of C-T process history, described Phase II Plan Section 1, and in the evaluation of radiological characterization of the site, described in Section 4:

- 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).

Surface activity limits (activity per unit area) have been developed in Phase II Plan Section 5 for pavement or building slabs and bulk concentration limits (activity per unit mass) have been developed for subsurface materials. Two types of release criteria apply. The first, $DCGL_W$, is intended to be applied to estimates of the mean concentration in a survey unit. The second, $DCGL_{EMC}$, is intended to apply to localized, elevated measurements exceeding the $DCGL_W$. The $DCGL_{EMC}$ values are derived as the product of $DCGL_W$ and an area factor. Derivation of DCGL and area factor values is described in Phase II Plan Section 5. Values for application to volumetrically contaminated material (soil) in the FSS are listed in Table 5-1 and Figure 5-1. Values for application to areally contaminated surfaces (*e.g.*, slabs, pavement, basin surfaces) in the FSS are listed in Table 5-3 and Figure 5-2.

14.2. CHARACTERIZATION SURVEYS

An extensive radiation survey designed to characterize the radiological status of the site has been conducted in accordance with an NRC-approved plan[4] and results have been reported in detail.[5] A discussion of this effort, including a general description of methodologies employed and a summary of results obtained, is provided in Phase II Plan Section 4.

Characterization Survey results of interest in the Phase II Plan are those related to surfaces of pavement, building floor slabs, and subsurface materials. The measurements of primary importance for pavement and building slabs were direct beta/gamma measurements using large-

[3] Radionuclides of interest exclude those regulated radionuclides contributing less than 10 percent of the total effective dose equivalent and not present in a fixed ratio to a key radionuclide (DG-4006, p. 18).

[4] Mallinckrodt Chemical, Inc., C-T Plant Characterization Plan, January 1994. Supplement May 1994.

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

area detectors in both scan and static mode. The measurements of primary interest for subsurface materials were laboratory analyses of key radionuclides in samples collected from boreholes.

Characterization survey results have been or will be used:

- to provide sufficient information to permit planning for site remediation that will be effective and will be performed in a way that meets regulatory requirements,
- to demonstrate that it is unlikely that significant quantities of residual radioactivity have gone undetected,
- to provide information that will be used to design the final status survey, and
- to serve as elements in the FSS (to the extent that characterization surveys can be shown to meet quality assurance requirements applied in the Characterization Survey, as described in the Characterization Survey Report).

In serving as elements in the FSS, Characterization Survey measurements may comprise the entire data set for a particular survey unit. Where Characterization Survey data are insufficient in number to serve as the entire data set for a particular survey unit, those data may be supplemented, where appropriate, by additional FSS measurements using a statistically based sampling design, such as a two-stage sampling plan[6].

14.3. REMEDIAL ACTION SUPPORT SURVEYS

Surveys designed to guide and monitor remedial action are planned. Methodologies to be used are those that provide adequate sensitivity to determine compliance with DCGL while minimizing the time required for measurement and reporting.

Methodologies for slab materials will include direct field measurements (both stationary and scan) of surface β-γ radioactivity. Methodologies for subsurface materials may include *in situ* measurements, such as down-hole gamma spectrometry, or measurement of radioactivity in soil samples by commonly used laboratory techniques, such as gamma spectrometry, in a radioanalytical laboratory located on-site for rapid response or off-site. The *in situ* measurement methodology is described in Appendix F, Radionuclide Analysis in Soil by In-ground Gamma Spectrometry.

Remedial action support surveys will be designed to be used as elements of the Final Status Survey where practical and where satisfaction of all FSS requirements described in this section is achieved. In serving as elements in the FSS, remedial action support measurements may comprise the entire data set for a particular survey unit. Where remedial action survey data are insufficient in number to serve as the entire data set for a particular survey unit, those data may be supplemented, where appropriate, by additional FSS measurements using a statistically based sampling design, such as a two-stage sampling plan[7].

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[6] NUREG-1757, Appendix C.
[7] NUREG-1757, Appendix C.

14.4. FINAL STATUS SURVEY DESIGN

This section describes the planned Final Status Survey. This survey will demonstrate that the two types of media: pavement and subsurface material, meet the criteria for release. To the extent practical, guidance from the Multi-Agency Radiation Survey and Site Investigation Manual (MARSSIM) (NUREG-1575) has been incorporated in this Final Status Survey Plan. Measurement instrumentation is described in section 14.4.1, "Instrumentation." Background determination is described in Section 14.4.2. "Background." Section 14.4.3, "Survey Methodology," describes the statistical sampling and data evaluation methodology. Section 14.4.4 discusses quality assurance aspects of the survey.

14.4.1. Instrumentation

A Final Status Survey will consist of scanning, direct stationary surveying, down-hole *in situ* measurement, and or laboratory analysis of subsurface material samples. Therefore, scanning instruments, direct measuring instruments, and laboratory instruments will be used in conducting the final radiation surveys and sample analyses. All instruments will be appropriate for the type of survey and the concentration of radioactivity to be measured.

Typical instrumentation is listed in Tables 14-1 (field methods) and 14-2 (laboratory methods). Other instrumentation meeting requisite detection capabilities may be used provided it meets quality objectives for calibration, operability, and detection capability.[8] Table 14-1 lists the instrumentation to be used for survey activities, along with typical parameters and detection sensitivities for the instrumentation and survey technique. The combination of instrumentation and technique will be chosen to provide a detection sensitivity to satisfy survey objectives. Sensitivities for scanning techniques are based on movement of the detector over the surface at one detector-width per second and use of audible indicators to sense changes in instrument count rate.

[8] Appendix E, "Lower Limit of Detection"

Table 14-1

Typical Field Methods for Performing Final Radiation Status Surveys

Instrument Type	Radiation Detected	Scale/Range	Typical Background	Typical MDA 95% confidence Level[2,3]	Usage
Scintillation (Ludlum 2224) Scaler/ Ratemeter with 43-89 probe	Alpha Beta Beta	0-500,000 cpm	<10 cpm ≈750 cpm closed ≈1500 cpm open	100 dpm/100 cm^2 (direct) 1600 dpm/100 cm^2 (direct) 5100 dpm/100 cm^2 (scan)	General Characterization[4]; FSS[5]
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	General Characterization[4]
3" x ½" NaI Scintillation Detector Digital Scaler	Gamma	0-500,000 cpm	2,500 cpm avg shielded[7] 7,000 cpm avg unshielded	250 cpm 500 cpm	General Characterization[4]
100 cm^2 gas flow (43-68) Digital Scaler[1]	Alpha Beta Beta	0-500,000 cpm	<10 cpm ≈750 cpm closed ≈1500 cpm open	100 dpm/100 cm^2 (direct) 1600 dpm/100 cm^2 (direct) 7100 dpm/100 cm^2 (scan)	General Characterization[4]; FSS[5]
Ludlum 2" GM Tube (Pancake)	Beta Gamma	0-500,000 cpm 720 cpm = 0.2 mR/h	<200 cpm	2300 cpm	General Characterization[4]
5" plastic scintillation detector with multi-channel analyzer	Beta	N.A.	TBD[1]	TBD[1]	General Characterization[4]
2" x 2" or 3" x 3" NaI scintillation detector w/ multi-channel analyzer for down-hole *in situ* quantitative analysis	Gamma spec	N.A.	TBD[1]	TBD[1]	FSS[5]
Floor monitor with gas proportional detector and scaler/rate meter (Ludlum 239-1F with Model 2221 or 2224 alpha/beta scalar/ratemeter)	Alpha Beta	0-500,000 cpm	TBD[1]	TBD[1]	FSS[5]
Pressurized Ion Chamber (Reuter-Stokes HPIC)	Gamma	0 to 10 R/hr	Background of its environment	About 0.1 µR/hr Accuracy ± 5% at 10 µR/hr	Environmental gamma exposure rate
Bicron AB-100 Scintillation Probe	Alpha Beta Beta	0-500,000 cpm	<10 cpm ≈750 cpm closed ≈1500 cpm open	70 dpm/100 cm^2 (direct) 850 dpm/100 cm^2 (direct) 3900 dpm/100 cm^2 (scan)	General Characterization[4]; FSS[5]

Notes: [1] TBD = to be determined prior to initial use and calibration.
[2] Instrument MDA are based upon static measurements, one minute count times unless otherwise noted.
[3] Instrument MDA depends upon background.
[4] Characterization instrument; may include non-quantitative uses
[5] FSS method, or may be used in support of FSS

Table 14-2

Typical Laboratory Methods for Performing Final Radiation Status Surveys

Instrument Type	Radiation Detected	Scale/Range	Typical Background	Typical MDA 95% confidence Level[4]	Instrument Usage
Ludlum Model 2929	Alpha Beta	0-99,999,999 cpm	0.2 cpm 45 cpm	3 dpm 50 dpm	General Characterization[2]
Tennelec LB5100 Computer Based Auto Sample Counter	Alpha Beta	0-99,999,999 cpm	<0.3 cpm 1.5 cpm	0.4 dpm 1.5 dpm	General Characterization[2]
Waste Counter – Computer Linked MCA 3" x 3" NaI (Tl) Detector	Gamma	-	TBD[1] pCi/g Total U TBD[1] pCi/g Th (Nat)	TBD[1] pCi/g U TBD[1] pCi/g Th (Nat)	Waste Characterization
5" Slide-Drawer ZnS Scintillation Counter	Alpha	0-500,000 cpm	<0.3 cpm	2 dpm	General Characterization[2]
Shielded high-resolution solid-state gamma detector with multi-channel analyzer for quantitative and qualitative analysis of gamma emitting radionuclides in soil or similar materials in Marinelli beaker or similar container	Gamma spec	N.A.	N.A.	Low in comparison to typical naturally occurring concentrations of nuclides of interest that are measurable by this method	General Characterization[2] FSS[3]
Shielded high-resolution solid state alpha detector with multi-channel analyzer for quantitative and qualitative analysis of alpha-emitting radionuclides chemically separated from sample and deposited in low self-absorption form	Alpha spec	N.A.	N.A.	Low in comparison to typical naturally occurring concentrations of nuclides of interest that are measurable by this method	General Characterization[2] FSS[3]
Photon Electron Rejecting Alpha Liquid Scintillation Counter (PERALS)[5]	Alpha	N.A.	N.A.	Low in comparison to typical naturally occurring concentrations of nuclides of interest that are measurable by this method	General Characterization[2] FSS[3]
Kinetic phosphorescence analyzer	Total uranium (mass)	N.A.	N.A.	Low in comparison to typical naturally occurring concentrations of elements of interest that are measurable by this method	General Characterization[2] FSS[3]

Notes: [1] TBD = to be determined prior to initial use and calibration.
[2] Characterization instrument
[3] FSS method, or will be used in support of FSS
[4] Instrument MDA depends on background
[5] *Photon Electron Rejecting Alpha Liquid Scintillation (PERALS)*, ORDELA, Inc., Oak Ridge, TN

Direct measurements for gross α activity will be performed using a scintillation or gas proportional detector. Direct surface measurements for gross beta activity will be performed using scintillation probes or gas proportional probes. Special consideration will be given to the use of large area probes on the order of 100 cm^2 or greater. Scanning shall be performed using scintillation probes or gas proportional probes such as the Bicron Surveyor M with A100 or B100 probes and gas proportional floor monitors for beta activity.

Exposure rate measurements will be performed by NaI scintillation detectors such as the Ludlum model 19 or by a pressurized ion chamber such as a Reuter-Stokes HPIC, *e.g.*, model RSS-131.

The methods of interpreting stationary and scanning sensitivity[9] to beta radiation are described in Appendix E, Lower Limit of Detection. Those methods will be used to estimate the lower limit of detection (LLD or MDA) of each instrument before it is used to perform a final status survey (*a priori* LLD). LLD are estimated in Tables 14-1 and 14-2 for instruments for which representative background data are available.

The quantity determined in measurement of subsurface samples will be concentration of individual key radionuclides. Concentrations of radionuclides not measured directly will be inferred either from measurement results (*e.g.*, lead-210 assumed in equilibrium with radium-226) or, from radionuclide concentration ratios observed in characterization data. This approach will be highly accurate for short-lived progeny, which can, in fact, be assumed to be in equilibrium. The approach will also be either conservative or reasonably accurate for the one long-lived radionuclide for which concentration will be imputed rather than measured directly, thorium-230. Examination of the dose factors for thorium-230 in relation to other nuclides and the concentrations of thorium-230 in relation to concentrations of other nuclides, as measured in site characterization, demonstrates that even if even if improbably high ratios of thorium-230 to other measured nuclides are assumed, thorium-230 is not a significant contributor to dose.

A derived index, the sum over all nuclides of interest of the fraction of each nuclide's concentration to its DCGL value, may be used as a single-valued representative of a sample's suite of radionuclide concentration determinations for purposes of interpreting sample results as they relate to release criteria and investigation levels. For example, ignoring background, a single sample investigation level is not exceeded if its index value does not exceed 1. In the FSS, background radiation can be accommodated by including the index value computed for background samples in the statistical evaluation.

14.4.2. <u>Background</u>

The nuclides of interest are naturally occurring and are detectable using measurement methods used in the surveys described in this section. For this reason, estimates of the levels of background radiation are required so that the evaluation of survey results can properly account for the influence of background radiation.

For example, when β or γ is measured, then β or γ background values will be needed for the media to be surveyed under the Final Status Survey. As part of the Characterization Survey, described in Section 14.2, background surveys were made for building slab and pavement surface materials. Background measurements were taken on site or in the immediate vicinity of the site in areas that were not affected by site operations. Table 14-3 shows the background levels which have been determined for asphalt pavement and concrete.

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9 also called lower limit of detection (LLD), minimum detectable concentration (MDC), or minimum detectable areal density (MDAD)

Similarly, estimates of background radionuclide concentrations in subsurface material are also required. Such estimates are usually made by sampling similar materials at locations some distance from and beyond the influence of the site of interest. A complicating factor in such an approach at this site characterization is that the C-T area is not a "green field" site underlain by materials similar to those present at locations distant from the site. The site has been used for industrial purposes for over 130 years. Coal cinders and rubble were used to fill this portion of the Mississippi flood plain 100 to 125 years ago. In addition, the MED, AEC, and DOE has had an active presence at the site for about 50 years. MED-AEC radioactive material in soil is found within 100 meters of the C-T area. Consequently, an area containing sufficiently similar subsurface materials known to be free of impact from C-T operations could not be located. An alternate method of estimating background for subsurface materials is provided as Appendix B.

Table 14-3

Background Values of Pavement

Material	Number of Samples	Average Background (β/min/100 cm^2)	Standard Deviation (β/min/100 cm^2)
Asphalt	42	254	166
Concrete	70	180	79

In general, the sensitivity of a survey is greatest when the number of measurements is split between the background and the survey unit. In the event that the number of background data points acquired during characterization is insufficient, additional background data points will be taken as needed and as practicable.

14.4.3. Survey Methodology

The Final Status Survey will be designed in accordance with MARSSIM, NUREG-1727 Appendix E, and NUREG-1505 to the extent practical. The FSS is designed to provide a high degree of assurance that release criteria are met. The MARSSIM process is intended to accomplish these goals with an optimized sampling effort. First, areas will be classified according to potential for residual contamination or known contamination level, as described in Section 14.4.3.1. Next, these areas will be grouped into survey units as described in Section 14.4.3.2. Statistical analysis will then be conducted to determine the number of samples required for a survey unit. This analysis includes hypothesis formulation, determination of tolerable decision error, and determination of the number of samples required to limit decision error to tolerable levels, as described in Sections 14.4.3.3 through 14.4.3.5. Sampling locations are then determined as discussed in Section 14.4.3.6. Surveys are then conducted and results are evaluated as described in Sections 14.4.3.7 and 14.4.3.8.

14.4.3.1. Area Classification

The intent of the plan is to focus most of the survey effort on areas where the likelihood of exceeding the DCGL is greatest. Therefore, for the purposes of establishing the sample density and the sampling pattern, pavement and subsurface material will be classified according to the potential for residual contamination.

Pavement and subsurface material will first be classified as either Non-Impacted or Impacted. Non-Impacted areas are areas that have had no reasonable potential for containing residual radioactive material and do not need any level of survey coverage. These areas have not been radiologically impacted from site operations. Floor slabs of structures erected after cessation of C-T operation are included in non-impacted areas. Impacted areas are areas which have potential for containing residual radioactive material. Impacted areas will be further subdivided into one of three classifications for purposes of determining monitoring intensity.

Characterization survey data will be used in classifying areas. Characterization survey data results for building slabs and pavement represent the range of beta radiation areal density measurements on surfaces. Net beta reported is derived by subtracting open window (β+γ) minus closed window (γ). To aid statistical analysis, the measured result, even if it is a negative number, is recorded.[10] Characterization survey data and conservative release criteria from Phase II Plan Section 5 will be employed to classify the locations surveyed.

Class 1 Areas: An area that has a potential for radioactive contamination (based on site operating history) or known contamination (based on previous radioactivity surveys) in excess of $DCGL_W$ is a candidate for Class 1. Areas containing contamination in excess of the DCGL prior to remediation shall be classified as Class 1 areas. For classification of subsurface soils, the soil concentration compared to the $DCGL_W$ is the soil column average concentration from the surface to the depths of interest at 1-m depth increments (*e.g.*, 0-1 m, 0-2 m, 0-3 m, etc.).[11] Examples of Class 1 areas include: 1) site areas previously subjected to remedial actions, 2) locations where leaks or spills are known to have occurred, 3) former burial or disposal sites, and 4) waste storage sites.

Class 2 Areas: These areas have, or had, a potential for radioactive contamination or known contamination, but are not expected to exceed the DCGL for unrestricted release. To justify changing an area's classification from Class 1 to Class 2, the existing data shall provide a high degree of confidence that no individual measurement will exceed the DCGL. For classification of subsurface soils, as in the case of Class 1 areas, described above, the soil concentration compared to the $DCGL_W$ is the soil column average concentration from the surface to the depths of interest at 1-m depth increments (*e.g.*, 0-1 m, 0-2 m, 0-3 m, etc.). Examples of areas that might be classified as Class 2 for the final status survey include: 1) locations where radioactive

[10] Currie, L.A., Lower Limit of Detection: Definition and Elaboration of a Proposed Position for Radiological Effluent and Environmental Measurements, NUREG/CR-4006, p. 76, 1984.

[11] Vertical averaging of subsurface soil concentrations in this manner is consistent with prior NRC-approved practice, as described in the letter dated February 13, 1997 from Mr. John T. Buckley (USNRC) to Mr. Howard A. Pulsifer (AAR Corporation) regarding NRC review of the AAR Site Remediation Plan for the Former Brooks and Perkins, Inc. Site, dated April 8, 1996.

materials were present in an unsealed form (*e.g.*, process facilities), 2) potentially contaminated transport routes, 3) areas where low concentrations of radioactive materials were handled, and 4) areas on the perimeter of former contamination control areas.

Class 3 Areas: Any *Impacted* area that is not expected to contain any residual radioactivity resulting from CT operations, or is expected to contain levels of residual radioactivity at a very small fraction of the DCGL for unrestricted use, based on site operating history and previous radiological surveys. A nominal level of 10 percent of the applicable $DCGL_W$ is the upper level limit for classification purposes. For subsurface soils, this limit applies to the soil column average concentration from the surface to the depths of interest at 1-m depth increments (*e.g.*, 0-1 m, 0-2 m, 0-3 m, etc.), following the same approach as used for Class 1 and Class 2 areas. Examples of areas that might be classified as Class 3 include buffer zones around Class 1 or Class 2 areas, and areas with very low potential for residual contamination but insufficient information to justify a *Non-Impacted* classification.

The classification of areas of interest is delineated graphically in Figures 14-1a, 14-1b (contaminated surface classification) and 14-2 (contaminated subsurface soil classification).

14.4.3.2. Survey Unit Definition

To facilitate survey design and assure that the number of survey data points for the land areas are relatively uniformly distributed within areas of similar contamination potential, and to focus most of the survey effort on areas where the likelihood of exceeding the DCGL is greatest, the media will be divided into survey units which have a common history or other similar characteristics, or are naturally distinguishable form other portions of the site. Separate survey units will be established for pavement and subsurface material areas. Survey units will be limited in size based on classification and site-specific conditions. The maximum areas for survey units area described in Table 14-4.

Table 14-4

Typical Maximum Areas for Survey Units

Area Classification	Pavement	Subsurface Material
1	2000 m^2	3000 m^2
2	2000 m^2 to 10000 m^2	2000 m^2 to 10000 m^2
3	no limit	no limit

The maximum area specified for Class 1 subsurface material, 3,000 m^2, somewhat exceeds the MARSSIM recommendation of 2,000 m^2. It is expected that implementation of the plan will require only one Class 1 subsurface soil survey unit approximately 2,000 m^2 in area. The higher maximum area is specified to allow for slight expansion of this area without requiring creation of a separate additional survey unit.

As described in Section 8 of the Phase II Plan, main sewer lines immediately to the west and north of Building 238 will be removed or plugged in the process of remediation of subsurface soils beneath Building 238.) If the sewers are plugged, the sewers and their contents will be considered for FSS purposes a part of the subsurface survey unit in which they are located. If they are removed, the sewers and the sludge in them will be treated as potential radioactive waste, as described in Section 12 of the Phase II Plan.

Sediment in sewers remaining in use downstream of Building 238 extending to the Waste Water Treatment Basin area and other sewers in the Plant 5 area will be considered a separate Class 3 survey unit. For classification and evaluation purposes, this sediment is considered no different from other subsurface soil at the equivalent depth. At each location, a single vertical average radionuclide concentration (as described in Section 14.4.3.1) in the sewer sediments and in soils located between the ground surface and the sewer, all taken as combined, been used to establish the basis for comparison to limits for classification, and will be used for FSS evaluation.

Certain Class 1 and Class 2 areas were covered with temporary paving material following completion of C-T Phase I Decommissioning Plan (Phase I Plan) work. All of this material in Class 1 areas and some of this material in Class 2 areas will be removed to allow FSS surface contamination measurements as part of the Phase II Plan. The material removed has very low potential for contamination, and will be considered non-impacted subject to confirmatory survey to determine that average radionuclide concentration does not depart significantly from background. In the unlikely event that the material were to fail this test, it would be subjected to FSS as equivalent to a Class 3 subsurface soil survey unit located near the surface (*i.e.*, no vertical concentration averaging). If warranted, the material may be released for unrestricted use and handled in the same way as other excavated bulk material subject to release.

14.4.3.3. Hypothesis Formulation

The decision whether the DCGL is met is based on a hypothesis test. Usually, the null hypothesis will be that the survey unit exceeds the release criterion[12]; *i.e.*, Scenario A. This will require that significant evidence exists that the residual radioactivity in the survey unit is less than the release criterion to reject the null hypothesis (and pass the survey unit). If the evidence is not significant at decision error level α, the null hypothesis of a non-complying survey unit will be accepted and the survey unit will fail to comply with the release criterion, $DCGL_W$.

Alternatively, the tested hypothesis may be that measurements in a survey unit do not exceed background + $DCGL_W$, *i.e.*, Scenario B,[13] and apply alternate, appropriate statistical test(s).

14.4.3.4. Selection of LBGR and Tolerable Decision Error

The number of measurements in a survey unit is a function of the LBGR, Types 1 and 2 decision error rates, and standard deviation of residual radioactivity. A reasoned balance between values of these parameters and number of measurements will be sought. A decision maker should balance costs of survey design, measurements, analyses, and reporting against consequence of

[12] NUREG-1505, pp. 2-14 & 2-15; MARSSIM, p 5-25.
[13] NUREG-1505, §2.5.

decision error. When estimating consequence of decision error, radiological risk is assumed to be linearly proportional to radiological dose, and dose is linearly proportional to average radioactivity concentration or areal density;

The following additional factors will be considered when deliberating selection of LBGR and Types 1 and 2 decision error rates other than default LBGR = 0.5 x $DCGL_W$ or $\alpha = \beta = 0.05$.

- conservatism in derivation of the DCGL;
- the residual radioactivity concentration or areal density range in the survey unit;
- cost-benefit of additional remediation, measurement, analysis, and or reporting versus concentration, dose, and risk reduction;
- physical distribution of residual source as it may affect remediation and logical survey unit boundary;
- appropriate LBGR and gray region, Δ, relative to background, variability in background, and multiple materials backgrounds in the survey unit;[14] increased α error may be tolerable when Δ is small in order to avoid an unreasonably large number of measurements;
- difficult or adverse measurement conditions;
- interference in measurements, *e.g.* K^{40} interference in beta radiation measurement;
- whether measurement error can be reduced reasonably; and
- safety considerations.

The LBGR is the minimum concentration or areal density differentiable from the DCGL, *i.e.*, the minimum increment from the DCGL where one should begin to control false negative decision error. If a Scenario A hypothesis is posed, the LBGR is bounded on the upside by the DCGL and on the downside by background.

Tolerable decision error rates are based on consideration of the consequence of making an incorrect decision about whether a survey unit complies with radiological criteria for release. The same value of both Type 1 (α) and Type 2 (β) errors will be selected;[15] although it is recognized that any value of β would be acceptable with respect to radiological safety.[16] The target for α and β will be 0.05. Selection of any greater value, not to exceed 0.15, will depend on consideration of these factors and documentation of the reasons in the survey report and will require NRC approval.

14.4.3.5. Determination of Number of Stationary Measurements

The number of measurements required for each survey unit will be determined by two considerations, as discussed in the subsections below. The first consideration is the sensitivity required by statistical analysis to support the hypothesis test. The second, applicable only to Class 1 pavement survey units, is the sampling density required for elevated area detection.

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[14] NUREG-1505, p. 3-17.
[15] MARSSIM, p. D-26.
[16] DG-4006, p. 14.

Number of Samples Required for Central Tendency Analysis. In the MARSSIM methodology, two different approaches are used for central tendency analysis. The first applies to the situation in which the radionuclides of interest are present in the background as naturally occurring radioactive material. The second applies to the situation in which they are not present in the background. Because all of the radionuclides of interest in this decommissioning plan are present in the background, only the former approach will be used here, as described below.

The simplest situation is that in which licensed radionuclides at concentrations exceeding levels of interest are confined to the surface, such as pavement, or the uppermost shallow subsurface layer, taken to be no more than one meter thick. In that case, the number of data points required when the contaminant is present in the background will be determined in accordance with section 5.5.2.2 of MARSSIM:

1. Estimate the relative shift, Δ/σ, where σ is the expected standard deviation of the survey unit measurements[17] and Δ is the width of the "gray region." The gray region, as used in MARSSIM, can be considered as a region of central tendency nuclide concentration that corresponds to dose. Within the gray region, the probabilities of either a Type I decision error (deciding the unit meets DCGL when it does not) or a Type II decision error (deciding the unit exceeds DCGL when it does not) exceed desired limits. The upper bound of the gray region necessarily corresponds to the release criterion concentration. However, setting the boundary too low drives down the central tendency concentration below which one is highly confident in a decision that a unit exceeds DCGL. Setting the value too high drives up the number of measurements required to achieve the desired decision error probabilities. If decontamination is not performed, for purposes of estimating the number of data points, the value of σ will be estimated from characterization survey data or from background measurements, whichever is representative of the survey unit. If decontamination is performed, variability, σ, will be estimated from either 1) post-remediation survey, 2) characterization survey after deleting measurements exceeding the DCGL, or 3) background survey data. The determination of Δ/σ may be iterative.

2. Determine P_r, the probability that a measurement performed at a random location in the survey unit will result in a larger value than a measurement performed at a random location in the reference area. P_r is determined from Table 5.1 of MARSSIM using the estimated relative shift, Δ/σ, determined in step 1.

3. Determine the decision error percentiles, $Z_{1-\alpha}$ or $Z_{1-\beta}$, corresponding to the desired error probabilities α and β using Table 5.2 of MARSSIM. Tolerable decision error, α and β, will be decided in accordance with §14.4.3.4, above.

4. Calculate the total number of measurement points (survey unit plus reference area) for the WRS Test using Equation 14-1 (Equation 5-1 from MARSSIM) with input parameter values determined in steps 1 through 3.

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[17] If a single-valued index is used to represent a suite of nuclides, such the sum over all nuclides of the ratio of each nuclide concentration to its DCGL value, the value of σ to be used is the standard deviation of the group of indices.

$$N = \frac{(Z_{1-\alpha} + Z_{1-\beta})^2}{3(P_r - 0.5)^2}$$ [Equation 14-1]

Where $Z_{1-\alpha}$ and $Z_{1-\beta}$ are the percentiles represented by the selected decision error levels; P_r is the probability that a measurement performed at a random location in the survey unit will result in a larger value than a measurement performed at a random location in the reference area; and N is the total number of data points to be obtained from both the reference area and survey unit combined. Because Equation 14-1 assumes equal numbers of background and survey measurements, the number of data points from the survey unit and the number of data points from the reference area would each be *N*/2.

As noted in the discussion on background in section 14.4.2, the number of background measurements may be constrained. There will be some advantage in sensitivity achievable by collecting a larger number of measurements from the survey unit, although there will be diminishing returns as the number of measurements from the survey unit increases. To calculate the number of samples in this case, Equation 14-2 (based on NUREG-1505, Equation 9-6) is first used:

$$N = \frac{(Z_{1-\alpha} + Z_{1-\beta})^2}{12c(1-c)(P_r - 0.5)^2}$$ [Equation 14-2]

where $Z_{1-\alpha}$ and $Z_{1-\beta}$ are the percentiles represented by the selected decision error levels; P_r is the probability that a measurement performed at a random location in the survey unit will result in a larger value than a measurement performed at a random location in the reference unit by less than the $DCGL_W$; c is the fraction of samples from the reference area; and N is the number of data points to be obtained from each reference area/survey unit combination.

In any survey there will be some missing or unusable data. The rate of missing or unusable measurements, R, expected to occur in survey units or reference areas will be accounted for during survey planning. To assure sufficient data points to attain the desired power level with the statistical tests and allow for possible lost or unusable data, the number of data points will be increased by 20% (R=0.2), and rounded up, over the values calculated in the final step. In the event it is not practical to collect 1.2·N measurements, as few as N measurements will be acceptable without verification by a retrospective power curve.

The required number of measurements determined in the first iteration may exceed reasonable bounds. The process can be repeated using more suitable values of Δ, α, and β as appropriate.

The procedure described above is complete for the simplest situation in which licensed radionuclides at concentrations exceeding levels of interest are confined to the surface, such as pavement, or the uppermost shallow subsurface layer, taken to be no more than one meter thick. However, in some situations involving subsurface materials, radionuclides may be present deeper in subsoil: and explicit consideration of the volumetric distribution of radionuclides within the survey unit will be required. This is accomplished by extension of the procedure described above, as follows:

1. Determine the number of sampling locations (boreholes), N_B,[18] as if the survey unit were only 1 meter deep, using only characterization or remedial action survey data from the 0 to 1 meter layer to determine the survey unit sample standard deviation.

2. Repeat the computation of the number of boreholes, N_B, using data from borehole samples vertically averaged or homogenized over either the 0 to 2 m thickness or the impacted thickness at each characterization borehole location, whichever is less. (This is intended to prevent averaging down by inclusion of non-impacted subsurface material in the survey.)

3. Repeat the computation of the number of boreholes, using vertically averaged data from 0 to 3 m deep, or the impacted thickness, whichever is less.

4. Continue computing N_B for each successively increasing thickness, until the entire volume of interest in the survey unit is captured in the analysis. The vertical limit of the volume of interest for any given borehole location will be observation of a 1-meter thick layer within which the average radionuclide concentration falls below the Class 2 survey unit stationary measurement investigation level, provided below. The application of this limit implies stopping sampling when concentrations in a 1-m thick layer fall below the DCGL on a net basis.

5. Select the maximum computed value of N_B as the minimum number of boreholes to construct and sample.

Average radionuclide concentration over each 1-m vertical increment down to the level at which concentrations fall below DCGL will be determined for each borehole. For purposes of data evaluation, each subsurface layer (0-1 m, 0-2 m, 0-3 m, etc.) will be evaluated as though it were a survey unit.

Number of Samples Required for Small Areas of Elevated Activity and Stationary Sample Spacing. The measurements addressed in previous subsection are designed to test whether the $DCGL_W$ are met based on measures of central tendency. The survey must also demonstrate that $DCGL_{EMC}$, the criterion for a small area where activity exceeds the $DCGL_W$, is also met.

Scanning measurements, where practical, are the primary method for detecting small areas of elevated contamination. To the extent that scanning measurements are not sufficiently sensitive to assure this, they are supplemented by additional stationary measurements, beyond the number needed to demonstrate compliance for the measure of central tendency. The method for determining the number stationary measurement points to demonstrate compliance with $DCGL_{EMC}$, is described below.

[18] $N_B = N \div 2$ from Equation 14-1 or $(1 - c)N$ from Equation 14-2

Scanning will be performed only for building slab and pavement Class 1 and Class 2 survey units. Scanning is not practical for subsurface soil survey units. Scanning is unnecessary for Class 3 building slab and pavement survey units. For these reasons, $DCGL_{EMC}$ limits are not applied to a subsurface or a Class 3 survey unit.

For Class 2 survey units, scanning is confirmatory only, because no individual measurement is expected to exceed $DCGL_W$. For Class 1 survey units, individual measurements that may exceed $DCGL_W$ are anticipated. The interest in these units is to assure that the concentration and areal extent of elevated contamination are sufficiently constrained to assure that the unrestricted release dose criteria are met.

The minimum detectable areal radioactivity density by scanning (scan MDC) needs to be less than the $DCGL_{EMC}$, the maximum acceptable areal radioactivity density for any given area of contamination smaller than the area of a grid cell for systematic measurement, determined in the previous subsection. Thus, the required scan MDC must be less than or equal the product of the $DCGL_W$ and the area factor associated with the area of a grid cell for systematic measurement. Suppose an area of elevated contamination equals a systematic grid cell area. In that instance, the required scan MDC must be less than or equal to the product of $DCGL_W$ and the area factor corresponding to grid cell area. When the scan MDC is estimated, the area factor corresponding to this estimated, or *actual* scan MDC is:

$$\text{area factor corresponding to actual scan MDC} = \frac{\text{actual scan MDC}}{DCGL_W} \qquad \text{[Equation 14-3]}$$

The contaminated area corresponding to the area factor that corresponds to the *actual* scan MDC is the largest area of elevated radioactivity potentially causing 25 mrem/yr that is detectable by that scan instrument MDC. This area is determined from the plot of area factor versus area in DP Section 5.

The maximum possible number of areas of elevated radioactivity in a survey unit that may not be detectable by scanning, n_{EA}, is derived by the equation:

$$n_{EA} = \frac{\text{survey unit area}}{\text{area corresponding to actual scan MDC}} \qquad \text{[Equation 14-4]}$$

If n_{EA} is less than $n_{wilcoxon}$,[19] no additional stationary measurement samples are required. If n_{EA} is greater than $n_{wilcoxon}$, the additional stationary measurement locations are required to supplement scanning in testing compliance with the elevated measurement criterion.

14.4.3.6. Survey Locations

The number of data points required and the area of the survey unit will determine the location of the data points. The same approach will be taken for the pavement and subsurface material.

[19] $n_{wilcoxon}$ = number of measurements needed to provide desired confidence in a Wilcoxon Rank Sum test, as calculated from either Equation 14-1 or 14-2

A scale drawing of the survey unit will be prepared, along with the overlying planar reference coordinate system or grid system. Any location within the survey area is thus identifiable by a unique set of coordinates. The maximum length, X, and width, Y, dimensions of the survey unit are then determined.

Measurements or samples in Class 3 areas and reference areas will be taken at random locations. These locations will be determined by generating sets of random numbers (2 values, representing the X axis and Y axis distances). Each set of random numbers will be used to provide coordinates, relative to the origin of the survey unit reference grid pattern. Coordinates identified in this manner, which do not fall within the survey unit area or which cannot be surveyed, due to site conditions, will be replaced with other survey points determined in the same manner.

Class 1 and Class 2 areas will be surveyed on a random-start systematic pattern. The number of survey locations calculated to satisfy statistical tests and elevated measurement tests, will be used to determine the spacing of a systematic pattern by the following equations: Equation 14-5 for a triangular grid or Equation 14-6 for a square grid. In the equations, *L* is the spacing, *A* is the area of the survey unit. For pavement survey units, *n* is the larger number of calculated survey locations, either n_{EA}, if applicable, from Equation 14-4, or N÷2 from Equation 14-1 or (1 - c)N from Equation 14-2. For subsurface survey units, *n* is N_B, the required number of boreholes.

$$L = \sqrt{\frac{A}{0.866n}} \qquad \text{[Equation 14-5]}$$

$$L = \sqrt{\frac{A}{n}} \qquad \text{[Equation 14-6]}$$

The choice of grid pattern will be made by considering elevated area contamination potential and general shape of the survey unit. The grid which is most practical to establish, survey and evaluate will be chosen.

After L is determined, a random coordinate location will be identified, as described previously, for a survey pattern starting location. Beginning at the random starting coordinate, a row of points will be identified, parallel to the X axis, at intervals of L. For a triangular grid, a second row of points will then be developed, parallel to the first row, at a distance of 0.866•L from the first row. Survey points along that second row will be midway (on the X-axis) between the points on the first row. This process will be repeated to identify a pattern of survey locations throughout the survey unit. If identified points fall outside the survey unit or at locations which cannot be surveyed, additional points will be determined using the random process described above, until the desired total number of points is identified.

In addition to the survey locations identified for statistical evaluations and elevated measurement comparisons, it is likely that data will also be obtained from judgment locations, selected due to unusual appearance, location relative to contamination areas, high potential for residual activity, general supplemental information, *etc.* These data points selected based on professional judgment will not be included with the data points from the random-start triangular or square grid for statistical evaluations because they are not unbiased, as is assumed in the statistical analysis. These measurements will be compared to the investigation levels described in section 14.4.3.8. Characterization and or remediation survey data may serve this purpose provided they are of acceptable quality.

14.4.3.7. Surveys

After the number of required measurements or samples has been established and the location of the measurements or samples is determined, a survey strategy will be developed using the following guidelines. Both scans and stationary measurements will be performed for pavement and building slabs. Pavement and building slabs will be surveyed by scans and stationary measurements for beta radiation or conservatively, $\beta + \gamma$. Subsurface materials will be subject to stationary measurements, but not scan surveys.

Class 1 Areas. Scans will be performed over 100% of pavement and building slab surfaces. Locations of radioactive material concentration above the scanning survey investigation level will be identified and evaluated. Stationary location measurements of radioactive material concentration will be performed on pavement at locations identified by scans and at previously determined stationary measurement locations selected to test compliance with $DCGL_W$ and $DCGL_{EMC}$, as described above in Sections 14.4.3.5. Average concentrations of radionuclides in subsurface materials over 1-m vertical increments (0-1 m, 0-2 m, 0-3 m, *etc.*, down to and including the sampling cutoff layer specified in §14.4.3.5) will be determined at predetermined borehole locations to test compliance with $DCGL_W$. Locations of radioactive material concentrations above the stationary measurement investigation level will be identified and evaluated. Results of initial and follow-up direct measurements and sampling at these locations where measurements exceed investigation levels will be recorded and documented in the Final Status Survey Report. Temporary pavement was applied following the completion of Phase I Plan work in some Class 1 pavement and slab areas. Prior to the FSS, this temporary pavement will be removed from areas subject to survey to permit accurate survey of the pavement and slab surfaces of interest.

Class 2 Areas. Scans will be performed on at least 10% of pavement and building slab surfaces. Locations of radioactive material concentration above the scanning survey investigation level will be identified and evaluated. Stationary location measurements of radioactive material concentration will be performed at pavement locations identified by scans and at previously determined stationary measurement locations selected to test compliance with $DCGL_W$, as described above in Sections 14.4.3.5. Average concentrations of radionuclides in subsurface materials over 1-m vertical increments (0-1 m, 0-2 m, 0-3 m, *etc.*, down to and including the sampling cutoff layer specified in §14.4.3.5) will be determined at predetermined borehole locations to test compliance with $DCGL_W$. Locations of radioactive material concentrations above the stationary measurement investigation level will be identified and evaluated. Results of initial and follow-up direct measurements and sampling at these locations where measurements exceed investigation levels will be recorded and documented in the Final Status Survey Report. Temporary pavement was applied following the completion of Phase I Plan work in some Class 2 pavement and slab areas. Prior to the FSS, this temporary pavement will be removed from areas subject to survey to permit accurate survey of the pavement and slab surfaces of interest.

Class 3 Areas. Scans of surfaces will be performed at designated locations determined through the use of historical knowledge and contractor experience. Locations of direct radiation above the scanning survey investigation level will be identified and evaluated. Stationary measurements of radioactive material concentration will be performed at locations identified by the scans and locations selected to test whether concentrations exceed more than a small fraction of $DCGL_W$. Average concentrations of radionuclides in subsurface materials over 1-m vertical increments (0-1 m, 0-2 m, 0-3 m, *etc.*, down to and including the sampling cutoff layer specified in §14.4.3.5) will be determined at predetermined borehole locations to test whether concentrations exceed more than a small fraction of $DCGL_W$.

14.4.3.8. Data Analysis

The evaluation of survey results is performed in four stages. The first stage will consist of a preliminary review of the data. The second stage of evaluation will consist of an evaluation of elevated measurements against investigation levels. The third stage of data evaluation will consist of statistical analysis to determine whether measurements exceed the $DCGL_W$. The last stage of data evaluation will consist of concluding whether the results of the survey meet the design objectives. Based on results from the first three stages, resurvey, reclassification, remedial action, or some combination of these measures may be required. The survey will not be complete until the conclusion that survey objectives have been met can be supported. Each of these stages is discussed in greater detail in the following subsections.

Final status surveys will be managed in the following way. In summary:

- Each final status survey design will be documented and approved for execution.
- Final status survey measurements will be recorded.
- Final status survey data of record will be examined for legibility, completeness, conformance with the survey design specifications, and apparent errors.
- Original survey design specifications and survey records will be retained.
- If the data are acceptable, tests of compliance with DP §5 release criteria will be performed. These would test each measurement for compliance with the *elevated measurements criterion* and would test the systematic measurements in the survey unit for compliance with collective data criteria.
- A final status survey report of the data, screening tests, and compliance tests is examined.
  - o If either the final status survey records, checks, or a test is not accepted, contingent actions, as described in the Section 14.4.3.9, "Contingencies," will be considered.
  - o Else, if the data, screening tests, and compliance tests for that survey unit are accepted, a final status survey report for that survey unit will be written.

Preliminary Data Review. The first stage of data evaluation will consist of a preliminary review of the data to check quality and reasonableness, including:

- Legibility of recorded data,
- Assessment of completeness of the data,

- Verification of instrument selection and calibration,
- Verification of survey technician training qualifications,
- An initial judgment about the overall quality of the data. This would aim to identify gross errors in data recording,
- Conversion of raw data to standard units where appropriate. (For pavement surfaces, the units are (dpm/100 cm^2). For subsurface materials, units are activity per unit mass, or an equivalent index),
- Whether the number of points taken are in accordance with the specific survey design,
- Whether the locations of systematic grid points correspond to what was prescribed in the survey design,
- Whether scan data were adequately processed, (Scan data sheets will be reviewed to determine whether any high reading requires investigation and, if so, has been adequately verified with a direct confirmatory measurement), and
- Whether biased measurements (measurements at survey unit locations where detection of licensed radioactive material would be considered to be most likely) were taken in accordance with FSS design instructions and their location accurately documented on drawings and in the database.

If, during this initial review, any measurement is considered inadequate, additional survey information may be collected. Once this review is complete and the analyst is satisfied, the survey records will be "locked," completing preliminary data review and acceptance of the survey. Permanent archive files of all survey data taken in connection with the C-T project will be maintained to provide for their security, organization, and availability to authorized reviewers, including the NRC.

The remaining stages of evaluation are performed for each survey unit, or, in the case of subsurface materials, each vertical layer (0-1 m, 0-2 m, 0-3 m, etc.) within a survey unit.

Evaluation of Measurements Individually. In the second stage of evaluation, scan results and individual measurements of pavement surface and vertically averaged (0-1 m, 0-2 m, 0-3 m, etc.) subsurface materials[20] will be compared to an appropriate investigation level for evidence of a small area of elevated radioactivity. An investigation level is a radioactivity concentration, areal density, or index that is used to indicate when additional investigation may be necessary. An investigation level depends on survey unit classification. A scan result which exceeds the corresponding investigation threshold listed in Table 14-5 shall be confirmed by stationary location measurement. Scan measurement results will remain as paper records. The direct measurement data only will be recorded and used for further analysis and classification.

Investigation Levels. Individual measurements from pavement and indices calculated from nuclide concentration measurements in subsurface material samples will be compared to investigation levels for evidence of small areas of elevated activity. The purpose of investigation levels is to make the best use of individual sample results that may call into question validity of

[20] Although the procedures for evaluation of measurements individually applies strictly only to vertically averaged concentrations in subsurface soils, application of these procedures to individual samples (*i.e.*, not vertically averaged concentration) is more restrictive and may be used to demonstrate compliance.

analyses or validity of assumptions underlying the survey. Investigation levels are not intended to be limits. Results exceeding investigation levels should not be used as the sole basis for deciding whether a survey unit has failed. Scan results for those units subject to scanning will also be compared to investigation levels. The levels established for investigation will depend upon the survey unit classification. Lower investigation thresholds will be set for those units having lower potential for elevated areas. Depending on the outcome of the elevated measurement test and other tests, resurvey, reclassification, partial or complete remediation, or some combination of these measures may be required. (If only partial remediation is required, resurvey of some portion of the unit after supplementary remediation will also be required. To the extent practical and appropriate, original survey data from portions of the unit outside the supplementary remediation area will be used in conjunction with new survey data from the supplementary remediation area in new tests to determine whether the unit meets release criteria.).[21,22] The results of all investigations will be documented in the final status survey report. Investigation levels are described in greater detail below.

In Class 3 survey units, no residual nuclides are expected above a small fraction of DCGL.. Therefore, investigation levels are set to flag measurements that are just above the range expected for background levels and a small increment (10%) of DCGL, or just above detection limits for the measurement method, whichever is greater.

In Class 2 survey units, measurements of net levels above the DCGL are not expected. Therefore, investigation levels are set to flag measurements exceeding the DCGL on a net basis. If the scanning MDA exceeds the DCGL on a net basis, any scanning result exceeding the MDA will also be investigated.

For Class 1 survey units, measurements above the DCGL are not unexpected. For slab and pavement survey units, a special derived concentration guideline for elevated measurements, $DCGL_{EMC}$, is used as the basis for investigation levels. The derived concentration guideline level for the EMC (elevated measurement comparison) is determined as described in Section 5. For subsurface survey units, $DCGL_{EMC}$ is not applicable. For these units, the investigation level is a value indicating substantial departure from the distribution of concentrations used as the basis for determining the number of measurement locations for the central tendency analysis.

Values for $DCGL_{EMC}$ will be calculated and supplied in the final status survey design. The derived concentration guideline level for the elevated measurement comparison (EMC) is determined as described in Section 5 of this DP. For initial evaluation, the area on which $DCGL_{EMC}$ is derived *a priori* will be the systematic grid cell area derived in section 14.4.3.5. The background reference level for each data point will be the average of background measurements associated with the same reference material. Any value exceeding the EMC criterion in Table 14-5 is not sufficient to fail the survey unit, but will be flagged for investigation and evaluation.

Table 14-5 summarizes the investigation levels.

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[21] NUREG-1727, Appendix E
[22] MARSSIM, §5.5.2.6.

Table 14-5
Summary of Investigation Levels

Survey Unit Class	Flag Stationary Location Measurement or Sample Result When Value Exceeds:	Flag Scanning Measurement Result When Value Exceeds:
Class 1 slab and pavement	$DCGL_{EMC} + \bar{x}_{ref}{}^{a} + 2s_{ref}$	$(DCGL_{EMC} + \bar{x}_{ref}{}^{a} + 2s_{ref})$ or MDA
Class 1 subsurface	$DCGL_W + \bar{x}_{ref}{}^{a} + 6s_{ref}$	NA
Class 2	$DCGL_W + \bar{x}_{ref} + 2s_{ref}$	maximum of $(DCGL_W + \bar{x}_{ref} + 2s_{ref})$ or MDA
Class 3	maximum of $(0.1\ DCGL_W + \bar{x}_{ref} + 2s_{ref})$ or MDA	maximum of $(0.1\ DCGL_W + \bar{x}_{ref} + 2s_{ref})$ or MDA

[a] $\bar{x}_{ref}$ and s_{ref} are the mean and standard deviation of the reference or background measurements. If a single-valued index, I_i, is used to represent a suite of nuclides for a particular sample, such as the sum over all nuclides of the ratio of each nuclide concentration to its DCGL value, the above expressions are modified by setting $DCGL_W$ to 1, and using for $\bar{x}_{ref}$ and s_{ref} the mean and sample standard deviation, respectively, of the I_i values for the reference or background area.

Data Set Screening Analysis. The data set for the survey unit will be processed within a database using screening software developed and verified for the project.[23] The screening software will perform the following comparison tests:

Data Screening Tests
Min/Max screen
Low Level screen
$DCGL_w$ screen
EMC limit screen

[23] Although the procedures for screening evaluation of data sets applies strictly only to vertically averaged concentrations in subsurface soils (0-1 m as one data set, 0-2 m as a second, etc.), application of these screening procedures to an entire survey unit data set of individual samples (*i.e.*, not vertically averaged concentration) is more restrictive and may be used to demonstrate compliance.

A brief description of each test applied follows.[24]

- Min/Max Screening. Recorded data points in the survey unit will first be processed to derive the difference between the largest survey value and the smallest applicable background value. If that difference is less than the $DCGL_w$, a class 1 or class 2 survey unit will be rated acceptable and no further computation will be needed.[25] A class 3 survey unit will be passed on to the low level screen. If a class 2 or 3 survey unit fails this test, it will be evaluated for additional analysis, remediation, or other appropriate action. A class 1 unit that fails this test will be passed on for the remaining tests.
- Low Level Screening. All class 3 survey units will be processed through low level screening. Each data point that fails the test will be flagged as an exception in the evaluation of measurements individually. In a class 3 survey unit, residual, regulated radioactivity at concentrations more than a small fraction of $DCGL_W$ is not expected. Therefore, the investigation level is set to flag any measurement that is just above the range expected for background and a small increment (10%) of $DCGL_W$, or just above the detection limit for the measurement method, whichever is greater (ref. Table 14-5). If the class 3 survey unit contains no flagged measurements, the unit will be rated acceptable, and no further evaluation will be needed. If the class 3 survey unit fails this test, it will be evaluated for additional analysis, remediation, or other appropriate action.
- $DCGL_W$ Limit Screening. The net radioactivity of each survey point within the survey unit will be compared with the $DCGL_W$. The reference level for each data point will be the average of background measurements associated with the same matrix. Each value exceeding $DCGL_W$ will be flagged as an exception, point by point. In addition, the mean value for the reference area and the survey unit will be compared for class 1 and class 2 survey units. If the average radioactivity observed in a survey unit exceeds background average, such that the difference between the two is greater than the $DCGL_W$, the entire survey unit will be flagged for additional analysis, remediation, or other appropriate action as to its reclassification.[26]
- Elevated Measurement Comparison (EMC) Limit Screening. In a class 1 pavement survey unit, measurements above the $DCGL_W$ are expected. In the event that an area of elevated radioactivity is identified above $DCGL_W$, an additional test is performed to ascertain whether the overall radioactivity concentration in the survey unit is greater than the release limit.[27] Following determination of the size of the elevated area and

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[24] MARSSIM, Table 8.2.

[25] If a single-valued index, I_i, such as the sum over all nuclides of the ratio of each nuclide concentration to its $DCGL_w$ value, is used to represent a suite of nuclides for a particular sample, the test is that the difference between I_{max} from the survey unit and I_{min} from the reference area is less than 1.

[26] If a single-valued index, I_i, such as the sum over all nuclides of the ratio of each nuclide concentration to its $DCGL_w$ value, is used to represent a suite of nuclides for a particular sample, each I_i value in the survey unit is compared the average of the I_i values from the reference area, and is flagged if the difference exceeds 1. In addition, if the average of the survey unit I_i values exceeds the average of the reference area I_i values by more than 1, the entire survey unit is flagged.

[27] MARSSIM, §8.5.1.

radioactivity concentration therein, a sum-of-fractions rule[28] should be used to ascertain whether the radioactivity concentration over all of the survey unit is less than the $DCGL_W$. To pass the test, the combined contribution from the elevated area and the remainder of the survey unit must conservatively be less than 0.95 instead of unity (1).

If a test is failed, an analyst will decide about reclassification, remediation or release of the survey unit. Exceptions will be handled on a case-by-case basis. For example, the analyst may opt to reapply the tests after accounting for an unusually high level of K-40, if it is present. The resolution of each flagged datum will be documented to provide a clear understanding of how the survey unit was ultimately released in the final status survey report.

Conduct Statistical Analysis. Unless they passed the *Min-Max test*, stationary measurements at systematic grid locations in class 1 and class 2 survey units will be examined statistically to determine whether release criteria have been satisfied. This stage will also include reassessment of the power of the hypothesis test, based on survey data. If the survey unit does not pass, consideration according to §14.4.3.4 of values of Δ/σ, α, and β more suitable than those used in the survey design may be appropriate.

Statistical analysis is required only on class 1 or 2 survey units where the mean survey value is above the mean reference value by an amount less than $DCGL_W$. The analyst will perform the Wilcoxon Rank Sum Test (WRS).[29] The test result will be examined to decide whether it passes or fails the tested hypothesis. If criteria are not met, resurvey or remedial action may be required.

The logic described in Table 14-6 will be used to judge compliance with the DCGL:

Table 14-6
Summary of Statistical Tests

Survey Result	Conclusion
All survey unit measurements are less than $DCGL_W$ on a net basis	Survey unit meets release criteria
Difference between any survey unit measurement and any reference area measurement greater than $DCGL_W$ (not to be used for survey units with less than 5 measurements)	Conduct WRS test and, for pavement survey units, elevated measurement comparison

If statistical analysis is necessary for a survey unit, the two-sample Wilcoxon Rank Sum (WRS) test will be conducted. The WRS test assumes that the reference area and survey unit data distributions are similar except for a possible shift in the medians, and is applied as follows:

[28] MARSSIM equation 8.2.

[29] Also called the "Mann-Whitney Test", a *Wilcoxon Rank Sum Test* should be used when there is background radiation present and the background characteristics and radioactivity distribution are similar for the materials present in the survey unit.

1. Obtain the adjusted reference area measurements, Z_i, by adding the DCGLw to each reference area measurement, X_i.[30]

$$Z_i = X_i + DCGL_W \qquad \text{[Equation 14-7]}$$

2. The *m* adjusted reference sample measurements, Z_i, from the reference area and the *n* sample measurements, Y_i, from the survey unit are pooled and ranked in order of increasing size from 1 to *N*, where $N = m+n$.
3. If several measurements are tied (have the same value), they are all assigned the average rank of that group of tied measurements.
4. Use of "less than" values in data reporting will be minimized to the extent practical. If more than 40 percent of the data from either the reference area or survey unit are "less than," the WRS test will not be used. If there are *t* "less than" values, they are all given the average of the ranks from 1 to t. Therefore, they are all assigned the rank t(t+1)/(2t) = (t+1)/2, which is the average of the first t integers.[31]
5. Sum the ranks of the adjusted measurements from the reference area, W_r.
6. Compare W_r with the critical value given in Table I.4 of the MARSSIM manual for the appropriate values of *n*, *m*, and α. If W_r is greater than the tabulated value, reject the hypothesis that the survey unit exceeds the release criterion.

Draw Conclusions and Document Survey. The last stage of data evaluation will examine whether final survey results met survey design objectives. An affirmative conclusion indicates the survey is complete. Otherwise, reclassification, resurvey, remedial action, or some other contingent action described below would be appropriate.

A final status survey will provide a record of the radiological status of the survey unit, relative to the DCGL. To the extent practicable, this report will be a stand-alone document with minimum information incorporated by reference. Each final radiation status survey shall be documented as described in Section 14.5.

Contingencies. In the event final survey unit measurement(s) appear not to satisfy a release criterion, some alternative actions may be taken to assess whether it does and or to enable the survey unit to pass criteria. Some acceptable alternatives to remediating the entire survey unit and performing another final status survey follow. One or more may enable demonstration of compliance.

- Objectives would be reviewed with respect to how to assess whether a survey unit meets survey criteria.[32, 33]

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30 If a single-valued index, I_i, such as the sum over all nuclides of the ratio of each nuclide concentration to its $DCGL_w$ value, is used to represent a suite of nuclides for a particular sample, adjusted reference area measurements are computed as $Z_i = I_i + 1$. These values are then pooled with the I_i values from the survey unit for statistical analysis.

31 NUREG-1505, p. 2-19; MARSSIM, p 8-18.

32 MARSSIM, p. 8-25.

33 NUREG-1505, p. 3-1.

- Ordinarily, survey data would first be reviewed to confirm its acceptability. One may also decide whether additional data are needed to determine whether the survey unit complies with release criteria.[34]

- Reassess the reference area or material to be compared with the survey unit

If DQO are inappropriate or if a survey unit is misclassified, Mallinckrodt may:

- Review the DQO. If warranted, adjust values of parameters such as Type 1 and Type 2 error criteria or the lower bound of the gray region (LBGR).

- Reclassify part of a survey unit that contains elevated measurements. Remediate if necessary. Measure at the density appropriate to the new classification. If the reclassified part were Class 1, the measurement density appropriate for Class 1, and the number of measurements in it were fewer than would be estimated for an entire Class 1 survey unit, compliance would be accepted if every measurement[35] in the reclassified part were less than the $DCGL_W$.

    - In the event a Class 1 survey unit area is less than 500 m^2 and the number of measurements are specified and tested statistically for compliance with $DCGL_W$, the area factor shall not exceed that specified in Section 5 for the elevated measurement test. Alternatively, in the event a Class 1 survey unit area is less than about 500 m^2, the number measurements estimated to satisfy a WRS, Quantile, or Sign test might be unreasonably large in that survey unit. When both conditions exist, measurement density will be at least one measurement per 100 square meters at locations based on judgment. In that circumstance, the criterion for release shall be that every measurement in the survey unit does not exceed the $DCGL_W$.[36]

    - In the event a Class 2 survey unit area is less than 2500 m^2, the number measurements estimated to satisfy a WRS test might be unreasonably large in that survey unit. When so, measurement density will be at least one measurement per 500 m^2 at locations based on judgment. The criterion for release in that circumstance, shall be that every measurement in the survey unit does not exceed the $DCGL_W$.[37]

- If the scanning method was not sensitive enough in a Class 2 unit, a portion containing measurements greater than $DCGL_W$ may be reclassified as Class 1, measured at the measurement density required for a Class 1 area, with the rest of the survey unit remaining Class 2.[38]

[34] MARSSIM, p. 8-24.
[35] Interpret to be measurement net of background
[36] MARSSIM, p. 4-15.
[37] MARSSIM, p. 4-15.
[38] MARSSIM, p. 8-24.

If an elevated measurements test is failed, Mallinckrodt may:

- If a survey unit passes statistical test(s) but radioactivity concentration in a local area exceeds the $DCGL_{EMC}$, *i.e.*, the product of $DCGL_W$ x area factor, for its actual size, remediate the local area. If a post-remediation survey of the local area demonstrates residual radioactivity is below the $DCGL_W$, compliance is acknowledged. Else, statistical tests for the survey unit are performed again.[39]

- If a survey unit passes. Compute the radiological dose associated with each measurement as if it represented the entire survey unit and calculate the arithmetic mean dose represented by all the measurements in the area of elevated radioactivity. If the mean dose does not exceed the product, area factor x radiological dose criterion, *i.e.*, AF x $DCGL_W$, compliance would be demonstrated for the elevated measurements criterion for that local area.

If a non-parametric statistical test is failed, Mallinckrodt may do one or more of these:

- Construct a retrospective power curve[40] of the measurements. Evaluate whether the survey unit would have passed the release criterion using the non-parametric statistical test, *e.g.*, WRS test. If not, it would be acceptable to make more measurements at random locations in the survey unit and perform statistical test(s) on the expanded data set.[41]

- Make more appropriate measurements to improve determination of background.

- Reverse the tested hypothesis and apply an alternate, appropriate statistical test, *e.g.*, from Scenario A to Scenario B.[42] Specific DQO would be developed for this approach and be submitted to the NRC for approval, or would be addressed in the FSS report for survey units that fail.

- In lieu of statistical testing, compute the radiological dose associated with the mean of measurements in the survey unit. Alternatively, compute the radiological dose attributable to each measurement as if it represented the entire survey unit and calculate the arithmetic mean dose represented by all the measurements in the survey unit. If the mean dose does not exceed the radiological dose criterion, compliance would be demonstrated for the survey unit.

14.4.4. Final Status Survey QA/QC

To assure that the Final Status Survey meets data quality objectives, all elements of the Final Status Survey will be subject to the Quality Assurance Program (QAP) described in Section 13.

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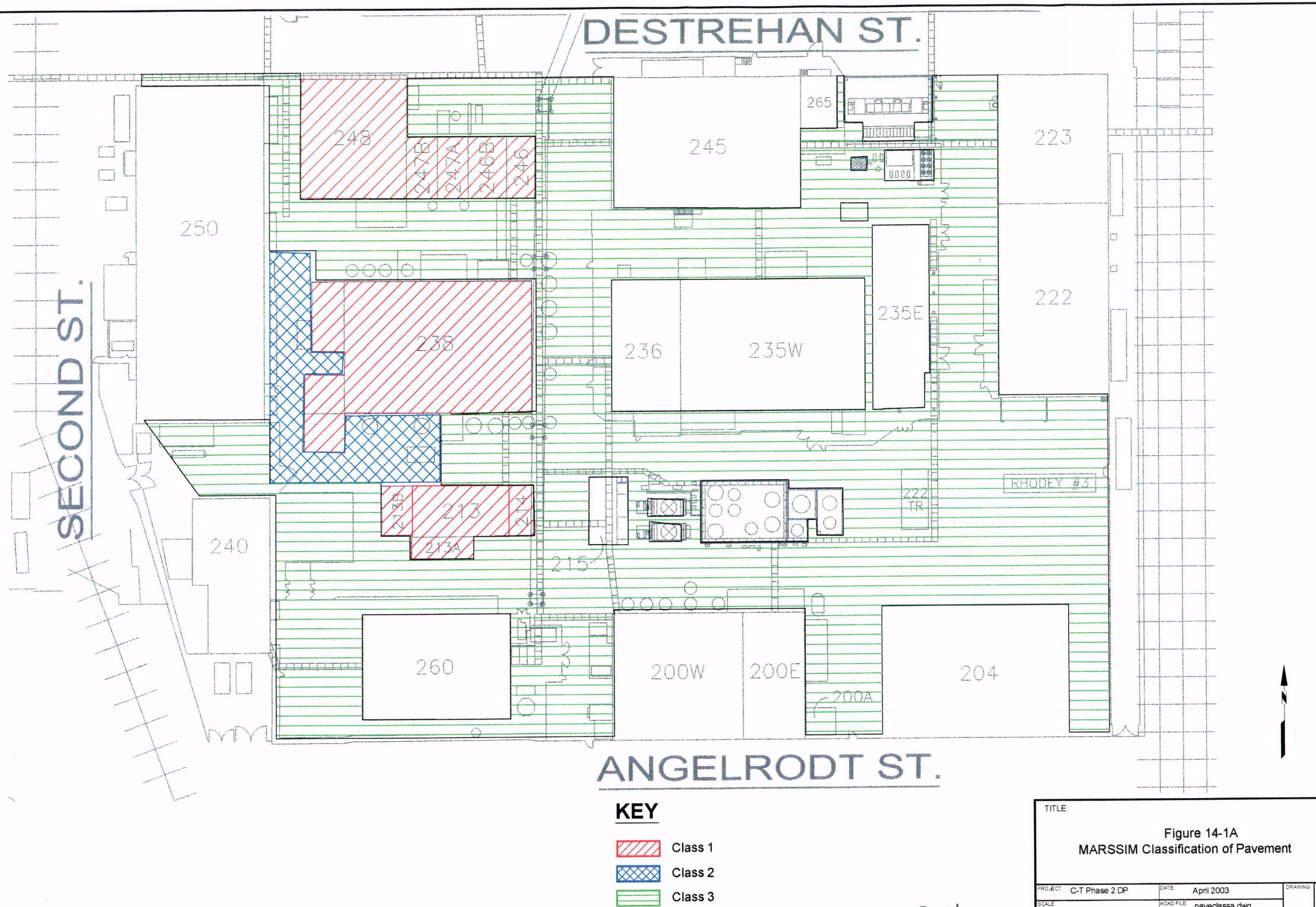
[39] MARSSIM, p. 8-24 & 25.
[40] MARSSIM, appx I.
[41] MARSSIM, p. I-25 & I-27.
[42] NUREG-1505, §2.5.

14.5. FINAL STATUS SURVEY REPORT

At the conclusion of the Final Status Survey, a Final Status Survey Report will be prepared to demonstrate that the areas addressed in this Phase II Plan meet the radiological criteria for license termination. The report will include the following information:

- Overview of the results of the Final Status Survey;
- Discussion of any changes made in the Final Status Survey from what was proposed in the Phase II Plan and associated submittals;
- A description of the method by which the number of samples was determined for each survey unit;
- A summary of the parameter values used to determine the number of samples and a justification for them;
- The survey results for each survey unit, including:
    - The number of samples;
    - A figure (map or drawing) depicting the survey unit, the location reference system, start locations for survey units subject to systematic sampling, randomly selected sampling locations for other survey units;
    - Sample measurement results;
    - Results of statistical evaluation of sample measurements;
    - Judgmental and miscellaneous sample data sets reported separately from those samples collected for performing the statistical evaluation;
    - Identification of each area of elevated direct radiation detected during scanning that exceeded the investigation level or measurement location(s) in excess of $DCGL_W$; and
    - A statement that the survey unit satisfied the $DCGL_W$ and, if any samples exceeded the $DCGL_W$, a statement that the survey unit satisfied the elevated measurement comparison;
- If a survey unit fails, a description of the investigation conducted to ascertain the reason for the failure and a discussion of the impact that the failure has on the conclusion that the facility if ready for final radiological surveys; and
- If a survey unit fails, a discussion of the impact of the cause of failure on other survey unit information.

The report will be reviewed and approved prior to release, publication, or external distribution.



C-01

TITLE:

Figure 14-1A
MARSSIM Classification of Pavement

PROJECT: C-T Phase 2 DP	DATE: April 2003	DRAWING:	REVISION:
SCALE:	ACAD FILE: paveclassa.dwg		

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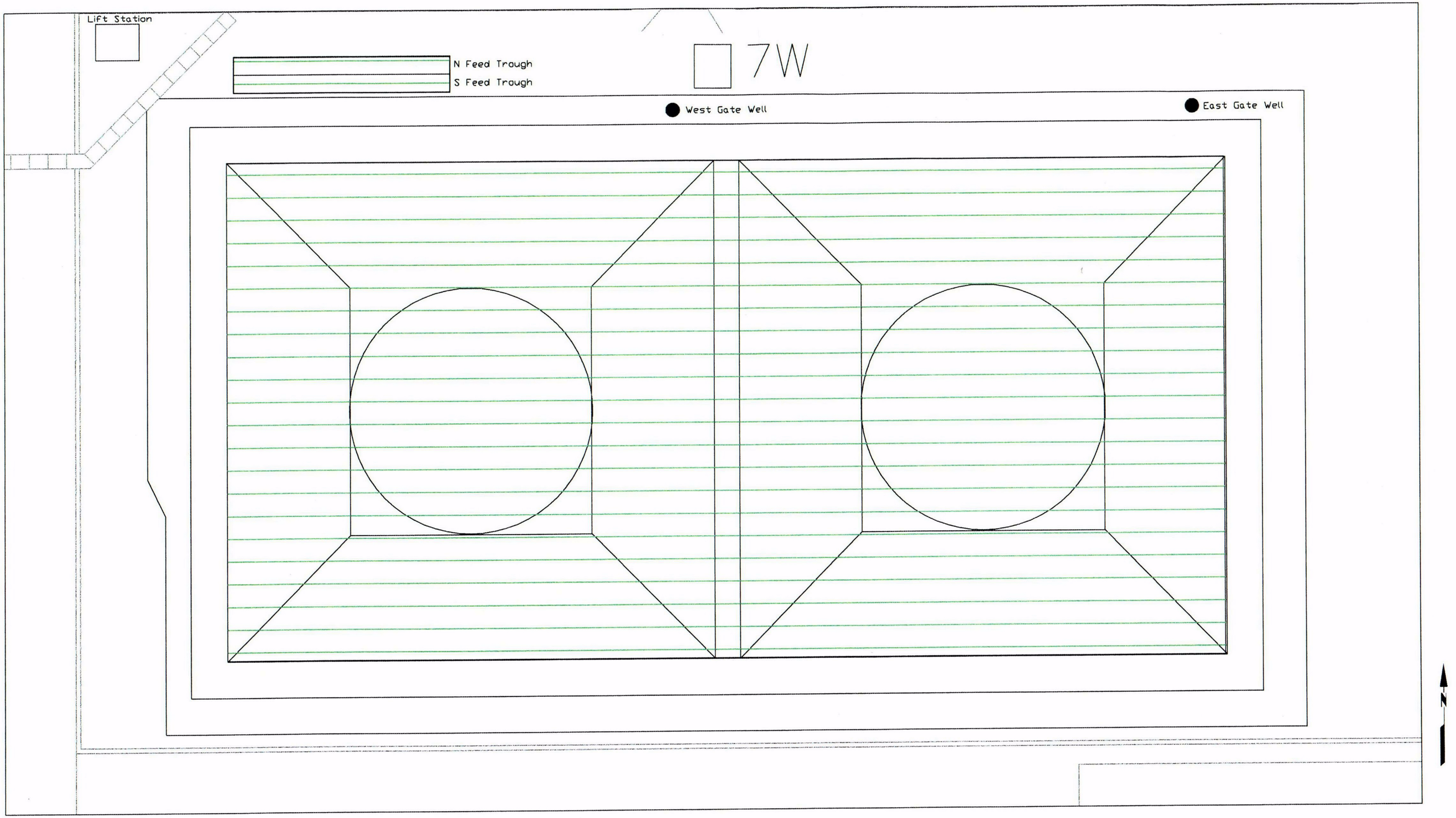


KEY

Class 3

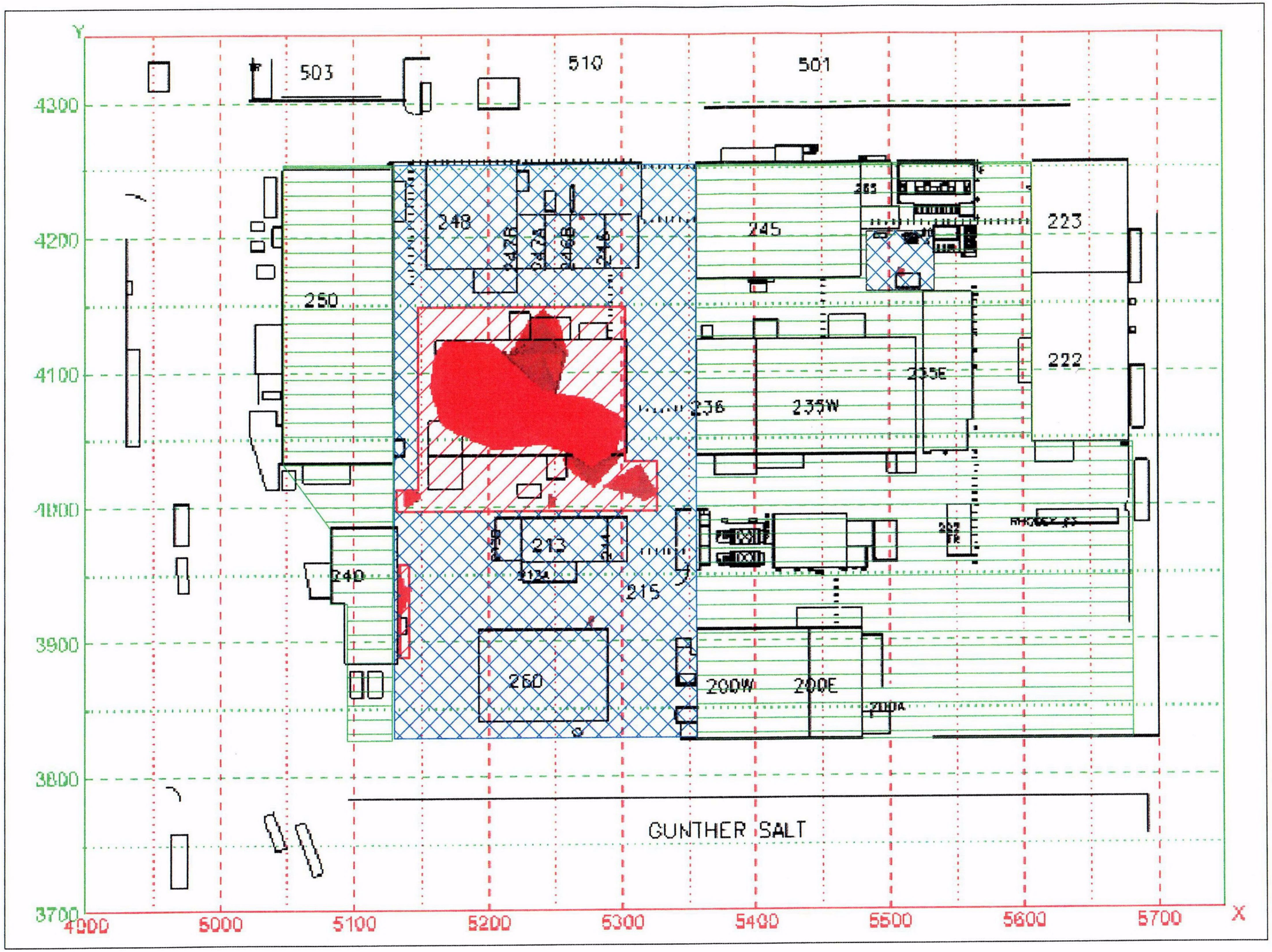
TITLE:

Figure 14-1B
MARSSIM Classification of Pavement

PROJECT: C-T Phase 2 DP		DATE: April 2003		DRAWING:	REVISION: △
SCALE:		ACAD FILE: paveclassb.dwg			

C-02

omega PROJECT SERVICES LLC



Key

Class 1
Class 2
Class 3

C-03

TITLE:

Figure 14-2
MARSSIM Classification of Subsurface Soil

PROJECT: C-T Phase 2 DP	DATE: April 2003	DRAWING	REVISION
SCALE	ACAD FILE: soilclass.dwg		

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SECTION 15

FINANCIAL ASSURANCE

Mallinckrodt Inc.

C-T Phase II Decomissioning Plan
May 15, 2003

NRC Docket: 40-06563
NRC License: STB-401

15.0 FINANCIAL ASSURANCE

Mallinckrodt originally submitted a Phase I/Phase II financial assurance plan along with the submittal of the Phase I Plan, and the latest revision of the financial assurance plan was issued on January 11, 2002. Since the Phase I plan has been completed, the decommissioning cost estimate has been revised to be consistent with the planned Phase II work.

15.1 DECOMMISSIONING COST ESTIMATE

15.1.1 Facility Description

Contaminated structures are not in the scope of this Phase II decommissioning plan. A precursor document to this one, the Phase I Plan[1], describes the activities involving above-grade decommissioning of the buildings. The objective of the Phase I Plan was to remediate the C-T buildings to obtain unrestricted release or to dismantle them and dispose of the rubble. The NRC approved the Phase I Plan in May 2002. Above-grade decommissioning has been completed and Phase I is now in Final Status Survey.

Phase II addresses below-grade decommissioning. A description of the below-grade radiological status can be found in Section 4 of this plan.

15.1.2 Estimated Decommissioning Costs

Exhibit A presents the revised decommissioning cost estimate for the Phase II work which is $17,085,180 and is based on anticipated cleanup activities using characterization data and the derived solid concentration guidelines determined in Section 5 of this plan for determining the extent of contamination. This estimate may be revised as work is implemented.

In Exhibit A, the estimated costs are broken out by the following major activities:

1. Planning and Preparation
2. Decontamination and Decommissioning, and Restoration
3. Final Radiation Survey
4. Institutional Controls

As recommended by the NRC, the contingency is 25 percent.

The key assumptions are that nominally 88,100 cubic feet of soil and debris will be removed and disposed of, and the work, once started, will be completed in approximately one year.

No credit is taken for any *salvage value*.

[1] Mallinckrodt, Inc. Phase I Plan for C-T Decommissioning. Submittals January 10, 2002, February 13, 2002, and March 8, 2002.

15.2 FORM OF FINANCIAL ASSURANCE

Mallinckrodt will provide a total of $17,085,180 by revising the current Letter of Credit (LC) issued to Mallinckrodt by Sanpaolo IMI S.p.A. which meets the criteria required by the NRC and an Amended Standby Trust Agreement (STA) with supporting documentation that will include (as required per NUREG-1757, Vol. 3, Draft Report for Comment), but not be limited to, the following:

1. Evidence of corporate authorization;
2. Original execution copy of the LC;
3. Evidence that LC obtained from an authorized financial institution;
4. Specific dollar amount identified by terms of LC;
5. Include a definite term along with automatic renewal provisions;
6. Specific instructions regarding obligation to pay beneficiary; and
7. Language regarding licensee's obligation to reimburse issuing institution upon withdrawals from the LC.

The STA currently includes a specimen corporate certificate of resolution regarding decommissioning activities and a Specimen Certificate of Events along with the LC. Mallinckrodt believes these documents meet the NRC requirements for appropriate financial assurance instruments.

Mallinckrodt will revise the LC upon approval by NRC to reduce the current LC amount to reflect the remaining decommissioning activities and provide executed copies to NRC prior to commencement of decommissioning activities.

Mallinckrodt will not modify the content of both the LC and STA except for the dollar amount to streamline review and approval by NRC.

15.3 COMPARISON OF THE COST ESTIMATE TO THE CURRENT LEVEL OF FINANCIAL ASSURANCE

The existing financial assurance mechanism is a LC in the amount of $21,113,000. Since the current estimate to complete Phase II work is $17,085,180 once the amended LC and amended STA are obtained Mallinckrodt will request that NRC approve termination of the current LC in the amount of $21,113,000.

15.4 MEANS FOR ADJUSTING THE COST ESTIMATE AND ASSOCIATED FUNDING LEVEL

Mallinckrodt will proceed with implementation of Phase II when the NRC issues final approval of the Phase II Plan. The Phase II Plan will be managed through a Mallinckrodt project team which will work from a defined scope of work and schedule. As work proceeds, the cost estimates previously provided in this Financial Assurance Plan will be reviewed at least annually. As work is completed, Mallinckrodt will reduce the amount of financial assurance based upon money spent and work completed to date in accordance with the Phase II Plan and schedule. This will occur after discussion and review, if necessary, with the NRC. Mallinckrodt will periodically report to the NRC on the status of the project and necessary revisions to the financial assurance instruments.

15.5 CONCLUSION

Mallinckrodt plans to proceed with the decommissioning activities upon approval of the Phase II plan by the NRC. Upon concurrence by NRC, Mallinckrodt will obtain an amended LC reflecting the new cost estimate and amend the STA to reflect a cost estimate to complete Phase II decommissioning activities in the amount of $17,085,180 and will submit the LC and the revised STA to the NRC.

Table 15.1: Phase II Estimated Decommissioning Costs

		Duration	
	full time	65	weeks
	1/2 time	32.5	weeks
	1/4 time	16.25	weeks
	months (=12/52 X duration)	15.00	months
Assumptions		Contractor has 6 weeks to mobilize	

Scope	Number	Duration	Description	Mhrs	Labor Rate	Total Labor	Total Equipment	Total Material	Total Price
1. Planning and Preparation									
Phase II Plan Prep/EIS	1		contract			$1,000,000.00		$1,000,000.00	
Phase II characterization and sampling	1		set			$70,000.00		$70,000.00	
Sub Total						$1,070,000.00			$1,070,000
2. D&D and Restoration									
Total Labor Costs									
General Laborer	3	65	man-weeks	7800	$55.00	$429,000.00			
General Loborer Foreman	1	65	man-weeks	2600	$65.00	$169,000.00			
General Laborer Superintendent	1	65	man-weeks	2600	$70.00	$182,000.00			
Equipment Operators	2	65	man-weeks	5200	$70.00	$364,000.00			
Field Rad Tech	2	65	man-weeks	5200	$60.00	$312,000.00			
Lab Scientist	1	71	man-weeks	2840	$80.00	$227,200.00			
Lab Tech	1	65	man-weeks	2600	$60.00	$156,000.00			
Sub Total				28840		$1,839,200.00			$1,839,200
Project Management Support									
MI Oversight Costs	1	65	man-weeks	2600	85	$221,000.00			
Project Manager	1	71	man-weeks	2840	125	$355,000.00			
Health Physics Professional	1	71	man-weeks	2840	125	$355,000.00			
Industrial Safety Professional/QA	1	71	man-weeks	2840	125	$355,000.00			
Field Supervisor	1	71	man-weeks	2840	100	$284,000.00			
Field Clerk	1	71	man-weeks	2840	40	$113,600.00			
Temporary Living Expenses	5	15.00	man-months		2000	$150,000.00			
HP Consultant 1/4 time	1	16.25	man-weeks	650	150	$97,500.00			
Sub Total				14200		$1,931,100.00			$1,931,100
Equipment Costs						Cost/Unit			
Excavator (Cat 330L-1.8CY)	2	15.00	months			$12,800.00	$384,000.00		
Dozer (2CY)	1	15.00	months			$12,800.00	$192,000.00		
Bobcat and accessories (1/2 time)	1	7.50	months			$4,480.00	$33,600.00		
Concrete Crusher (triple roller 30x18)(1/4 time)	1	3.75	months			$6,675.00	$25,031.25		
Front-end Loader (Cat IT18B -1.5CY)(1/2 time)	1	7.50	months			$2,000.00	$15,000.00		
Compressor(1/4 time)	1	3.75	months			$725.00	$2,718.75		
Jackhammer(1/4 time)	2	3.75	months			$275.00	$2,062.50		
Dump Truck (articulating)	2	15.00	months			$2,400.00	$72,000.00		

Scope	Number	Duration	Description	Mhrs	Labor Rate	Total Labor	Total Equipment	Total Material	Total Price
Sheet Pile driver (1/4 time)	1	3.75	months			$5,600.00	$21,000.00		
Hydraulic Hammer (1/4 time)	1	3.75	months			$8,320.00	$31,200.00		
Rad H&S laboratory in process counter	1	15.00	months			$15,000.00	$225,000.00		
Rad H&S radiological monitors	12	15.00	months			$750.00	$135,000.00		
Rad H&S chemical and ind. Hygiene monitors	4	15.00	months			$2,400.00	$144,000.00		
Sub Total							$1,282,612.50		$1,282,613
						Cost/Unit			
Small Tools @$40/man day	2	65	man-weeks			$40.00		$26,000.00	
PPE @ $60/man day	6	65	man-weeks			$60.00		$117,000.00	
Pressure Washer 1	1	15.00	months			$2,595.00		$38,925.00	
Sheet Piling (Z panels 1.6x1.6x0.25)		16.00	tons			$625.00		$10,000.00	
Backfill (71,000cfx 100#/cf /2,000 #/ton)		3,550	tons			$15.00		$53,250.00	
Waste Water Retainage (1/4 time)		3.75	months			$7,500.00		$28,125.00	
Demarcation Barrier		40,000	sq. ft			$2.00		$80,000.00	
Sub Total								$353,300.00	$353,300
Sub-Contracts						**Cost/Unit**			
Transportation (88,100cf X 1cy/27cf X 1railcar/68cy)	48		railcars			$8,500.00		$407,870.37	
Shaw load out		16.00	months			$120,000.00		$1,920,000.00	
Pavement Disposal (4,100cf x 100#/cf / 2,000 #/ton) WCS/USE	205		tons			$66.00		$13,530.00	
Building Slab Disposal (13,000 x 150#/cf /2,000 #/ton) WCS/USE	975		tons			$66.00		$64,350.00	
Subsurface Disposal (29,000cf x 100#/cf /2,000 #/ton) WCS/USE	1,450		tons			$66.00		$95,700.00	
Subsurface Disposal (42,000cf x 100#/cf /2,000 #/ton) Envirocare	2,100		tons			$200.00		$420,000.00	
Underground Sewers - Replace								$1,000,000.00	
URO Excavation and Disposal	1		Contract			$2,000,000.00		$2,000,000.00	
Radiological Lab (71,000cf X 1cy/27cf x 1 sample/10cy)	263		sample			$500.00		$131,481.48	
Chemical Lab (1 sample per railcar)	39		sample			$1,000.00		$39,000.00	
Sub Total								$6,091,931.85	$6,091,932
3. Final Status Survey									
Final Status Survey	1		set			$700,000.00		$700,000.00	
Sub Total								$700,000.00	$700,000
4. Institutional Controls									
Institutional Controls	1		set			$100,000.00		$100,000.00	
Sub Total								$100,000.00	$100,000
Total Direct Costs									$13,368,144
NRC Oversight Costs									$300,000
Phase II Total									$13,668,144
25% Contingency									$3,417,036
Grand Total Phase II									$17,085,180

APPENDIX A

GROUNDWATER AT THE ST. LOUIS DOWNTOWN SITE

Mallinckrodt Inc.

C-T Phase II Decomissioning Plan
May 15, 2003

NRC Docket: 40-06563
NRC License: STB-401

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APPENDIX A

GROUNDWATER AT THE ST. LOUIS DOWNTOWN SITE

1.1. INTRODUCTION

The hydrogeology of the Mallinckrodt site has been extensively studied by Mallinckrodt, Inc. (Mallinckrodt, 2001), and by the U.S. Department of Energy (DOE) and U.S. Army Corps of Engineers (USACE) under FUSRAP. The site hydrogeology is described in Section 1.2. Section 1.3 describes historical groundwater sampling events and analytical results. Section 1.4 presents a groundwater exposure assessment.

1.2. SITE HYDROGEOLOGY

1.2.1. Surface Water

The site is adjacent to the Mississippi River (Figure A1). A man-made levee constructed by the USACE along the riverfront protects the site from floodwater. According to flood insurance rate maps, the site is not located in a floodplain. The buildings and the concrete and asphalt pavement that cover most of the site have altered natural runoff and recharge. As a result, groundwater recharge via infiltration of precipitation is judged to be minimal. Surface water runoff from the site is collected and discharged to the St. Louis Metropolitan Sewer District.

1.2.2. Groundwater

The historical development of the riverfront in St. Louis involved the placement of man-made fill over the alluvial soils of the Mississippi River floodplain. The alluvial deposits beneath the fill material consist of a fining-upward sequence that thickens eastward towards the river. A generalized subsurface geologic profile is shown in Figure A2.

Four stratigraphic units have been identified beneath the Mallinckrodt site. These are, from top down: 1) man-made fill, 7 to 30 ft thick, consisting of bricks, coal, slag, cinder, concrete, construction rubble, and glass in a matrix of sand and clay; 2) a relatively lower permeability fine-grained alluvial silt and clay unit, 20 to 30 ft thick; with isolated lenses of fine sand 3) a lower alluvial unit, 0 to 60 ft thick, consisting of relatively permeable sandy sediments; and, 4) limestone bedrock. The bedrock is Mississipian-aged limestone of the St. Genevieve Formation. Bedrock is exposed in highway cuts west of the site, and the bedrock surface slopes eastward to a depth of over 100 ft beneath the Mississippi River (DOE, 1990).

A generalized diagram of the hydrostratigraphic units at the site is shown in Figure A3. Two hydrostratigraphic units are recognized above the bedrock. The Upper Hydrostratigraphic Unit (upper zone) consists of the man-made fill and the underlying layers of low-permeability alluvial silt and clay. The second or Lower Hydrostratigraphic Zone (lower zone) is composed of relatively permeable sandy silt, sand, and fine gravel. The groundwater in the upper zone occurs within man-made fill and is perched upon the low-permeability silt and clay layers. The perched groundwater is intermittent in nature and limited in its lateral continuity, saturated thickness, and transmissivity. The perched groundwater is not hydraulically connected to the lower zone or to the Mississippi River. Groundwater in the lower zone is hydraulically connected to the Mississippi River and, as such, is influenced by changing river stage. The direction of groundwater flow in the lower zone is generally towards the river during low river stage and away from the river during high river stage. Recharge of groundwater in the lower zone is thought to occur through riverbed infiltration (bank storage) from the Mississippi River and upward seepage of groundwater from bedrock.

Detailed hydrogeologic profiles were prepared from boring logs provided by the DOE and USACE. A well/piezometer location map is shown in Figure A4, and the detailed profiles are presented in Figure A5.

It should be noted that the boundary between the upper and lower zones is gradational in certain areas. Although the lower zone consists generally of high-permeability alluvial sediments, the top of the lower zone includes local regions of relatively low permeability silty sediments.

Representative hydraulic and geotechnical properties of the alluvial silt and clay were evaluated by U.S. DOE under FUSRAP. An in-situ, changing head test performed in this unit in Plant 7 yielded a horizontal hydraulic conductivity of 9.9×10^{-6} cm/s. DOE also collected fourteen undisturbed samples of this unit from various boreholes across the Mallinckrodt site and tested them for laboratory permeability, cation exchange, and geotechnical parameters. The vertical hydraulic conductivity ranged from 4×10^{-4} to 1×10^{-6} cm/s with a geometric mean of 1×10^{-5} cm/s. Cation exchange capacities ranged from 70 to 200 meq/100 g, with an average value of 39 meq/100 g (DOE, 1990; 1993).

Time series plots of hydraulic head measurements in the upper zone, lower zone, and Mississippi River are shown in Figure A6. A strong correlation exists between hydraulic head fluctuations in the lower zone and those in the Mississippi River, indicating good hydraulic communication between the lower zone and the river. Hydraulic head fluctuations in the upper zone, however, do not correlate well with those in the lower zone and the river. This indicates a low degree of hydraulic communication between the upper and lower zones and between the upper zone and the river.

1.2.3. History of Well and Piezometer Installation

The network of monitoring wells and piezometers at the site was installed by Bechtel National Incorporated (BNI) on behalf of the DOE and by IT Corporation (IT) and SAIC on behalf of the USACE. Table A1 lists well and piezometer construction details and screened hydrostratigraphic zones.

Between February 1988 and April 1988, BNI installed eight monitoring wells at the site. The wells installed were designated B16W01S, B16W02S, B16W03S, B16W04S, B16W05D, B16W06D, B16W07D, and B16W08D. Two of the wells were installed in the upper zone and four in the lower zone. Monitoring well B16W03S was screened across both the upper and lower zones, and well B16W01S was screened across both the upper zone and bedrock. These two wells (B16W03S and B16W01S) were later decommissioned because of the potential for vertical cross contamination.

Monitoring well B16W09D was added to the lower zone in June 1989 by BNI to provide an additional data collection point.

In the Fall of 1992 eight additional monitoring wells were installed at the site by BNI (DOE, 1993). These monitoring wells were designated B16W05S, B16W06S, B16W07S, B16W08S, B16W10S, B16W11S, B16W12S, and B16W13SR. Five of the wells were installed in the upper zone and three in the lower zone. Although monitoring wells B16W06S, B16W08S, and B16W11S are denoted with an "S" at the end of the well designation, the wells are actually screened in the lower zone. The letters at the end of the well designations were provided for initial project planning and should not be used to differentiate between shallow (upper zone) and deep (lower zone) monitoring wells (DOE, 1990). Five of the eight wells were installed adjacent to existing deep monitoring wells. The remaining three wells were installed downgradient of Plant 1 and Plant 5.

During the winter of 1998, eight new monitoring wells were installed at the site under SAIC's FUSRAP contract with the USACE. These monitoring wells were designated: MW3 (DW14), MW4 (DW15), MW5 (DW16), MW6 (DW17), MW7 (DW18), MW8 (DW19), MW9 (DW20), and MW10 (DW21). Two of the monitoring wells (MW9 and MW10) were installed in the upper zone and the remaining six monitoring wells were installed in the lower zone.

In September of 2000, IT, in connection with the FUSRAP activities, installed three piezometers (PZ-1, PZ-2, and PZ-3) in the upper zone in the west half of Plant 6. Based on subsequently collected water level data, IT concluded that monitoring well B16W11S is screened in the lower zone since its observed water levels are greater than 20 feet below the elevation of the perched water table in the upper zone.

1.2.4. Groundwater Flow Directions

Groundwater elevation data from three recent events are presented in Table A2 and on the cross-sections in Figure A5.

Groundwater elevation contour maps for the perched water table in the upper zone are not presented because of the lack of systematic spatial trends and high variability in water levels. As stated in Section 1.2.1, the perched groundwater is intermittent in nature and limited in its lateral continuity, saturated thickness, and transmissivity. In addition, the flow of perched groundwater in the fill may be locally influenced by man-made features such as dewatered excavations.

Groundwater level contour maps were created for the lower zone from water level measurements gathered on March 9, 1999 since this event provides the most complete set of data. For the purposes of contouring, wells screened in the lower zone were placed into two groups based on their relative depth in the lower zone. Monitoring wells B16W09D, MW3 (DW14), MW4 (DW15), MW5 (DW16), MW6 (DW17), MW7 (DW18), and MW8 (DW19) represent the shallow part of the lower zone, and wells B16W05D, B16W06D, B16W07D, B16W08D represent the deep part of the lower zone. These groups are contoured on Figures A7 and A8, respectively. Monitoring wells B16W06S, B16W08S, and B16W11S were not used for contouring of the potentiometric surface in the shallow part of the lower zone since they are screened in a lower permeability, silty material at the top of the lower zone. This lower permeability material causes the water levels in these three wells to equilibrate more slowly than those in the other lower zone wells during periods of rising and falling hydraulic head.

Conventional hydrologic models of groundwater flow in alluvial settings predict that the river stage greatly affects groundwater flow directions. Groundwater flow is generally towards the river during periods of low river stage (*e.g.*, base flow conditions during which the river is recharged by groundwater discharge) as shown on Figure A9. Conversely, groundwater flows away from the river during periods of high river stage in association with bank recharge, as shown on Figure A10. A potentiometric low ("trough") will develop landward of the zone of bank recharge where riverward groundwater flow is juxtaposed by landward groundwater flow, as shown on Figure A11. The potentiometric contours for the lower zone on March 9, 1999 are interpreted to indicate groundwater flow away from the river during a period of bank recharge associated with high river stage (Figures A7 and A8). The deflection of the 394 foot contour in the vicinity of monitoring well MW8 (DW19) on Figure A7 from what is otherwise generally a river-parallel trend may be caused by a localized zone of low permeability material around the well.

1.3. GROUNDWATER SAMPLING AND ANALYTICAL RESULTS

Total uranium, radium-226, and thorium-230 were analyzed in samples collected from eight monitoring wells during four quarterly sampling events between July 1988 and April 1989 (USACE, 1998). The groundwater was sampled again by BNI in during a single event in late 1997/early 1998 that included 17 monitoring wells. Samples were analyzed for actinium-227, lead-210, protactinium-231, radium-226, radium-228, thorium-228, thorium-230, thorium-232, and total uranium (USACE, 1998). Table A3 presents statistical summary results (min, max, average) from the four sampling events performed in 1988 thru 1989. Table A4 presents total uranium results from the 1997/1998 sampling event.

Total uranium was the only radionuclide detected in filtered samples at elevated concentrations. The elevated concentrations have been detected in only a single well, B16W02S, located in Plant 1. Well B16W02S is a shallow well, screened in perched groundwater in the upper zone. The total uranium concentrations in this well have ranged from a 1988/1989 average of 228 µg/l to a 1997/1998 value of 1,187 µg/l. These detections do not present a groundwater ingestion hazard since the perched groundwater in the upper zone is not a drinking water source.

Although protactinium-231 was detected at concentrations up to 45 pCi/l in unfiltered groundwater samples from three wells, it was not detected in filtered samples from these three wells. USACE has concluded that the protactinium is bound to sediment particles and that the unfiltered results are not representative of groundwater quality at the site (USACE, 1998).

No radionuclides were detected above US EPA MCL in filtered groundwater samples from the lower zone. This finding suggests that the low-permeability silt and clay layers between the upper and lower zones retard contaminant migration between the two zones.

1.4. GROUNDWATER EXPOSURE ASSESSMENT

The groundwater beneath the site is not a current source of drinking water, nor will it be a source of drinking water in the future for the following reasons:

1. All of the drinking water for the City of St. Louis is derived from the Mississippi and/or Missouri Rivers, and all of the drinking water intakes for the City of St. Louis are located upstream of the site.
2. St. Louis City Ordinance 13,272, Section 3 (dated March 25, 1885), states that drinking water supply wells are prohibited within the City of St. Louis. The ordinance has restricted drinking water supply well installation in the City of St. Louis for over 100 years and will continue to restrict well installation for the foreseeable future.
3. There is no known drinking water well in the vicinity of the plant (DOE, 1990). According to information obtained from the Missouri Department of Natural Resources Division of Geology and Land Survey, two wells are located within a ½-mile radius of the site (EPA, 1993). Neither of the wells is a drinking water well. Well No. 2798 is located in the SE¼ of Township 45N Range 7E. It was installed in 1933 to a depth of 185 feet and produced 30 gallons per minute. Fisher Chemical Company is listed as the well owner. Well No. 19835 is located in the SE¼ NE½ Township 45 N Range 7E and was installed in 1961. It is 180 feet deep and screened in the Mississippian alluvium. Well No. 19835 has produced 260 gallons per minute, but is located at an abandoned site.
4. The quality of perched groundwater in fill historically placed along the riverfront in the St. Louis area is naturally poor due to the presence of brick, glass, concrete rubble, coal cinder, and slag, and associated metals and PAH compounds (DOE, 1990). 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 site.
5. Groundwater in the lower zone (sandy alluvial unit) is locally saline and generally very hard, with high iron and manganese content. Groundwater 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 the surficial soil is man-made fill, withdrawal of groundwater for agricultural irrigation also is not a reasonable expectation.
6. Groundwater in the St. Louis area is generally of poor quality and does not meet drinking water standards without treatment. The expected future use of groundwater at the site is minimal since the Mississippi and Missouri Rivers constitute high-quality, large-quantity, readily available sources (USACE ROD, p.6).

1.5. REFERENCES

1. DOE. *Radiological, Chemical, and Hydrogeological Characterization Report for the St. Louis Downtown Site in St. Louis, Missouri.* Sept. 1990.

2. DOE. Remedial Investigation Addendum Report for the St. Louis Site, DOE/OR/21950-132. Prepared by SAIC, May 1993.

3. Mallinckrodt. *RCRA Facility Investigation Report for AOC 1 (Site-Wide Groundwater)*, Mallinckrodt, Inc., St. Louis Facility, April 6, 2001; prepared by URS Corporation.

4. USACE. *Groundwater Characterization Report of 1997/1998 Baseline Data for the St. Louis Downtown Site.* St. Louis, MO. July 1998.

5. USACE ROD. *Record of Decision for the St. Louis Downtown Site*. St. Louis, MO. July 1998.

TABLE A1
Well and Piezometer Construction Details
Mallinckrodt Inc. - St. Louis Downtown Site

Monitoring Well No.	Installation Date	Surface Elevation (ft. MSL)	Top of Casing Elevation (ft. MSL)	Bottom of Boring (ft. bgs)	Borehole Diameter (in.)	Well Diameter (in.)	Screen Interval (ft. bgs)	Hydrologic Zone Monitored by Screen Interval
B16W02S	4/1/1988	420.2	419.4	33.1	8.25	2	20.4 to 30.7	upper zone
B16W04S	3/28/1988	425.5	424.6	31.3	8.25	2	22.2 to 27.2	upper zone
B16W05S	9/30/1992	423.1	422.8	20.0	9.75	4	9.7 to 19.7	upper zone
B16W05D	4/14/1988	423.0	422.2	74.8	8.25	2	57.3 to 67.7	lower zone
B16W06S	9/30/1992	424.1	423.8	43.0	9.75	4	32.5 to 42.5	lower zone
B16W06D	3/17/1988	423.5	422.7	94.2	8.25	2	70.2 to 80.2	lower zone
B16W07S	9/11/1992	422.1	421.8	21.2	8	4	10.6 to 20.6	upper zone
B16W07D	3/18/1988	421.9	421.4	94.1	8.25	2	66.5 to 76.8	lower zone
B16W08S	9/30/1992	422.4	422.1	38.0	9.75	4	27.7 to 37.7	lower zone
B16W08D	3/25/1988	423.5	422	80.7	8.25	2	59.7 to 70.1	lower zone
B16W09D	6/7/1989	421.9	421.1	61.7	7.00	2	44.8 to 54.8	lower zone
B16W10S	9/30/1992	420.6	420.4	25.0	8.75	4	14.2 to 24.2	upper zone
B16W11S	9/30/1992	424.2	423.9	39.0	9.75	4	29.7 to 39.7	lower zone
B16W12S	9/30/1992	427.2	426.9	20.0	10.75	4	9.7 to 19.7	upper zone
B16W13SR	9/30/1992	420.5	420.3	19.0	6.75	4	8.7 to 18.7	upper zone
MW3 (DW14)	11/16/1998	417.8	417.5	40.0	9.00	2	26.6 to 36.6	lower zone
MW4 (DW15)	11/24/1998	427.1	426.8	64.5	9.00	2	53 to 63	lower zone
MW5 (DW16)	12/1/1998	422.6	422.3	50.0	9.00	2	39 to 49	lower zone
MW6 (DW17)	11/20/1998	420.9	421.2	44.5	9.00	2	33.6 to 43.6	lower zone
MW7 (DW18)	11/16/1998	423.2	423.5	55.0	9.00	2	43.7 to 53.7	lower zone
MW8 (DW19)	11/20/1998	424.2	424.4	54.8	9.00	2	44.3 to 54.3	lower zone
MW9 (DW20)	11/9/1998	418.0	417.7	21.0	9.00	2	10 to 20	upper zone
MW10 (DW21)	11/16/1998	422.8	422.6	22.7	9	2	17.3 to 22.3	upper zone

Note: 1. MSL = Mean Sea Level, bgs = below ground surface, ft. = feet, and in. = inches

Table A2
Groundwater Elevation Data
Mallinckrodt Inc. - St. Louis Downtown Site

Monitoring Well No.	Top of Casing Elevation (ft. MSL)	Depth to Water (ft.)	Water Elevation (ft. MSL)	Depth to Water (ft.)	Water Elevation (ft. MSL)	Depth to Water (ft.)	Water Elevation (ft. MSL)
		March 9, 1999		May 17, 1999		February 5, 2001	
B16W02S	419.4	4.56	414.9	4.45	415.0	NT	NT
B16W04S	424.6	5.09	419.6	5.21	419.4	6.25	418.4
B16W05S	422.8	10.8	412.0	10.3	412.5	NT	NT
B16W05D	422.2	28.48	393.8	15.09	407.1	NT	NT
B16W06S	423.8	27.64	396.2	NT	NT	31.71	392.1
B16W06D	422.7	29.06	393.7	NT	NT	33.86	388.9
B16W07S	421.8	10.34	411.5	9.6	412.2	10.28	411.5
B16W07D	421.4	27.71	393.7	14.2	407.2	32.9	388.5
B16W08S	422.1	24.72	397.4	NT	NT	31.13	391.0
B16W08D	422.0	27.45	394.6	13.93	408.1	30.83	391.2
B16W09D	421.1	27.23	393.9	14.01	407.1	32.8	388.3
B16W10S	420.4	17.34	403.1	11.46	408.9	NT	NT
B16W11S	423.9	28.05	395.9	21.71	402.2	35.9	388.0
B16W12S	426.9	15.09	411.8	13.07	413.9	17.97	409.0
B16W13SR	420.3	7.3	413.0	6.01	414.3	NT	NT
MW3 (DW14)	417.5	22.32	395.2	10.27	407.2	NT	NT
MW4 (DW15)	426.8	32.83	394.0	19.6	407.2	38.92	387.9
MW5 (DW16)	422.3	28.49	393.8	14.96	407.4	34.29	388.0
MW6 (DW17)	421.2	27.12	394.1	13.45	407.7	33.95	387.2
MW7 (DW18)	423.5	29.25	394.2	16.02	407.4	34.2	389.3
MW8 (DW19)	424.4	30.29	394.2	17.0	407.4	NT	NT
MW9 (DW20)	417.7	17.95	399.8	10.57	407.1	19.87	397.8
MW10 (DW21)	422.6	10.95	411.6	9.7	412.9	13.46	409.1

Notes: 1. All measurements from top of casing (MSL = Mean Sea Level and ft. = feet).
2. NT= measurements not taken
3. The water level for Monitoring Well DW17 (MW6) during the February 5, 2001 event is questionable due to a bubbling sound coming from the well and sporadic beeping of the water level indicator.

Table A3
Statistical Summary Data from 1988-1989 Quarterly Sampling Events
Mallinckrodt Inc. - St. Louis Downtown Site

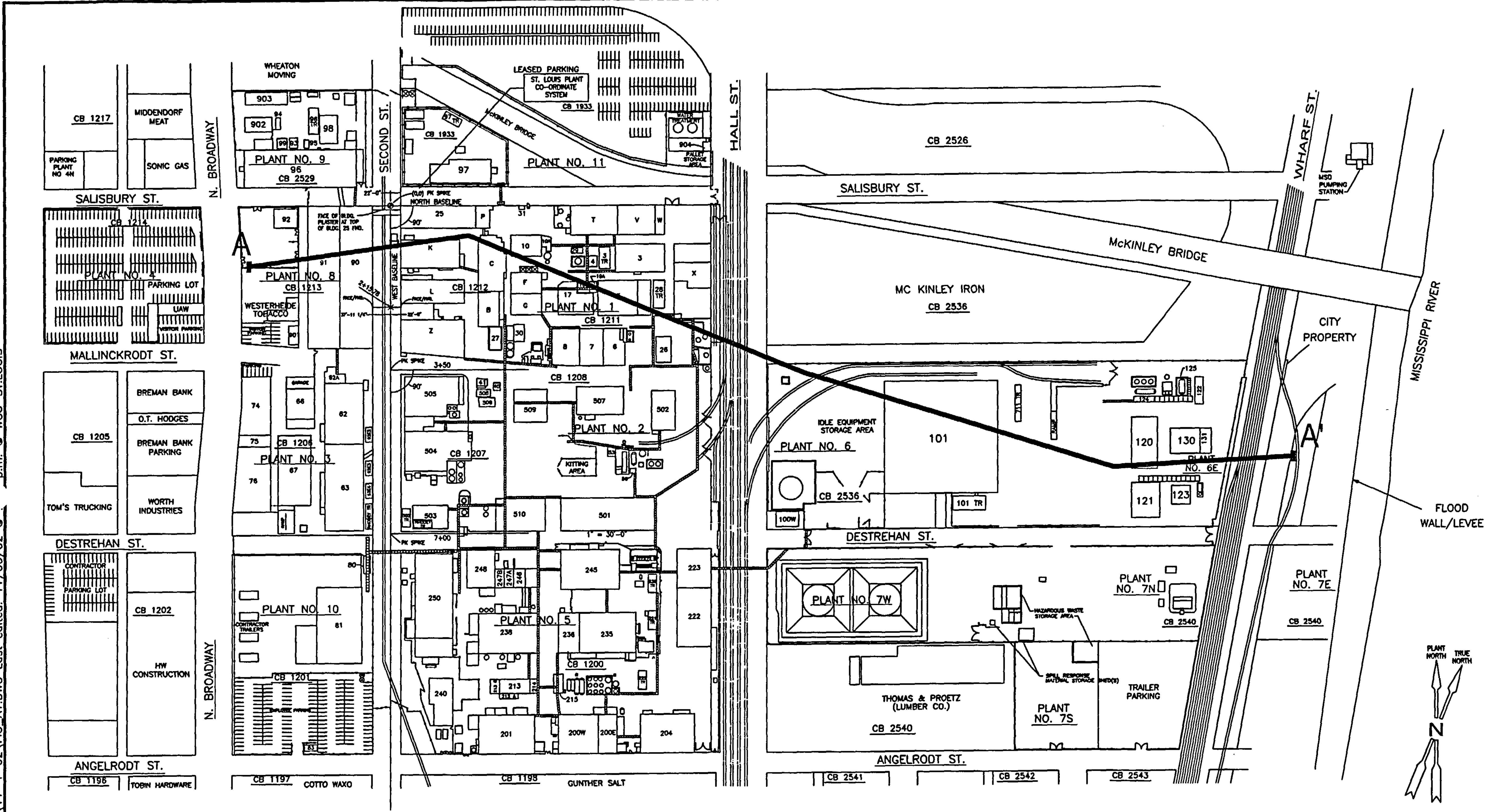
Sampling Location	Number of Samples	Statistical Minimum (10^{-9} µCi/ml)	Statistical Maximum (10^{-9} µCi/ml)	Statistical Average (10^{-9} µCi/ml)
Total Uranium				
B16W01S	4	< 3	5	4
B16W02S	4	107	193	162
B16W03S	4	< 3	< 3	< 3
B16W04S	4	< 3	< 3	< 3
B16W05D	4	< 3	3	< 3
B16W06D	4	< 3	3	< 3
B16W07D	4	< 3	< 3	< 3
B16W08D	4	< 3	< 3	< 3
Radium-226				
B16W01S	4	0.7	3.2	2.3
B16W02S	4	0.3	2.7	1.2
B16W03S	4	0.3	0.6	0.5
B16W04S	4	0.3	1.3	0.8
B16W05D	4	0.9	1.1	1
B16W06D	4	0.5	1.8	1.3
B16W07D	4	0.3	0.9	0.6
B16W08D	4	0.3	0.8	0.6
Thorium-230				
B16W01S	4	0.3	3.7	1.9
B16W02S	4	< 0.1	2.7	0.9
B16W03S	4	0.2	0.6	0.3
B16W04S	4	< 0.1	0.8	0.4
B16W05D	4	< 0.1	0.2	0.1
B16W06D	4	< 0.1	0.2	0.2
B16W07D	4	< 0.2	0.3	0.3
B16W08D	4	< 0.1	< 0.3	< 0.2

Reference: Table 6-9 of DOE (1990) (DOE/OR/20722-258)

Table A4
Total Uranium Results from the 1997/1998 Sampling Event
Mallinckrodt Inc. - St. Louis Downtown Site

Monitoring Well No.	Total Uranium (unfiltered) (µg/l)	Total Uranium (filtered) (µg/l)
B16W01S	4.22	5.42
B16W02S	1,175	1,187
B16W03S	7.39	4.84
B16W04S	7.48	1.74
B16W05S	1.62	1.60
B16W05D	0.22	< 0.03
B16W06S	< 0.03	< 0.03
B16W06D	0.30	< 0.03
B16W07S	0.24	0.33
B16W07D	2.45	2
B16W08S	1.62	1.56
B16W08D	0.38	0.34
B16W09D	< 0.03	< 0.03
B16W10S	3.69	4.12
B16W11S	49.90	71.70
B16W12S	6.29	6.23
B16W13SR	121	137

Reference: Table 4-4 of USACE (1998); (USACE/OR/DACW45-1050)



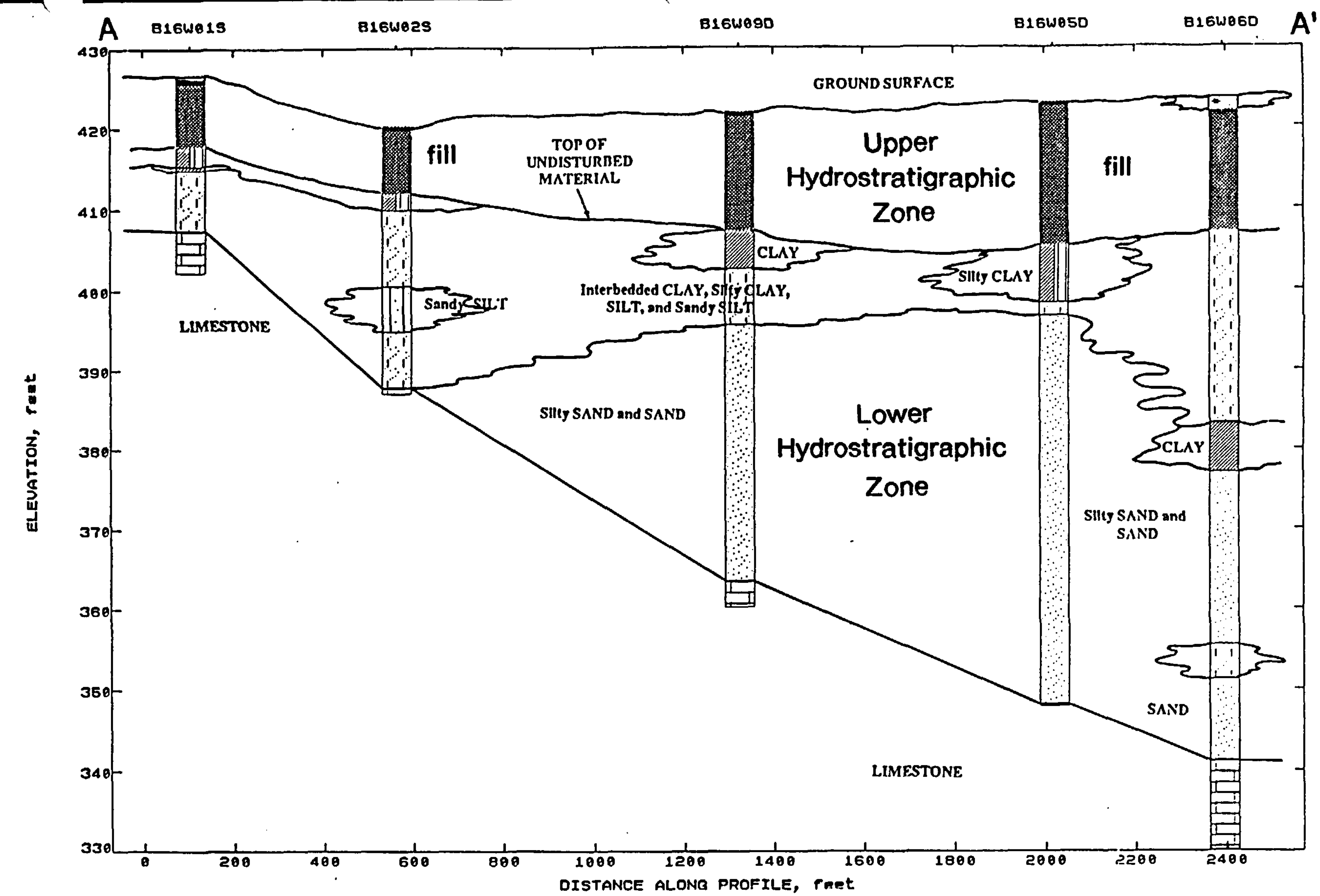
NOTE: PROFILE A-A' IS SHOWN ON FIGURE A2

0 200
SCALE FEET

MALLINCKRODT INC ST. LOUIS, MISSOURI	PROJECT NO. 21560918
URS	
DRN. BY: djd 11/6/02 DSGN. BY: ret CHKD. BY: RET 11/6/2002	Site Map	FIG. NO. A1

REFERENCE: MALLINCKRODT DRAWING NO. 5000, ST. LOUIS PLANT MAP, 1990

File: E:\2…0918.00000\11-4-02\FIG_A1.DWG Last edited: 11/06/02 @ … p.m. @ WCC-ST.LOUIS



Reference: Figure 6–40; (DOE, 1990)

MALLINCKRODT, INC ST. LOUIS, MISSOURI		PROJECT NO. 21560918
URS		
DRN. BY: rt 11/6/02 DSGN. BY: R2T CHKD. BY: R2T 11/6/2002	Generalized Subsurface Geologic Profile	FIG. NO. A2

Unit Designation	Graphic Column	Approximate Thickness (ft)	Description
Upper Hydro Stratigraphic Unit		0-25	**RUBBLE and FILL** Grayish black (N2) to brownish black (5YR2/1). Dry to slightly moist, generally becoming moist at 5-6 ft and saturated at 10-12 ft. Slight cohesion, variable with depth, moisture content and percentage of fines present. Consistency of relative density is unrepresentative, due to large rubble fragments. Rubble is concrete, brick, glass, and coal slag. Percentage of fines as silt or clay increases with depth from 5 to 30 percent. Some weakly cemented aggregations of soil particles. Adhesion of fines to rubble increases with depth and higher moisture content. Degree of compaction is slight to moderate with frequent large voids.
		0-10	**Silty CLAY (ML-CL)** Layers are mostly olive gray (5Y2/1), with some olive black (5Y2/1). Predominantly occurs at contact of undisturbed material, or at boundary of material with elevated activity. Abundant dark, decomposed organics. Variable percentages of silt and clay composition.
		0-5	**CLAY (CL)** Layers are light olive gray (5Y5/2), or dark greenish gray (5GY4/1). Slightly moist to moist, moderate cohesion, medium stiff consistency. Tends to have lowest moisture content. Slight to moderate plasticity.
		0-2.5	**Interbedded CLAY, silty CLAY, SILT and Sandy SILT (CL, CL-ML, ML)** Dark greenish gray (5GY4/1) to Light olive gray (5Y6/1). Moist to saturated, dependent on percentage of particle size. Contacts are sharp, with structure normal to sampler axis to less than 15 degrees downdip. Layer thicknesses are variable, random in alternation with no predictable vertical gradiation or lateral continuity. Some very fine-grained, rounded silica sand as stringers. Silt in dark mafic, biotite flakes. Some decomposed organics.
Lower Hydro Stratigraphic Unit		0-10	**Sandy SILT (ML)** Olive gray (5Y4/1). Moist with zones of higher sand content saturated. Slight to moderate cohesion, moderate compaction. Stiff to very stiff consistency, rapid dilatancy, nonplastic. Sand is well sorted, very fine and fine-grained rounded quartz particles.
		0-50	**Silty SAND and SAND (SM, SP, SW)** Olive gray (5Y4/1). Saturated, slight cohesion, becoming noncohesive with decrease of silt particles with depth. Dense, moderate compaction. Moderate to well-graded, mostly fine- and medium-grained, with some fine- and coarse-grained particles. Mostly rounded with coarse grains slightly subrounded. Gradual gradation from upper unit, silty sand has abundant dark mafic/biotite flakes. Sand is well-graded, fine gravel to fine sand. Mostly medium-grained, with some fine-grained and few coarse-grained and fine gravel.
Bedrock Unit		Total thickness not penetrated during drilling	**LIMESTONE** Light olive gray (5Y4/1) with interbedded chert nodules. Generally hard to very hard; difficult to scratch with knife. Slightly weathered, moderately fresh with little to no discoloration or staining. Top 5 ft is moderately fractured, with 99 percent of joints normal to the core axis. Joints are open, planar, and smooth. Some are slightly discolored with trace of hematite staining.

Reference: Figure 6-38; (DOE, 1990)

MALLINCKRODT, INC ST. LOUIS, MISSOURI	PROJECT NO. 21560918
URS	
DRN. BY: rt 11/6/02 DSGN. BY: RET CHKD. BY: RET 11/6/2002	Generalized Diagram of Hydrostratigraphic Units — FIG. NO. A3

NOTES:
UPPER ZONE WELLS
LOWER ZONE WELLS

MALLINCKRODT INC. ST. LOUIS, MISSOURI	PROJECT NO. 21560918
URS	
DRN. BY: djd 11/6/02 DSGN. BY: tja CHKD. BY: RET 11/6/2002	Monitoring Well Location Plan — FIG. NO. A4

C-04

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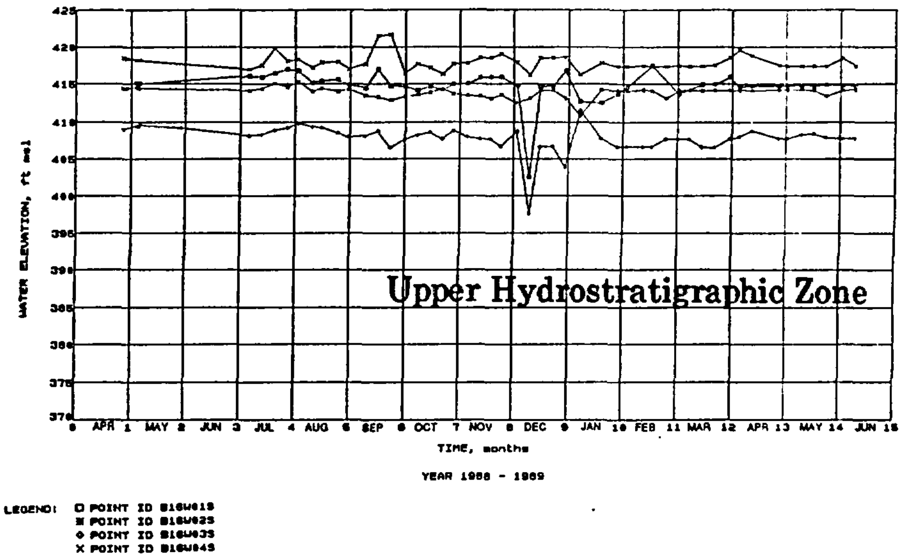
THIS PAGE IS AN OVERSIZED DRAWING OR FIGURE,

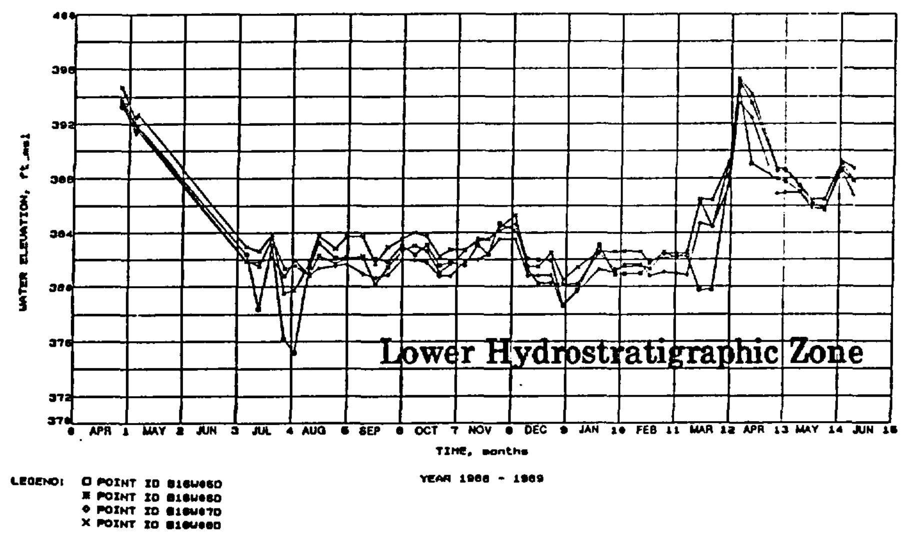
THAT CAN BE VIEWED AT THE RECORD TITLED: FIGURE A5, 11/6/02 "DETAIL HYDROGEOLOGIC PROFILES"

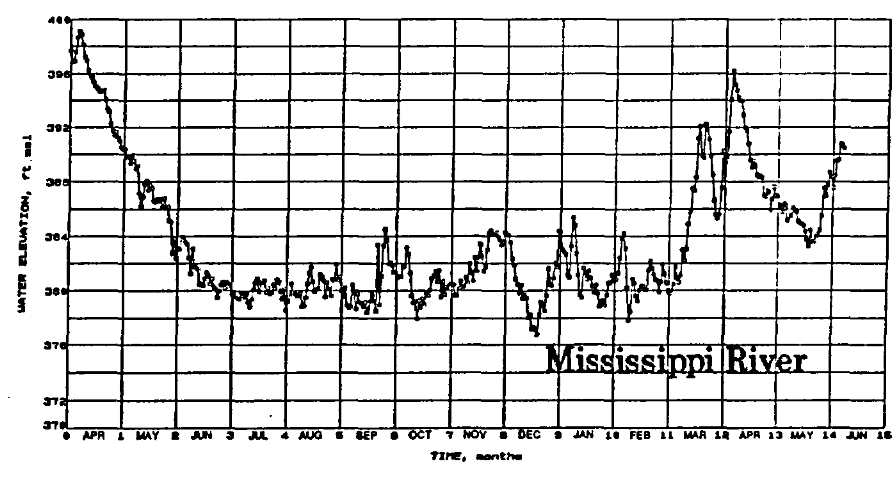
WITHIN THIS PACKAGE

NOTE: Because of this page's large file size, it may be more convenient to copy thefile to a local drive and use the Imaging (Wang) viewer, which can be accessed from the Programs/Accessories menu.

D-1







Reference:
Figures 6–44, 6–45, 6–46; (DOE, 1990)

MALLINCKRODT, INC ST. LOUIS, MISSOURI	PROJECT NO. 21560918
URS	

DRN. BY:rt 11/6/02 DSGN. BY: RET CHKD. BY: RET 11/6/2002	Time Series Plots of Water Level Measurements	FIG. NO. A6

LEGEND

MW5(DW16) — GROUNDWATER MONITORING WELLS IN THE SHALLOW PART OF THE LOWER ZONE

—394— GROUNDWATER CONTOUR (BASED ON MEASUREMENTS RECORDED ON MARCH 9, 1999.)

NOTE

1. ALL WATER LEVELS ARE ELEVATIONS IN FEET ABOVE MEAN SEA LEVEL (MSL)
2. THE RIVER STAGE DEPICTED ON THE FIGURE WAS INTERPOLATED BETWEEN USACE GAGING STATIONS AT CHAIN OF ROCKS, ST. LOUIS, MISSOURI AND THE FOOT OF MARKET STREET, ST. LOUIS, MISSOURI.

MALLINCKRODT INC. ST. LOUIS, MISSOURI		PROJECT NO. 21560918
	URS	
DRN. BY: djd 11/6/02 DSGN. BY: tjo CHKD. BY: RET 11/6/2002	Generalized Groundwater Contours of the Shallow Part of the Lower Zone	FIG. NO. A-7

LEGEND

MW5(DW16) — GROUNDWATER MONITORING WELLS IN THE DEEP PART OF THE LOWER ZONE

---394--- GROUNDWATER CONTOUR (BASED ON MEASUREMENTS RECORDED ON MARCH 9, 1999.)

NOTE

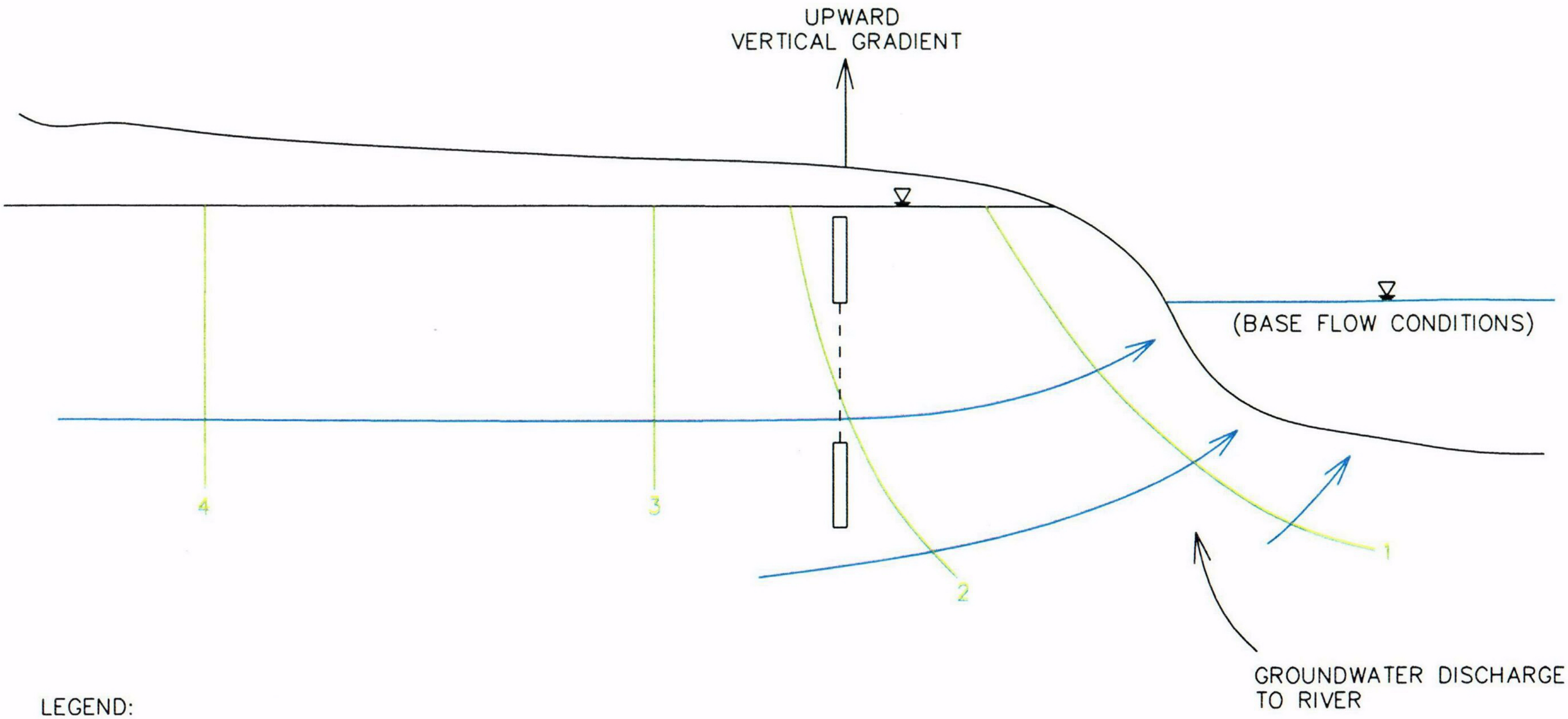
1. ALL WATER LEVELS ARE ELEVATIONS IN FEET ABOVE MEAN SEA LEVEL (MSL)
2. THE RIVER STAGE DEPICTED ON THE FIGURE WAS INTERPOLATED BETWEEN USACE GAGING STATIONS AT CHAIN OF ROCKS, ST. LOUIS, MISSOURI AND THE FOOT OF MARKET STREET, ST. LOUIS, MISSOURI.

MALLINCKRODT INC. ST. LOUIS, MISSOURI		PROJECT NO. 21560918
URS		
DRN. BY: chs 4/5/01 DSGN. BY: tja CHKD. BY: RET 11/6/2002	Generalized Groundwater Contours of the Deep Part of the Lower Zone	FIG. NO. A-8

File: F:\21560918 Docs\11-4-02\FIG_A8.DWG Last edited: NOV 06, 02 @ 2:07 p.m. URS Corp

File: E:\21560918.000...-02\FIG_A9.DWG Last edited: NOV. 06, 02 @ 1:29 p.m. by: DJDEGUIO

RIVER RECHARGE



LEGEND:

4 —— EQUIPOTENTIAL LINES (NUMBERS ARE EQUAL TO RELATIVE HYDRAULIC HEAD VALUES)

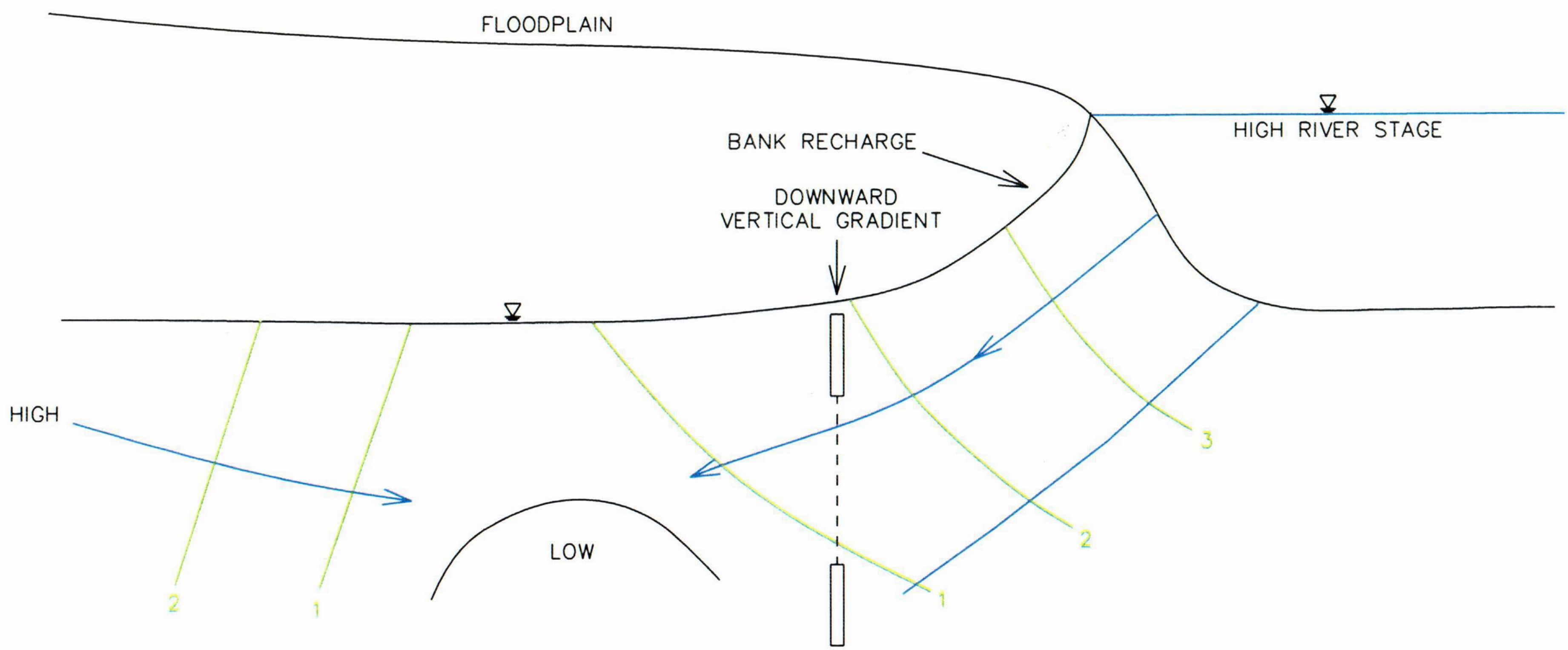
→ FLOW LINES

NOTE: DURING GROUNDWATER DISCHARGE TO THE RIVER AN UPWARD VERTICAL GRADIENT WOULD BE NOTICED AT THE WELL CLUSTER.

C-05

MALLINCKRODT INC. ST. LOUIS, MISSOURI		PROJECT NO. 21560918
URS		
DRN. BY: djd 11/6/02 DSGN. BY: ret CHKD. BY: RET 11/6/2002	Conventional Hydrologic Model of River Recharge in an Alluvial Setting	FIG. NO. A9

BANK RECHARGE



LEGEND:

4 —— EQUIPOTENTIAL LINES (NUMBERS ARE EQUAL TO RELATIVE HYDRAULIC HEAD VALUES)

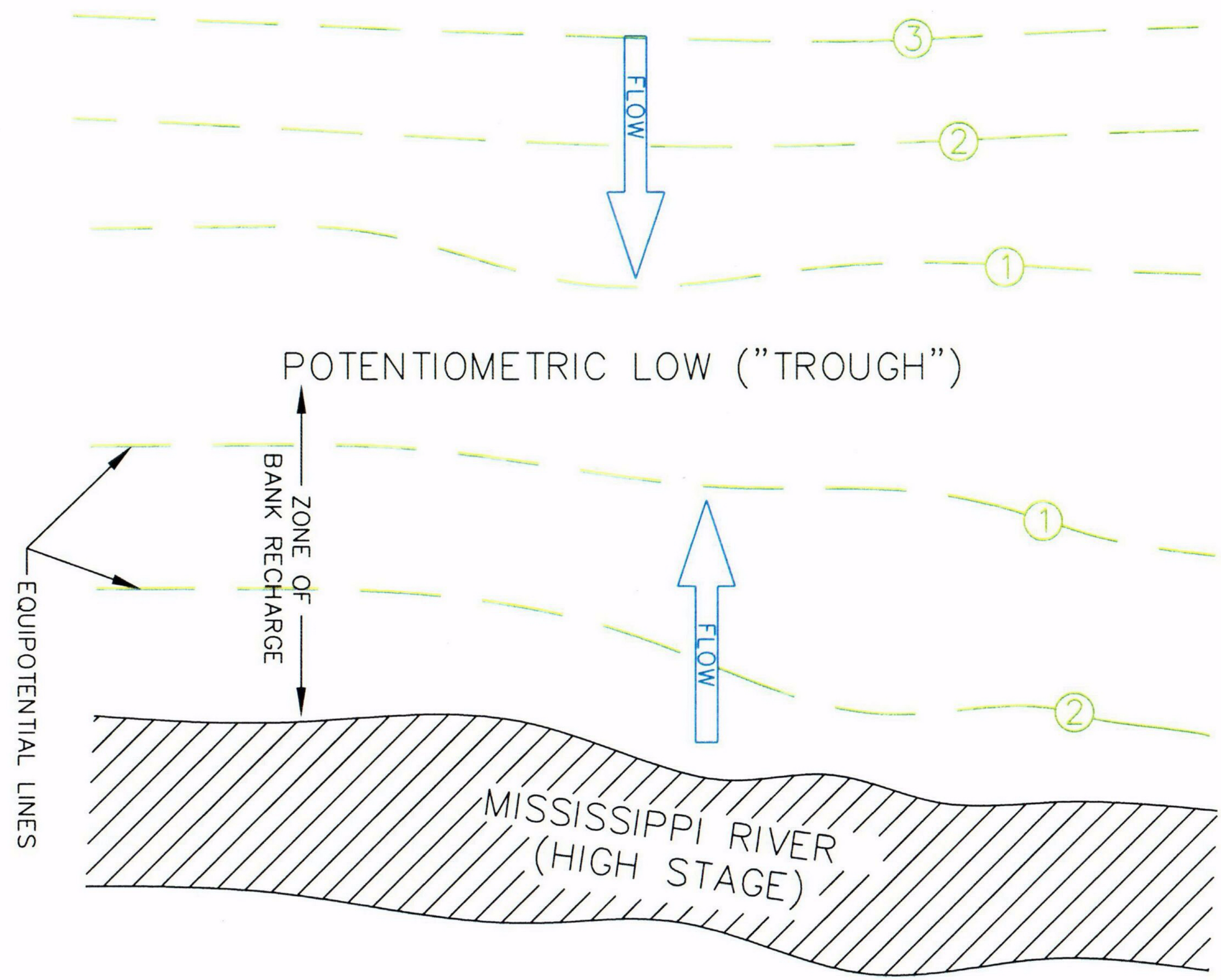
→ FLOW LINES

NOTE: DURING BANK RECHARGE TO THE FLOODPLAIN A DOWNWARD VERTICAL GRADIENT WOULD BE NOTICED AT THE WELL CLUSTER.

C-06

MALLINCKRODT INC. ST. LOUIS, MISSOURI	PROJECT NO. 21560918
URS	

DRN. BY: djd 11/6/02 DSGN. BY: ret CHKD. BY: RET 11/6/2002	Conventional Hydrologic Model of Bank Recharge in an Alluvial Setting	FIG. NO. A10



C-07

NOTE: THE DASHED LINE REPRESENT POINTS OF EQUAL HYDRAULIC HEAD.

MALLINCKRODT INC. ST. LOUIS, MISSOURI		PROJECT NO. 21560918
URS		
DRN. BY: djd 4/5/01 DSGN. BY: ret CHKD. BY: RET 11/6/2002	Idealized 2-D Model (Plan View) of Bank Recharge During High River Stage	FIG. NO. A11

APPENDIX B

INTERPRETATION OF NATURAL BACKGROUND RADIONUCLIDE CONCENTRATION IN CINDER/FILL FOR THE MALLINCKRODT COLUMBIUM-TANTALUM DECOMMISSIONING PLAN

Mallinckrodt Inc.

C-T Phase II Decomissioning Plan
May 15, 2003

NRC Docket: 40-06563
NRC License: STB-401

Appendix B

B. INTERPRETATION OF NATURAL BACKGROUND RADIONUCLIDE CONCENTRATION IN CINDER/FILL FOR THE MALLINCKRODT COLUMBIUM-TANTALUM DECOMMISSIONING PLAN

A large number of subsurface soil (cinder/fill) samples were collected in the Mallinckrodt Columbium-Tantalum (C-T) Plant 5 area. An assumption was made that not all of the subsurface soils were contaminated with uranium-series or thorium-series radionuclides from historical process operations. Those uncontaminated samples can be used to interpret the natural background concentration of uranium-series and thorium-series radionuclides in the subsurface soil.

B.1 PROBLEM

The Nuclear Regulatory Commission (NRC) provides criteria for release of a licensed facility for unrestricted use. A radionuclide concentration may be derived for soils corresponding to the release criterion; *e.g.*, a derived concentration guideline level (DCGL). The DCGL is established as a net radioactivity concentration; *i.e.*, a maximum acceptable concentration of a radionuclide in soil above the concentration of that radionuclide which occurs naturally in the soil. The naturally occurring concentration of a radionuclide in soil is also known as the respective radionuclide's background concentration. The DCGL and the background concentration may be similar in value. It is then essential to make an accurate estimate of the background concentration.

The natural background concentrations of uranium-series and thorium-series radionuclides vary in the environment, even on a local scale. An area that has similar physical, chemical, and radioactive, and biological characteristics as the site area being remediated, but which has not been contaminated by licensed activities is desired in order to estimate background concentrations. The distribution and concentration of background radiation in such a reference area would be expected to be the same as that at the site. If such a reference area is not available, an alternate method of interpreting natural background concentrations is necessary.

The Mallinckrodt Plant 5 area, where C-T processing occurred, has an undisturbed clay layer 15 to 20 feet below the present ground surface. As long as 150 years ago, fill material comprised of cinders from coal burned in the area and other material was deposited on top of the clay, raising the ground level a few to as many as 20 feet. Various other fill materials are found among the cinders, but there is no homogeneity to these materials.

It has not been possible to find near Plant 5 cinder/fill for which the natural radioactivity concentration is confidently similar to that in Plant 5. Figure B-1 shows the Mallinckrodt site and surrounding areas. It is likely not reasonable or feasible to complete drilling activities on the non-Mallinckrodt properties north and south of the Plant 5 area. Interstate 70 marks a limit toward the west where cinder fill was not used. The Mississippi River is a natural boundary to the east. Areas of the site north and east of Plant 5 are additionally limited by the condition that they were used to process radioactive materials for the Atomic Energy Commission and the Manhattan Engineering District (AEC-MED).

An attempt was made to find a reference area on Mallinckrodt property north of Plant 5. Figure B-1 shows borehole locations from which samples were collected to develop background concentrations for radionuclides of the uranium-series and thorium-series. This area is known as the "Coal Yard". In the Coal Yard, the cinder fill was in layers two to four feet thick and at variable depths. Variability in the sample results indicated that extensive additional sample collection would be necessary to provide requisite statistical confidence.

Several areas were further considered for additional sampling. Further north, the suspicion is that the cinder fill layer(s) would also be shallow and variable. There might also be a time difference in placement that would contribute additional variability in the fill material and in concentrations of radionuclides therein. It was not possible to go east due to AEC and MED activities, and then the Mississippi River. It was not possible to go west due to lack of cinders as fill material. Access to the south was hindered by industrial development of streets and structures.

It is reasonable to attempt to extract a background data set from samples collected in the Plant 5 area. In other words, a reference area would be developed from the total Plant 5 site characterization data set. Specifically, it is presumed that the entirety of the Plant 5 subsurface soils is not contaminated by C-T or MED-AEC activities. Then those uncontaminated samples could be used as the reference area data set from which background concentrations could be interpreted for radionuclides of the uranium-series and the thorium-series. Such a presumption is consistent with NRC guidance[1, 2], which states:

> A derived reference area may be used when it is necessary to extract background information from the survey unit because a suitable reference area is not readily available. For example, it may be possible to derive a background distribution based on area of the survey unit where residual distribution based on area of the survey unit where residual radioactivity is not present.

B.2 OBJECTIVE

The objective of this appendix is to interpret background concentrations by analysis of the site characterization data for the primary radionuclides in each of the uranium series and the thorium series. The scope of this objective is limited to three long-lived radionuclides from each series: the three from the uranium series are U-238, Th-230, and Ra-226; the three from the thorium series are Th-232, Ra-228, and Th-228.

Specifically, a set of measurements will be selected to represent the distribution of background concentration of the key radionuclides of the uranium series and the thorium series. The set of measurements will be selected from the larger data set of characterization samples. A best single-valued estimate of background for each key radionuclide will be derived to support

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[1] USNRC. "Demonstrating Compliance with the Radiological Criteria for License Termination". Draft Regulatory Guide DG-4006. Section 2.3.1. August 1998.

[2] USNRC. "Consolidated NMSS Decommissioning Guidance." NUREG-1757, 2, §A.3.1, p. A-5. Sept. 2002.

remediation efforts in which a decision is made on a single measurement. Also, the set of background measurements will be used as the background data set for performance of Wilcoxon Rank Sum tests of final status survey data sets.

B.3 SOLUTION

Several statistical methods were evaluated as means to achieve the objective. Application of these methods has been presented to the NRC elsewhere.[3,4] The presentations described each method, compared advantages and disadvantages, and demonstrated the validity of each method to achieve the objective. Background concentration of each key radionuclide was interpreted by a combination of differential and integral curve fits. A histogram, or differential curve, of measurements of each key radionuclide was constructed to interpret where a rational distinction occurs between natural background data and data that likely include licensed source material residue. The mean and standard deviation were then interpreted by constructing a cumulative probability plot, or integral curve, of the background data. This method of interpretation of background has the following advantages:

- Minimizes assumptions.
- Uses all of the data cumulatively.
- Enables visual interpretation of the data.
- Tests and illustrates nearness to the distribution assumed.
- Provides the desired results directly.
- Is practical to implement using curve fitting software.

B.3.1 Description

The application of this method to the C-T site characterization data first required estimation of the upper bound of background radioactivity concentration of each of the key, long-lived uranium-series and the thorium-series radionuclides. The upper bound was chosen by constructing a frequency histogram from all characterization data for the respective key radionuclide. The histogram was interpreted by acknowledging that the lowest peak must be a representation of background. Then the upper tail of this peak may also represent an upper bound of background radioactivity concentration.

The histogram of each of the six key radionuclides is shown in Figures B-2 through B-7. The histograms of Figures B-2 through B-7 were constructed of the entire set of characterization samples for the respective key radionuclide. However, in order to clearly show the lower end of the histogram, only that portion of the histogram between 0 and 20 pCi/g is shown. In the case of the uranium series (U-238, Th-230, and Ra-226), Figures B-2 through B-4 reflect that the background peak must be below 10 pCi/g. In the case of the thorium series (Th-232, Ra-228, and Th-228), Figures B-5 through B-7 reflect that the background peak must be below 5 pCi/g.

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[3] Mallinckrodt Chemical Company. "Interpretation of Natural Background Radionuclide Concentration in Soil in an Area Where Contamination by Regulated Materials May Occur". Sol Guber. July 9, 1997.

[4] Henry W. Morton. "Methods of Interpreting Background Radioactivity Concentration in Soil". Presentation to USNRC Staff. January 23, 2002.

The set of characterization samples was reduced to that set of samples for which each of the six key radionuclides was less than or equal to its respective upper bound. In other words, the set of background samples are those samples for which each of U-238, Th-230, and Ra-226 is less than 10 pCi/g; and each of Th-232, Ra-228, and Th-228 is less than 5 pCi/g. The resulting data set is presented in Table B-1. Since each radionuclide in each sample is less than its' respective upper bound, it is reasonable to assume each sample may be a background sample. Then any manipulation of this data set may be considered equivalent to manipulation of a background data set. The locations of the boreholes represented by the samples in Table B-1 are shown in Figure B-8.

A cumulative probability graph was constructed from the data in Table B-1for each of the six key radionuclides. A best-fit distribution was determined for each probability graph. In each case, the Weibull distribution provided the best fit compared to the normal and the lognormal. Gilbert has synopsized works of others supporting representation of some environmental pollution data, including background.[5] Figures B-9 through B-14 show the probability graph developed for each of the six key radionuclides. Tables B-2 through B-7 provide particular description of each figure. The graphs and tables were developed by using statistical software.[6]

B.3.2 Results

Table B-8 presents the results of the analyses for each key radionuclide: number of measurements, mean, standard deviation, and confidence limits.

B.4 CONCLUSION

The mean values in Table B-8 will be used as the background radioactivity concentrations for the C-T Phase II Decommissioning Plan. Additionally, the background data set described in Table B-1 will represent background radionuclide concentration in cinder/fill for utilization in population statistical tests of compliance for a final status survey.

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[5] Gilbert, R.O. Statistical Methods for Environmental Pollution Monitoring. Van Nostrand Reinhold. NY. pp. 155-157. 1987.

[6] MINITAB, Inc. MINITAB Statistical Software. Release 13.1. 2000. State College, PA. USA.

Table B-1, Samples With Result For Each Key Radionuclide and all Results Less Than Respective Background Cut-off of 10 pCi/g U-series 5 pCi/g Th-series

		Sample Depth (ft)		Radionuclide Concentration					
Location ID	Sample Matrix	Top	Bottom	U-238 (pCi/g)	Th-230 (pCi/g)	Ra-226 (pCi/g)	Th-232 (pCi/g)	Ra-228 (pCi/g)	Th-228 (pCi/g)
BH-002	Cinder	0.5	2.5	2.5	3.1	2.3	1.8	1.5	1.5
BH-003	Fill	0.5	2.5	7.1	6.1	3.5	1.4	1.5	1.3
BH-008	Fill	0.5	2.5	5.2	3.9	4.2	1.6	1.5	1.4
BH-008	Cinder	5.5	6.5	7.7	3.2	4.4	0.8	1.4	1.4
BH-011	Fill	1.5	2.5	0.65	0.16	2.12	0.24	1.53	0.23
BH-013	Fill	4.5	5.5	4.5	2.4	1.1	1.6	1.2	1.3
BH-013	Fill	8.5	9.5	4.4	1.7	3.4	1.1	1.6	1
BH-016	Fill	5.5	7.5	5.9	6.3	7.8	3.5	4.5	3.5
BH-019	Fill	–	9.5	4.8	1.5	2.8	1.1	2.9	1.4
BH-020	Fill	2.5	4.5	3.1	5	2.8	1.8	1.1	2.2
BH-023	Fill	–	9.5	6.6	1.8	0.13	0.61	1.1	0.64
BH-027	Fill	4.5	5.5	3.6	3.2	1.5	2.1	1.8	2.1
BH-027	Fill	7	8.5	7.1	7.3	4.6	2.9	2.4	2.9
BH-028	Fill	9	10.5	3	2.8	1.7	1	0.81	1.4
BH-029	Fill	9.5	11	5.5	7.8	4	1.9	1.5	1.5
BH-031	Fill	12.5	13.5	1.4	1.5	1.7	0.67	1.4	0.72
BH-034	Fill	2.5	3.5	5.2	6.3	6.9	1.2	1.5	1.3
BH-034	Fill	–	9.5	4.2	5.8	4.6	2.6	1.8	2.9
BH-035	Fill	15.5	16.5	1.4	1.8	1.5	1.2	1.5	1.6
BH-036	Fill	0	0.5	3	3.6	3.2	0.99	1.6	1.3
BH-036	Fill	4.5	5.5	3.4	3.9	4.5	1	1.6	1.1
BH-036	Fill	15	16.5	6	3.5	2.4	1.2	1.2	1.2
BH-037	Fill	0	1	9.9	6.5	< 0.44	1.4	< 0.47	1.4
BH-037	Fill	5	7	5.3	6.1	4.3	1.7	< 0.55	1.9
BH-037	Fill	10.5	11.5	4.4	2.9	6	1.7	1.7	1.4
BH-039	Fill	7.5	8.5	3	7.7	5	1	1.3	1.2
BH-039	Fill	15.5	17.5	1.6	1.8	1	1.3	1.5	1.2

Table B-1, Samples With Result For Each Key Radionuclide and all Results Less Than Respective Background Cut-off of 10 pCi/g U-series 5 pCi/g Th-series

Location ID	Sample Matrix	Sample Depth (ft) Top	Bottom	U-238 (pCi/g)	Th-230 (pCi/g)	Ra-226 (pCi/g)	Th-232 (pCi/g)	Ra-228 (pCi/g)	Th-228 (pCi/g)
BH-040	Fill	2.5	3.5	3.3	2.8	2.8	1.3	1.6	1.4
BH-040	Fill	10.5	11.5	8	4.3	1.7	2.3	2.9	2
BH-041	Fill	3.5	4.5	6.1	0.3	3.04	< 0.05	1.24	0.17
BH-041	Fill	5.5	6.5	0.85	0.07	1.37	< 0.03	1.03	< 0.05
BH-041	Fill	7.5	8.5	3.9	0.095	1.35	< 0.02	1.01	< 0.02
BH-041	Fill	10	12	3.9	2.6	5.6	1	2.8	2.6
BH-041	Cinder	14	16.5	4.2	2.3	3.9	1	1.5	1.2
BH-042	Silt	15.5	16.5	2.2	2.9	1.9	1.3	1.9	1.4
BH-043	Fill	9	10.5	5.2	7.7	0.91	1	1.2	1.7
BH-044	Fill	9.5	11	4.8	6	3	3.1	2.8	3.1
BH-045	Fill	0	2	3.1	5.6	1.8	0.89	0.96	1.1
BH-045	Fill	7.5	9.5	1.5	1.6	1.1	0.81	1	0.71
BH-046	Fill	0.5	2.5	2	2.2	1.4	1.4	0.67	0.85
BH-046	Fill	6.5	9.5	6.5	5.4	3.5	< 0.61	1.1	2.3
BH-046	Fill	11.5	13.5	5.5	3	7.4	2.6	1.6	3.8
BH-047	Fill	2.5	3.5	6.2	4.6	2.9	1.1	1.7	1.3
BH-047	Fill	6.5	7.5	5.8	2.5	2.3	1.3	1.6	1.4
BH-048	Fill	2	3.5	1.3	1.5	1.6	1	1.3	1.5
BH-048	Fill	8.5	9.5	2.6	1.6	2.4	1.1	1	0.94
BH-049	Fill	1.5	2.5	4.9	3.5	4.8	1.1	1.9	1.1
BH-049	Fill	9	10.5	6.8	3.4	4.8	1.2	1.5	0.85
BH-051	Fill	1.5	2.5	8.6	4.3	3.6	0.99	1.4	1
BH-051	Fill	5.5	6.5	1.9	0.18	2.5	0.66	1	0.85
BH-051	Fill	12.5	13.5	5.8	8.3	7.9	2.2	2.6	1.8
BH-053	Fill	0	2	7.8	7	9.8	1.4	2.2	1.8
BH-053	Fill	7.5	9.5	5.6	3.2	2.8	1.4	1.2	1.6
BH-054	Fill	4.5	5.5	4.4	1.8	1.6	0.97	1.6	0.81

Table B-1, Samples With Result For Each Key Radionuclide and all Results Less Than Respective Background Cut-off of 10 pCi/g U-series 5 pCi/g Th-series

		Sample Depth (ft)		Radionuclide Concentration					
Location ID	Sample Matrix	Top	Bottom	U-238 (pCi/g)	Th-230 (pCi/g)	Ra-226 (pCi/g)	Th-232 (pCi/g)	Ra-228 (pCi/g)	Th-228 (pCi/g)
BH-054	Fill	14.5	15.5	9.2	2	9.8	0.89	1.6	1.2
BH-056	Fill	3	4.5	3.9	2.1	3.1	1.1	2.8	1.5
BH-056	Fill	--	11.5	6.2	4.1	4.8	0.96	1.8	1
BH-056	Fill	13.5	14.5	8.7	3.8	4.4	0.81	1.7	1
BH-062	Fill	7	8	4.95	4.48	6.15	2.35	3.18	2.22
BH-063	Fill	1	2	7.62	5.25	4.77	1.42	1.46	1.38
BH-063	Fill	4	6	6.45	2.67	2.25	1.26	1.32	1.12
BH-064	Fill	4	5	5.06	3.4	4.07	0.87	1.54	1.03
BH-064	Fill	11	12	3.75	2.42	2.58	1.52	1.36	1.48
BH-065	Fill	0	0.5	5.92	3.78	5.35	1.01	1.98	1.03
BH-065	Fill	3	3.5	1.68	1.93	4.18	1.53	2.36	1.1
BH-066	Fill	3	3.5	5.69	3.8	4.19	1.18	1.4	0.97
BH-067	Fill	1	2	9.81	5.5	4.07	0.85	1.83	1.26
BH-067	Fill	4	6	6.47	4.47	4.66	1.03	1.98	1.19
BH-067	Fill	15	16	3.9	2.51	7.37	0.83	2.14	0.73
BH-068A	Fill	5	6	7.89	5.38	6.45	1.29	1.95	1.15
BH-082	Fill	6	7.5	2.68	1.88	2.06	0.89	0.59	1.04
BH-082	Fill	9	10.5	1	1.46	1.07	0.97	0.68	1.03
BH-082	Fill	12	13.5	2.32	2.6	2.02	0.97	0.23	0.92
BH-083	Fill	10.5	12	1.35	0.94	1.46	0.91	0.85	0.93
BH-083	Fill	13.5	15	1.89	0.86	0.92	0.75	0.79	0.76
BH-084	Fill	0.5	1.5	2.85	2.69	2.1	0.96	0.68	1.08
BH-084	Fill	3	4.5	2.58	2.34	1.14	1.05	0.65	1.05
BH-085	Fill	1	1.5	2.1	1.42	1.48	0.69	0.68	0.72
BH-085	Fill	3	4.5	2.89	2.64	1.6	0.96	0.79	1.16
BH-085	Fill	6	7.5	0.63	0.62	0.54	0.45	0.75	0.52
BH-087	Fill	6	7.5	7.6	1.81	0.047	0.64	-0.17	0.7

Table B-1, Samples With Result For Each Key Radionuclide and all Results Less Than Respective Background Cut-off of 10 pCi/g U-series 5 pCi/g Th-series

		Sample Depth (ft)		Radionuclide Concentration					
Location ID	Sample Matrix	Top	Bottom	U-238 (pCi/g)	Th-230 (pCi/g)	Ra-226 (pCi/g)	Th-232 (pCi/g)	Ra-228 (pCi/g)	Th-228 (pCi/g)
BH-087	Fill	9	10.5	7.5	1.91	1.03	1.12	0.83	1.28
BH-089	Fill	3	4.5	3.13	2.24	9.1	0.96	0.86	1.02
BH-089	Fill	9	10.5	6.2	3.14	5.25	1.45	1.19	1.5
BH-089	Fill	15	16.5	9	7.2	1.04	4.05	1.46	4.53
BH-090	Fill	3	4.5	7.2	2.06	1.7	0.98	1.25	1.3
BH-090	Fill	6	7.5	3.65	1.73	1.52	1.12	0.79	1.16
BH-090	Fill	9	10.5	5.4	0.94	2.4	0.61	0.7	0.86
BH-091	Fill	1	1.5	6.6	4.7	5.08	1.45	1.72	1.41
BH-091	Fill	3	4.5	2.05	2.21	1.86	0.93	1	0.92
BH-091	Fill	6	7.5	1.84	1.34	1.62	0.49	0.89	0.58
BH-091	Fill	9	10.5	2.96	1.5	1.06	0.55	0.17	0.68
BH-092	Fill	1	1.5	5.4	3.51	2.18	0.79	0.68	0.77
BH-092	Fill	3	4.5	3	4.34	3.85	1.07	0.84	1.24
BH-092	Fill	6	7.5	1.37	1.6	1.56	0.67	0.75	0.83
BH-092	Fill	9	10.5	2.23	1.52	1.59	0.59	0.73	0.9
BH-093	Fill	0.5	1.5	6.9	4	3.32	1.3	1.14	1.22
BH-093	Fill	3	4.5	5.4	1.7	1.48	0.96	0.76	0.92
BH-093	Fill	6	7.5	2.14	1.14	0.84	0.48	0.64	0.41
BH-099	Gravel	6	9	1.43	1.26	0.87	4.5	0.88	3.56
BH-100	Gravel	0	3	9.26	8.86	0.86	2.84	1.75	2.84
BH-100	Gravel	6	8.5	7.02	5.61	1.46	2.61	2.21	1.98
BH-101	Silt	3	6	1.9	1.09	1.92	2.61	2	4.27
BH-101	Silt	6	9	1.07	4.39	1.97	4.31	0.9	3.7
BH-102	Sand	3	6	1.2	6.38	2.04	3	0.54	3.19
BH-102	Sand	6	9	1.79	1.34	2.38	3.6	0.49	-1.03
BH-Z-02	Fill	0	1	6.25	4.36	0.27	1.16	0.49	1.42
BH-Z-02	Fill	1	3	7.21	3.48	0.38	1.01	0.76	0.95

(((

Table B-1, Samples With Result For Each Key Radionuclide and all Results Less Than Respective Background Cut-off of 10 pCi/g U-series 5 pCi/g Th-series

		Sample Depth (ft)		Radionuclide Concentration					
Location ID	Sample Matrix	Top	Bottom	U-238 (pCi/g)	Th-230 (pCi/g)	Ra-226 (pCi/g)	Th-232 (pCi/g)	Ra-228 (pCi/g)	Th-228 (pCi/g)
BH-Z-02	Fill	3	6	3.8	5.13	0.21	1.27	0.73	0.98
BH-Z-02	Fill	6	9	4.27	3.66	0.23	1.31	0.76	1.36
BH-Z-02	Fill	9	12	5.36	4.68	0.19	1.65	0.81	1.18
BH-Z-03	Fill	0	1	7.52	3.43	0.25	1.01	0.53	0.76
BH-Z-03	Fill	1	3	7.58	4.49	0.13	1.05	0.65	1.12
BH-Z-03	Fill	3	6	4.36	4.76	0.37	1.08	0.79	1.12
BH-Z-03	Fill	6	9	4.66	4.36	0.41	1.13	0.82	1.03
BH-Z-03	Fill	9	12	3.49	3.3	0.29	0.94	1.13	0.7
BH-Z-08	Fill	0	1	1.99	0.94	0.2	0.27	0.16	0.03
BH-Z-08	Fill	1	3	3.75	3.07	0.54	0.75	0.41	0.79
BH-Z-08	Fill	3	6	5.12	4.24	0.3	1.47	0.64	1.26
BH-Z-08	Fill	6	9	3.89	3.71	0.25	0.9	0.57	1.2
BH-Z-08	Fill	9	12	3.47	3.41	0.15	1.45	0.77	0.88
BH-Z-09	Fill	1	3	7.36	3.99	0.26	1.15	0.66	0.88
BH-Z-09	Fill	3	6	4.59	3.14	0.3	1.07	0.69	1.07
BH-Z-09	Fill	6	9	4.19	2.88	0.45	0.6	0.47	0.73
BH-Z-09	Fill	9	12	4.3	3.33	0.25	0.94	0.69	1.02
BH-Z-10	Fill	0	1	1.45	1.12	0.35	0.48	0.5	0.48
BH-Z-10	Fill	1	3	1.05	1.03	0.42	0.78	0.73	0.73
BH-Z-10	Fill	3	6	1.66	2.71	0.41	1.06	0.62	1
BH-Z-10	Fill	6	9	4.16	3.97	0.32	1.05	0.82	0.75
BH-Z-10	Fill	9	12	4.43	3.51	0.12	0.99	0.87	0.93

Table B-2

Distribution Function Analysis: U-238 background concentration for cinder/fill

Variable: U-238 < 10 pCi/g

Count 130

Estimation Method: Least Squares (X on Y)
Distribution: Weibull

Parameter Estimates

Parameter	Estimate	Standard Error	95% Confidence Interval Lower	Upper
Shape	2.0321	0.1458	1.7655	2.3389
Scale	5.0113	0.2276	4.5845	5.4778

Goodness-of-Fit
Correlation Coefficient = (0.9911 (Pearson correlation coefficient, r)

Characteristics of Distribution

	Estimate	Standard Error	95% Confidence Interval Lower	Upper
Mean	4.4400	0.2002	4.0644	4.8503
Standard Deviation	2.2879	0.1528	2.0071	2.6078
Median	4.1843	0.2135	3.7860	4.6245
First Quartile	2.7144	0.1971	2.3544	3.1296
Third Quartile	5.8851	0.2539	5.4080	6.4044
Interquartile Range	3.1707	0.1965	2.8081	3.5801

Table B-3

Distribution Function Analysis: Th-230 background concentration for cinder/fill

Variable: Th-230 < 10 pCi/g

Count 130

Estimation Method: Least Squares (X on Y)
Distribution: Weibull

Parameter Estimates

Parameter	Estimate	Standard Error	95% Confidence Interval Lower	95% Confidence Interval Upper
Shape	1.5803	0.1219	1.3464	1.8548
Scale	3.7939	0.2216	3.3836	4.2541

Goodness-of-Fit
Correlation Coefficient = (0.9763 (Pearson correlation coefficient, r)

Characteristics of Distribution

	Estimate	Standard Error	95% Confidence Interval Lower	95% Confidence Interval Upper
Mean	3.4055	0.1961	3.0421	3.8124
Standard Deviation	2.2041	0.2046	1.8374	2.6439
Median	3.0086	0.1938	2.6518	3.4134
First Quartile	1.7246	0.1622	1.4343	2.0737
Third Quartile	4.6650	0.2704	4.1641	5.2263
Interquartile Range	2.9404	0.2333	2.5170	3.4351

Table B-4

Distribution Function Analysis: Ra-226 background concentration for cinder/fill

Variable: Ra-226 Value < 10 pCi/g

Count 130

Estimation Method: Least Squares (X on Y)
Distribution: Weibull

Parameter Estimates

Parameter	Estimate	Standard Error	95% Confidence Interval Lower	Upper
Shape	1.1287	0.0791	0.9837	1.2951
Scale	2.6497	0.2167	2.2572	3.1104

Goodness-of-Fit
Correlation Coefficient = (0.9875 (Pearson correlation coefficient, r)

Characteristics of Distribution

	Estimate	Standard Error	95% Confidence Limit Lower	Upper
Mean	2.5358	0.1964	2.1787	2.9515
Standard Deviation	2.2510	0.2240	1.8522	2.7357
Median	1.9150	0.1758	1.5996	2.2926
First Quartile	0.8786	0.1140	0.6813	1.1331
Third Quartile	3.5389	0.2744	3.0399	4.1198
Interquartile Range	2.6603	0.2167	2.2678	3.1207

Table B-5

Distribution Function Analysis: Th-232 background concentration for cinder/fill

Variable: Th-232 Value < 5 pCi/g

Count 130

Estimation Method: Least Squares (X on Y)
Distribution: Weibull

Parameter Estimates

Parameter	Estimate	Standard Error	95% Confidence Interval Lower	Upper
Shape	1.8497	0.1034	1.6577	2.0639
Scale	1.4407	0.0724	1.3057	1.5898

Goodness-of-Fit
Correlation Coefficient = (0.9198 (Pearson correlation coefficient, r)

Characteristics of Distribution

	Estimate	Standard Error	95% Confidence Interval Lower	Upper
Mean	1.2797	0.0632	1.1615	1.4098
Standard Deviation	0.7177	0.0412	0.6414	0.8031
Median	1.1817	0.0654	1.0602	1.3173
First Quartile	0.7346	0.0539	0.6362	0.8482
Third Quartile	1.7190	0.0814	1.5666	1.8862
Interquartile Range	0.9844	0.0525	0.8866	1.0929

Table B-6

Distribution Function Analysis: Ra-228 background concentration for cinder/fill

Variable: Ra-228 Value < 5 pCi/g

Count 129 (one value excluded because less than zero)

Estimation Method: Least Squares (X on Y)
Distribution: Weibull

Parameter Estimates

Parameter	Estimate	Standard Error	95% Confidence Interval Lower	Upper
Shape	2.2898	0.1167	2.0721	2.5303
Scale	1.4042	0.0577	1.2955	1.5220

Goodness-of-Fit
Correlation Coefficient = (0.9802 (Pearson correlation coefficient, r)

Characteristics of Distribution

	Estimate	Standard Error	95% Confidence Interval Lower	Upper
Mean	1.2439	0.0515	1.1470	1.3490
Standard Deviation	0.5758	0.0252	0.5285	0.6275
Median	1.1965	0.0546	1.0941	1.3084
First Quartile	0.8149	0.0487	0.7249	0.9161
Third Quartile	1.6194	0.0617	1.5029	1.7450
Interquartile Range	0.8045	0.0342	0.7403	0.8744

Table B-7

Distribution Function Analysis: Th-228 background concentration for cinder/fill

Variable: Th-228 Value < 5 pCi/g

Count 129 (one value excluded because less than zero)

Estimation Method: Least Squares (X on Y)
Distribution: Weibull

Parameter Estimates

Parameter	Estimate	Standard Error	95% Confidence Interval Lower	95% Confidence Interval Upper
Shape	1.8390	0.1071	1.6406	2.0615
Scale	1.4925	0.0756	1.3515	1.6481

Goodness-of-Fit
Correlation Coefficient = (0.9157 (Pearson correlation coefficient, r)

Characteristics of Distribution

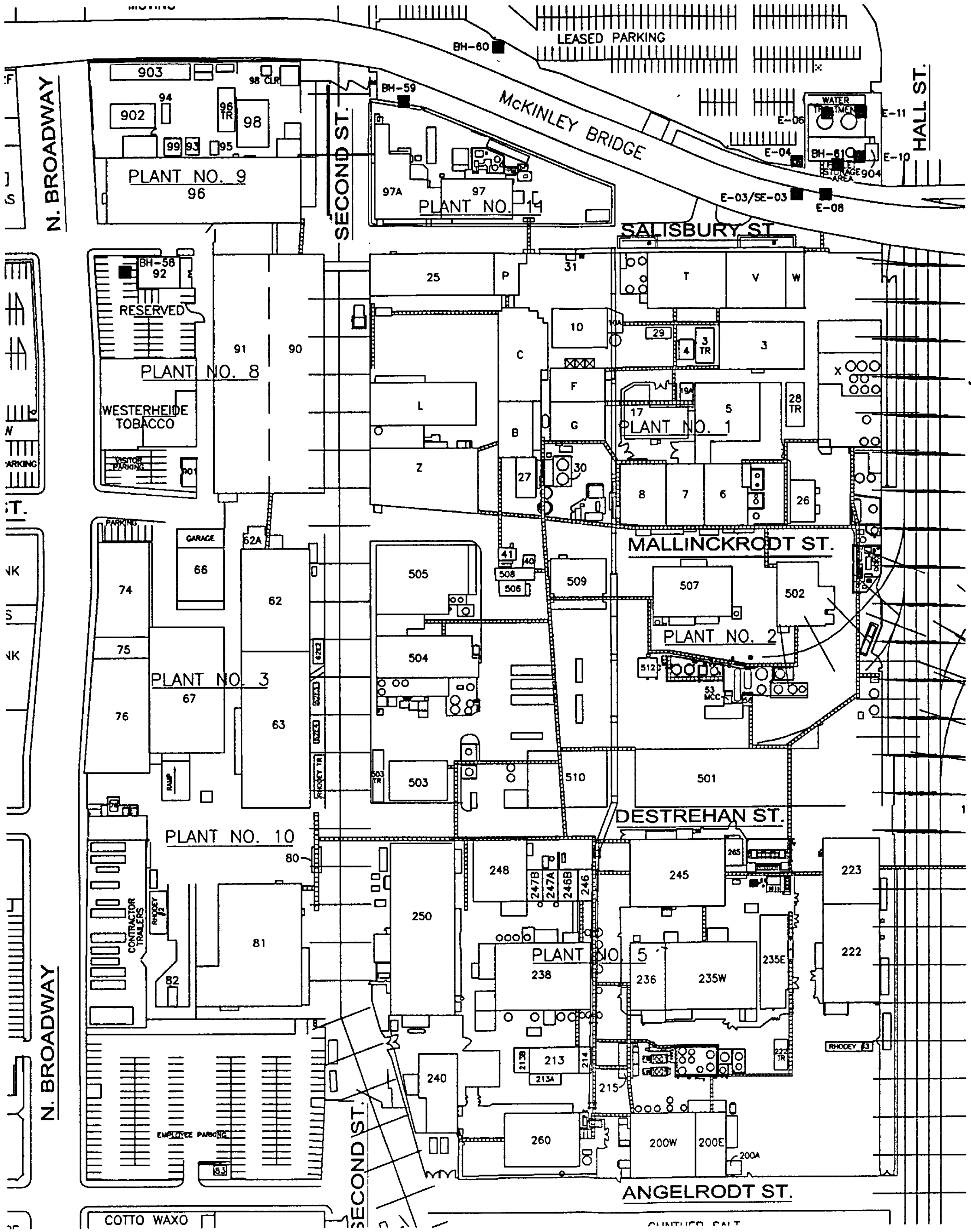
	Estimate	Standard Error	95% Confidence Interval Lower	95% Confidence Interval Upper
Mean	1.3259	0.0661	1.2026	1.4619
Standard Deviation	0.7476	0.4510	0.6643	0.8413
Median	1.2228	0.0682	1.0961	1.3641
First Quartile	0.7580	0.0564	0.6552	0.8769
Third Quartile	1.7825	0.0855	1.6226	1.9582
Interquartile Range	1.0245	0.0571	0.9185	1.1428

Table B-8, Estimates of Background Radioactivity Concentration in Cinder/Fill

Radionuclide	Number of Measurements	Mean Concentrationa (pCi/g)	Population Standard Deviationa (pCi/g)	95% confidence limits on the mean[a] (pCi/g)
U-238	130	4.4	2.3	4.1 to 4.9
U-235	n/a	0.2[b]	n/a	n/a
Th-230	130	3.4	2.2	1.8 to 2.6
Ra-226	130	2.5	2.3	1.9 to 2.7
Th-232	130	1.3	0.7	1.2 to 1.4
Ra-228	129	1.2	0.6	1.2 to 1.4
Th-228	129	1.3	0.8	1.2 to 1.5

[a] Derived from the Weibull probability distribution.

[b] The Mean Concentration of U-235 is 0.0455 times U-238; *i.e* . assumption of natural uranium.



KEY

■ -Location Identification

TITLE:

Figure B-1
Locations of Background Boreholes
Outside Plant 5

PROJECT: C-T Phase 2 DP	DATE: April 2003	DRAWING	REVISION
SCALE	ACAD FILE: BH58_E11.dwg		

omega

Figure B-2
Characterization Samples of Cinder/Fill

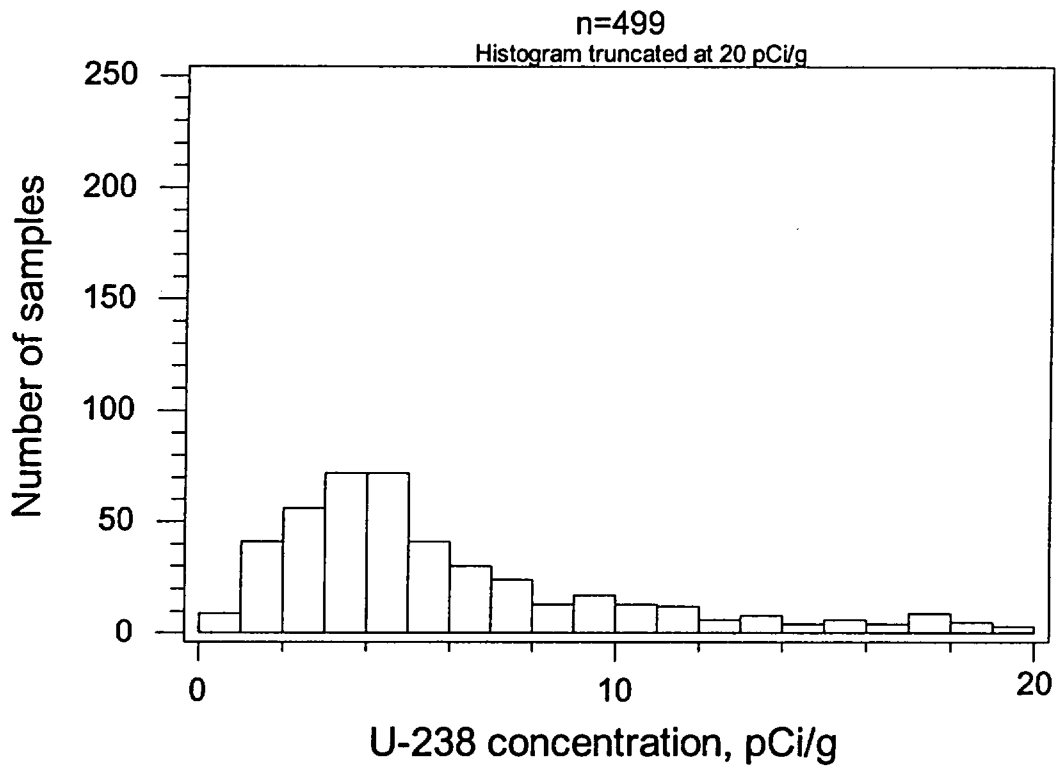


Figure B-3

Characterization Samples of Cinder/Fill

n=449

Histogram truncated at 20 pCi/g

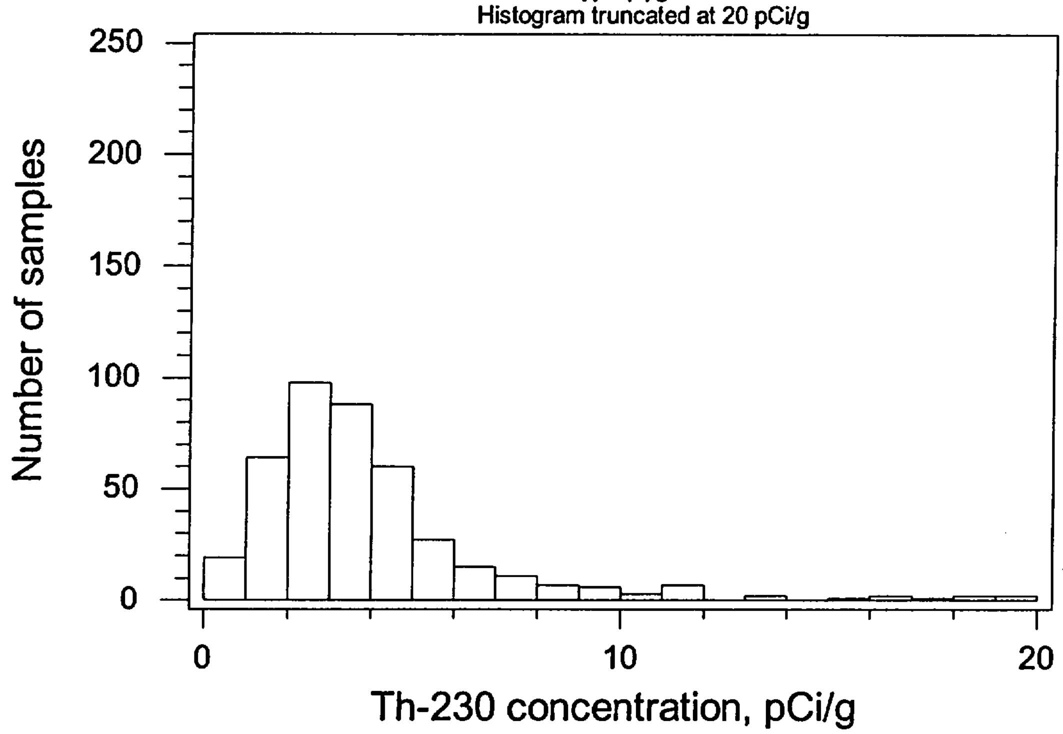


Figure B-4

Characterization Samples of Cinder/Fill

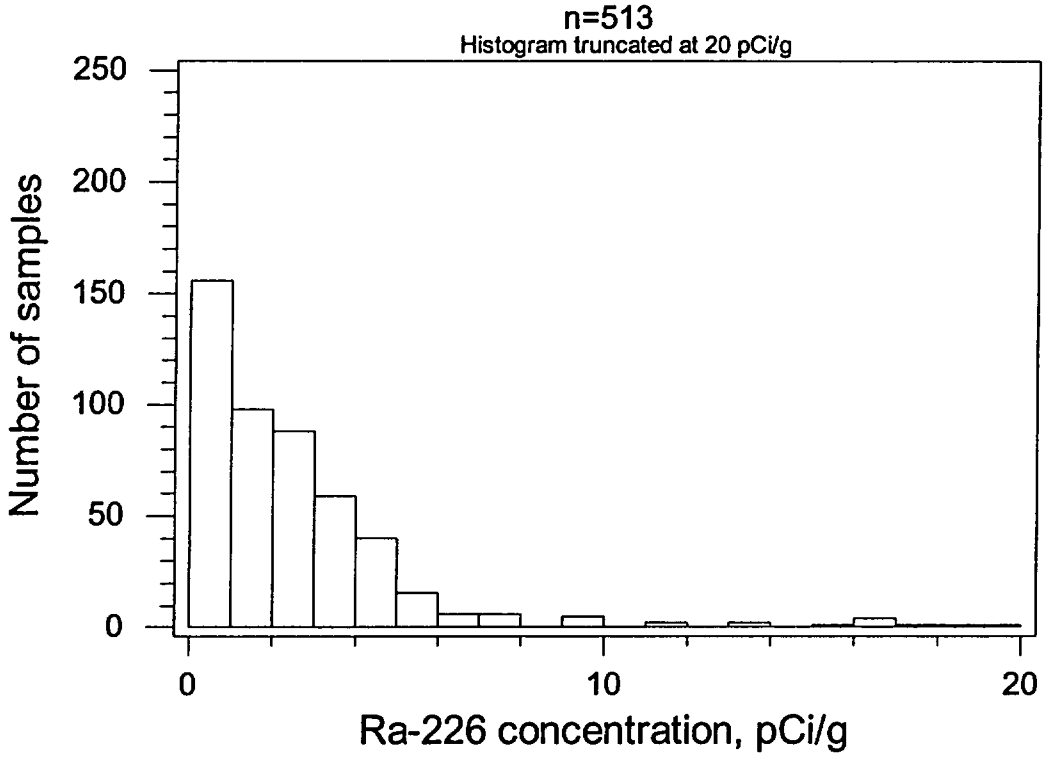


Figure B-5

Characterization Samples of Cinder/Fill

n=500

Histogram truncated at 20 pCi/g

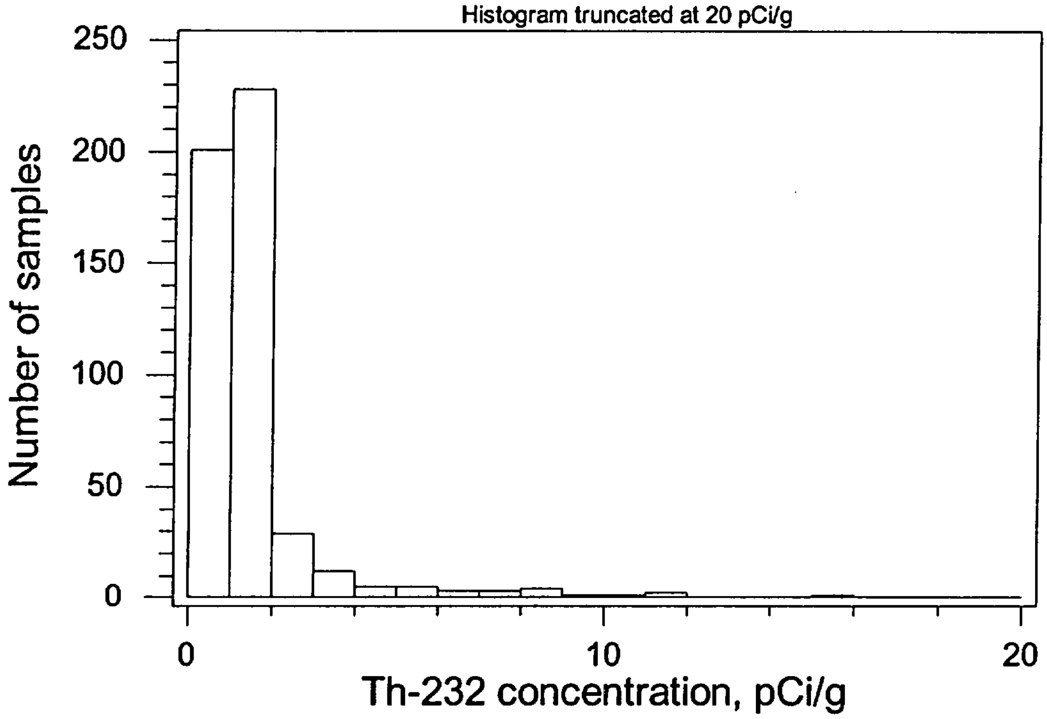


Figure B-6

Characterization Samples of Cinder/Fill

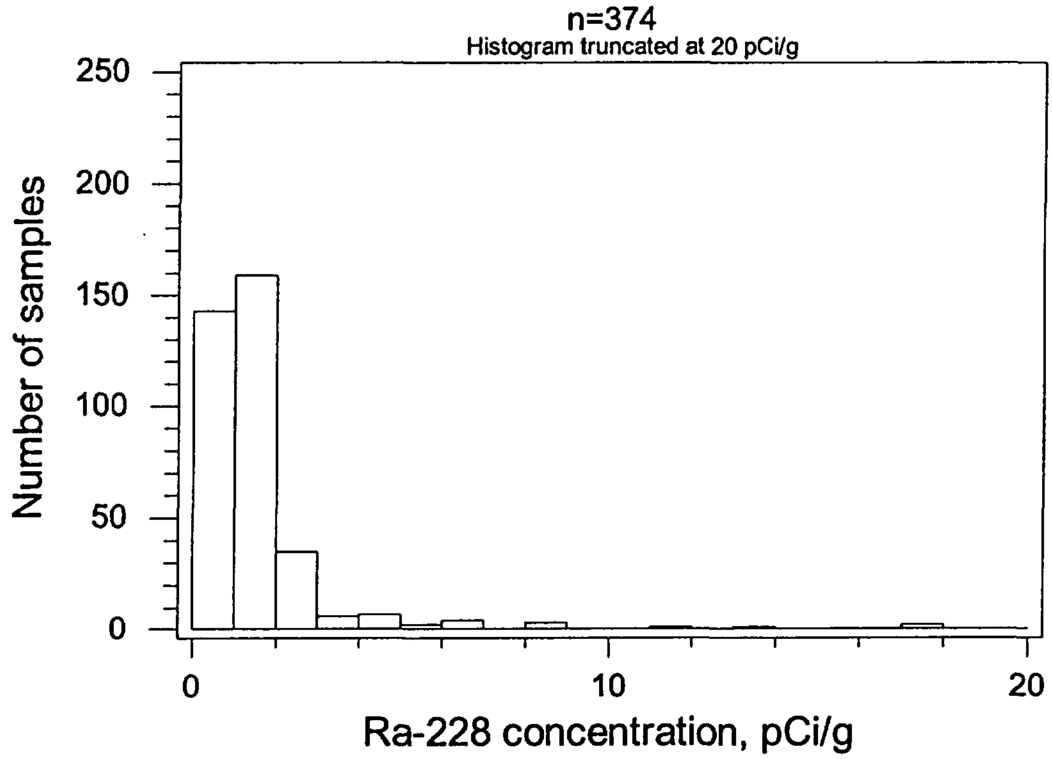
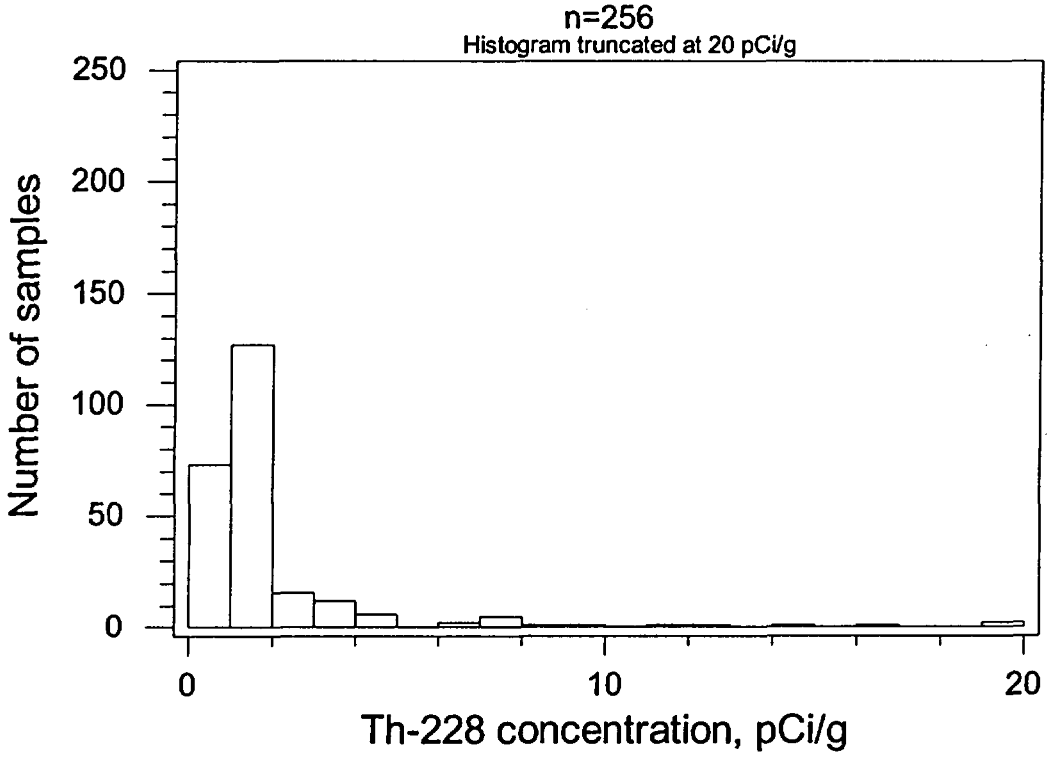
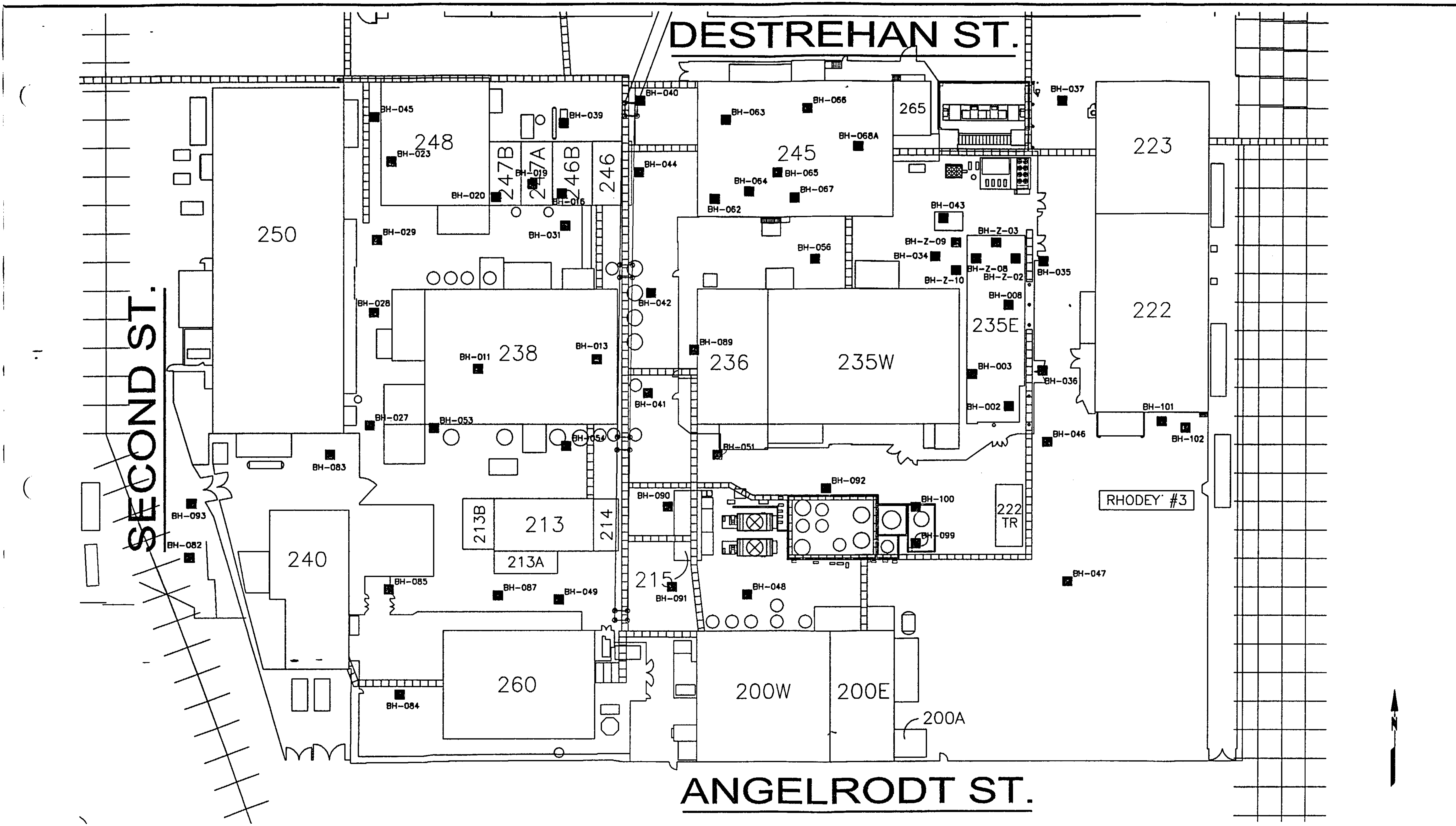


Figure B-7

Characterization Samples of Cinder/Fill

n=256





KEY

■ -Location Identification

TITLE:

Figure B-8
Locations of Boreholes Used in Evaluation of Background

PROJECT	C-T Phase 2 DP	DATE	April 2003	DRAWING	REVISION
SCALE		ACAD FILE	BHPlant5Bkg.dwg		△

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Figure B-9

Distribution Analysis: U-238 background concentration for cinder/fill

Weibull Distribution - Least Squares X on Y Estimates - 95% CI

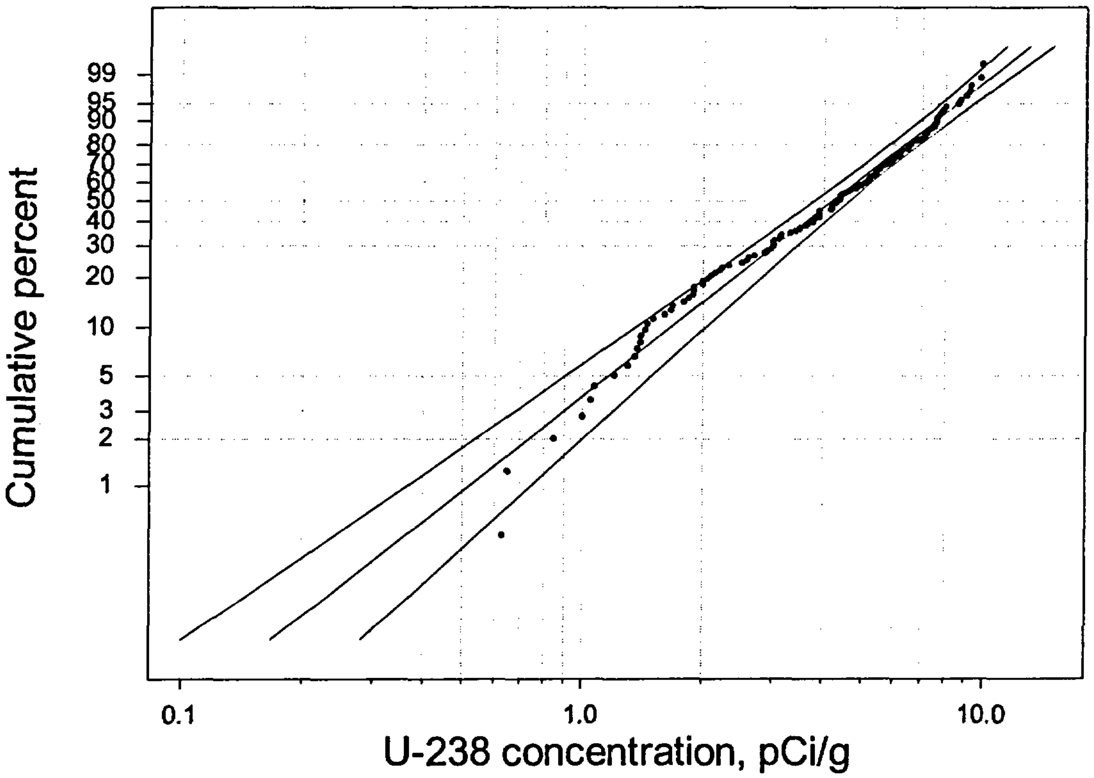


Figure B-10

Distribution Analysis: Th-230 background concentration for cinder/fill

Weibull Distribution - Least Squares X on Y Estimates - 95% CI

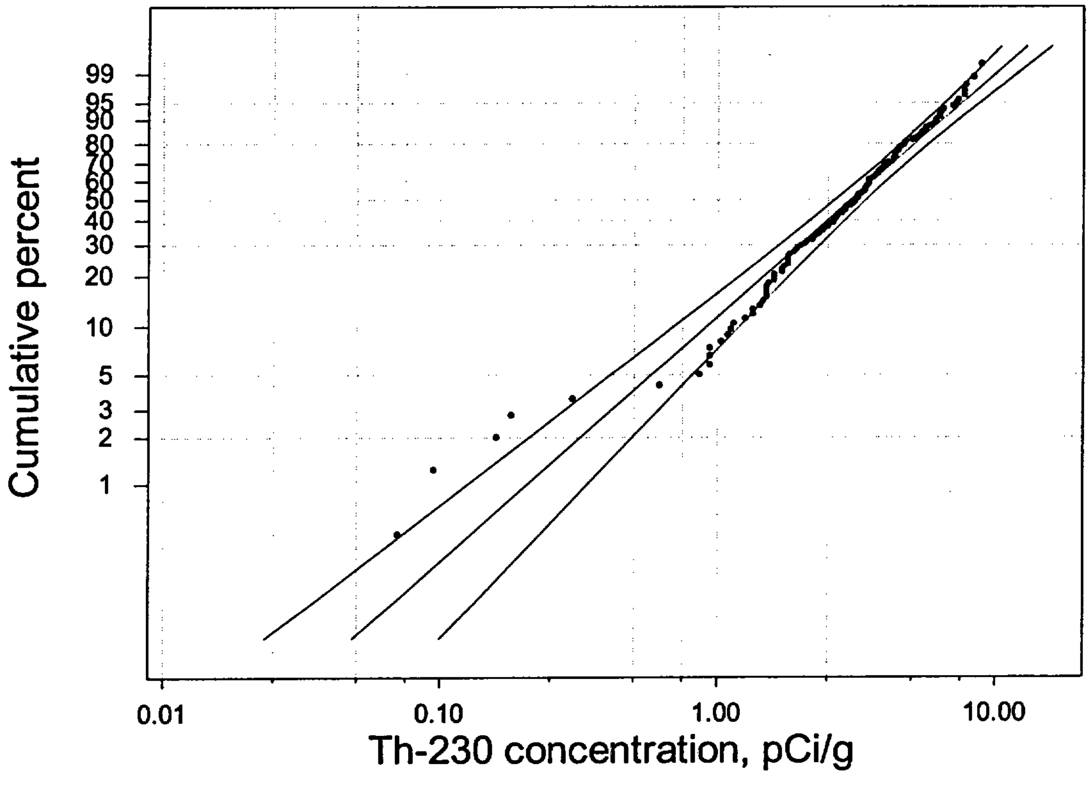


Figure B-11

Distribution Analysis: Ra-226 background concentration for cinder/fill

Weibull Distribution - Least Squares X on Y Estimates - 95% CI

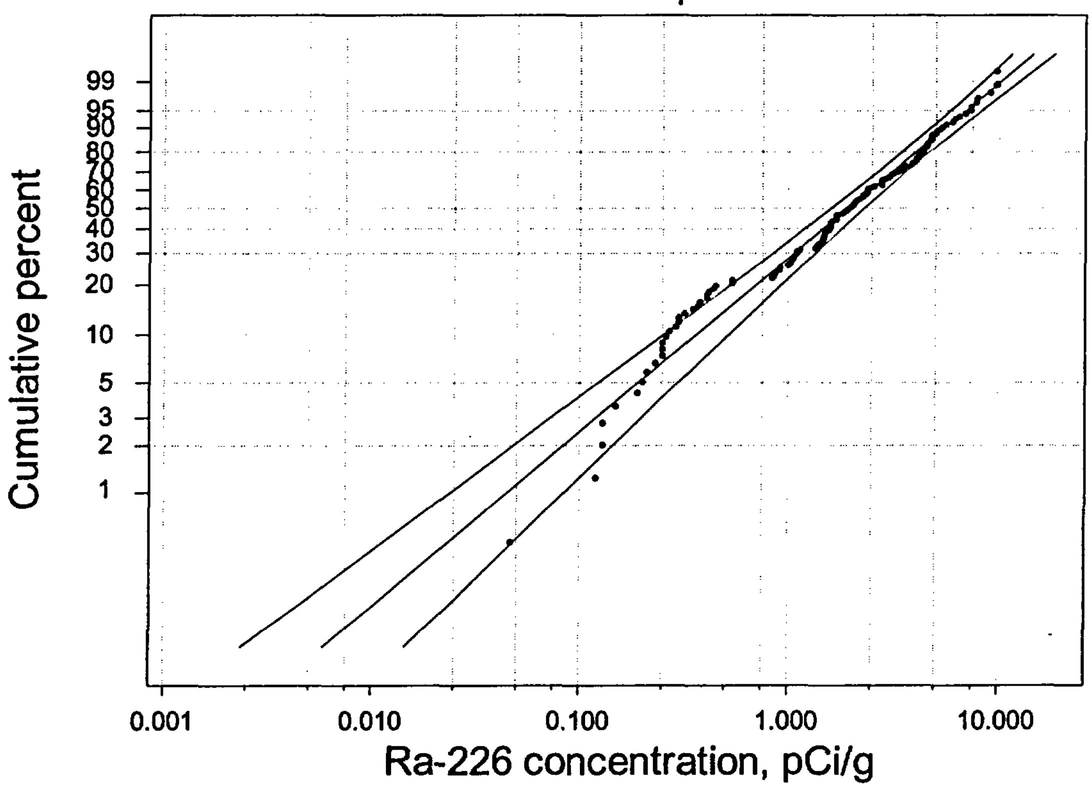


Figure B-12
Distribution Analysis: Th-232 background concentration for cinder/fill
Weibull Distribution - Least Squares X on Y Estimates - 95% CI

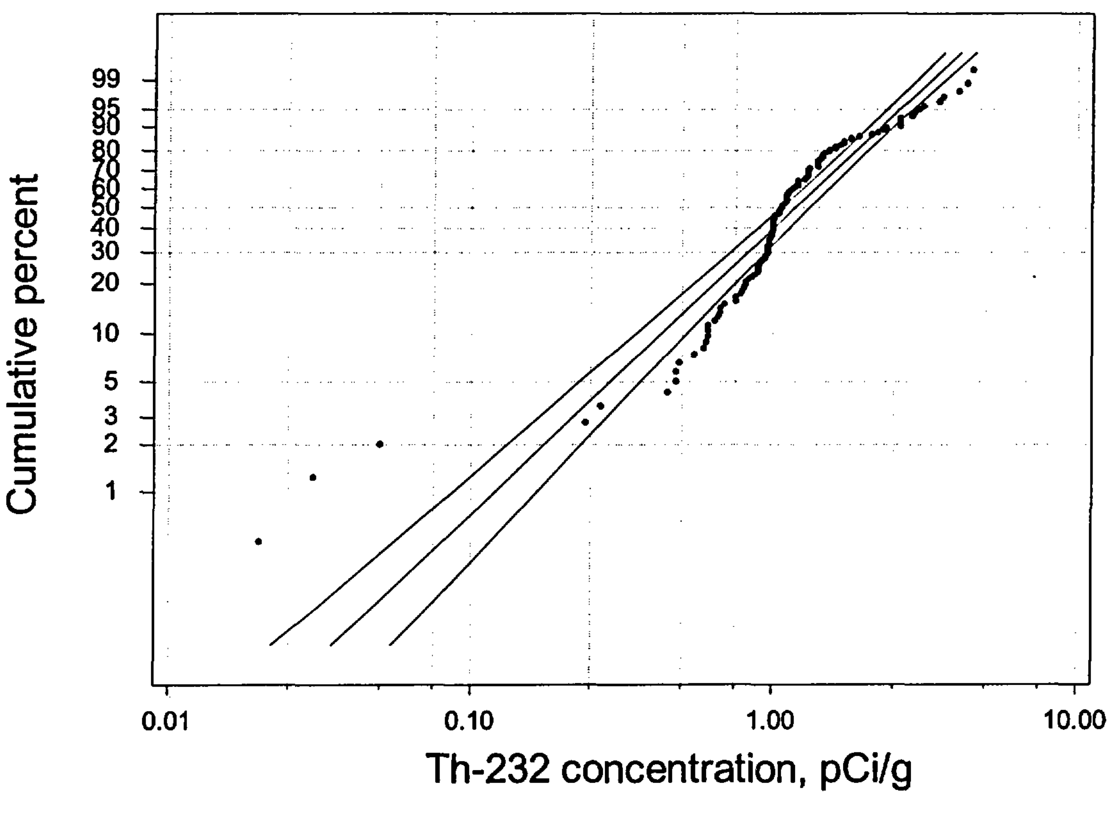


Figure B-13

Distribution Analysis: Ra-228 background concentration for cinder/fill

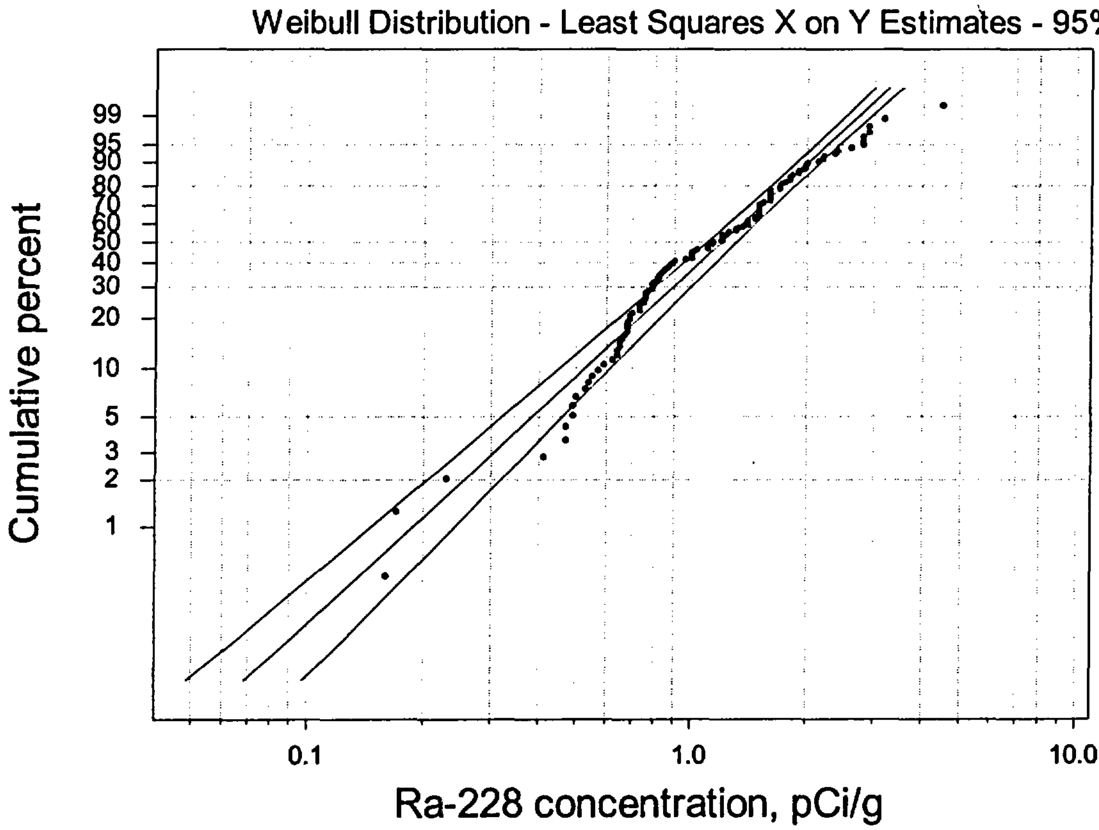
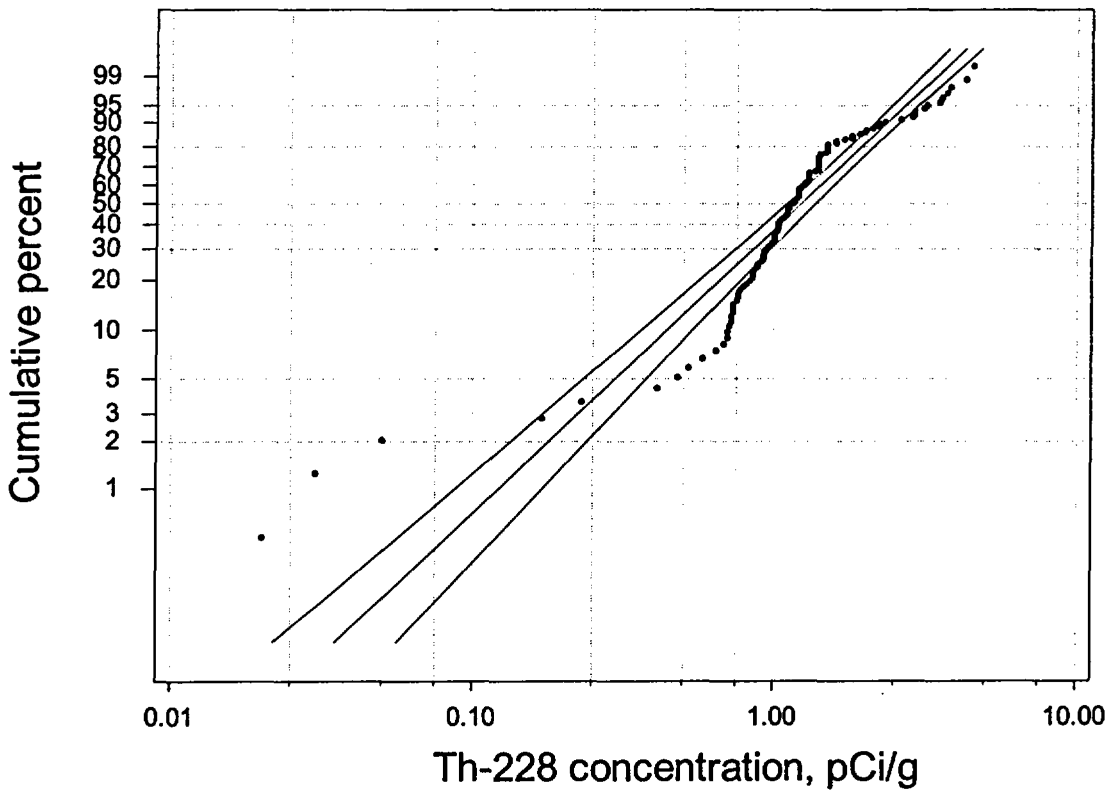


Figure B-14

Distribution Analysis: Th-228 background concentration for cinder/fill

Weibull Distribution - Least Squares X on Y Estimates - 95% CI



APPENDIX C

CALCULATION OF SUM-OF-FRACTIONS OF THE DCGL FOR C-T CHARACTERIZATION SOIL SAMPLES

Mallinckrodt Inc.

C-T Phase II Decomissioning Plan
May 15, 2003

NRC Docket: 40-06563
NRC License: STB-401

Appendix C

Calculation of Sum-of-fractions of the DCGL for C-T Characterization Soil Samples

A large number of subsurface soil (cinder/fill) samples were collected in the Mallinckrodt Columbium-Tantalum (C-T) Plant 5 area. They were analyzed for various combinations of the radionuclides in the natural uranium series and natural thorium series. Not all sample analyses generated a result for each of the key radionuclides described in Section 4 of this decommissioning plan. In some cases, the concentration of a key radionuclide in one or both series must be estimated in order to fully delineate soils contaminated in excess of the $DCGL_W$ in order to estimate the volume of soil subject to excavation.

C.1 PROBLEM

The Nuclear Regulatory Commission (NRC) provides a radiological dose criterion for release of a licensed facility for unrestricted use. A radionuclide-specific activity concentration may be derived for soil corresponding to the release criterion; *i.e.*, a derived concentration guideline level (DCGL). The DCGL is derived for each long-lived radionuclide considered a contaminant. In the case of a mixture of radionuclides, the release criterion is then evaluated against the unity rule. This is accomplished by determining the fraction of the concentration of each radionuclide in the mixture relative to its DCGL. The unity rule is that the sum of the fractions must be less than or equal to one to satisfy the release criterion.

Some subsurface soils in the C-T Plant 5 area are contaminated with uranium-series and thorium-series radionuclides. Three long-lived radionuclides from each series are being used to delineate the extent of contamination in the Plant 5 area; from the uranium-series: U-238, Th-230, and Ra-226; from the thorium-series: Th-232, Ra-228, and Th-228. Section 5 of this decommissioning plan describes a DCGL for each of these six key radionuclides. Then the extent of contamination in the Plant 5 subsurface soils is determined by application of the sum-of-fractions, *i.e.*, dividing each key radionuclide concentration by its respective $DCGL_W$ and summing the resulting fractions. The sum-of-fractions is an index in which unity represents a condition in which the concentration of a mixture of radionuclides equals the $DCGL_W$.

Some characterization samples of the Plant 5 subsurface soils do not include an analytical result for each of the six key radionuclides. In order to compute a sum-of-fractions and apply the unity rule to these characterization samples, a concentration must be estimated for one or more of the key radionuclides.

C.2 OBJECTIVE

The objective of this appendix is to explain development of a means to estimate the concentration of one or more key radionuclides in a characterization sample given the concentration of other key radionuclides in the sample. The scope of this objective is limited to the three key radionuclides from each series. The three from the uranium series are U-238, Th-230, and Ra-226; the three from the thorium series are Th-232, Ra-228, and Th-228.

C.3 SOLUTION

The relationship between key radionuclides may be examined to determine a function that would allow the concentration of one key radionuclide to provide for an estimate of the concentration of another key radionuclide. Specifically, the ratios of particular key radionuclide pairs were determined for the set of characterization samples of Plant 5. The resulting ratios were used to estimate the concentration of a key radionuclide in a sample. Once a concentration is available for each key radionuclide of a characterization sample, a calculation can be made of the sum-of-fractions, relative to the release criterion, for that characterization sample.

C.3.1 Description

The data set of characterization samples includes the following characteristics:

a) 221 = number of samples for which no estimate of any key radionuclide is needed,
b) 18 = number of samples for which U-238 may be estimated from Th-230,
c) 68 = number of samples for which Th-230 must be estimated from U-238,
d) 4 = number of samples for which Ra-226 must be estimated from U-238,
e) 16 = number of samples for which Th-232 must be estimated: 15 from Ra-228 and 1 from Th-228,
f) 142 = number of samples for which Ra-228 must be estimated: 141from Th-232 and 1 from Th-228, and
g) 261 = number of samples for which Th-228 must be estimated: 245 from Th-232 and 16 from Ra-228.

For each of these characteristics, the key radionuclide concentration pairs, for which both were measured, were gathered and a calculation was made of the respective ratios individually. In each case, the concentration pairs were limited to those pairs for which each key radionuclide concentration was greater than or equal to the upper bound background concentration (see Appendix B). As an example, the characterization sample data set included 46 samples with a U-238 concentration and a Th-230 concentration, each greater than or equal to 10 pCi/g. The data set of characterization samples includes the following characteristics:

h) 46 = number of samples for which U-238 and Th-230 are greater than or equal to 10 pCi/g (see items b and c, above),
i) 22 = number of samples for which U-238 and Ra-226 are greater than or equal to 10 pCi/g (see item d, above),
j) 15 = number of samples for which Th-232 and Ra-228 are greater than or equal to 5 pCi/g (see items e and f, above),
k) 19 = number of samples for which Th-232 and Th-228 are greater than or equal to 5 pCi/g (see item g, above), and

l) 13 = number of samples for which Ra-228 and Th-228 are greater than or equal to 5 pCi/g (see item h, above).

The selection of radionuclide concentration pairs was based solely on which radionuclide concentration was available as a surrogate for every case of another radionuclide concentration not available. For example, regarding item c), for each of the 68 samples missing a Th-230 concentration, a U-238 concentration was available. Then all 68 missing Th-230 concentrations were estimated from the U-238 concentration of the respective sample. In no case was an estimated concentration used to estimate another concentration.

The radionuclide concentration pairs described in items i) through m) are shown in Tables C-1 through C-5, respectively. The ratio of the individual pairs is also shown in the respective table.

In order to estimate the central tendency of the ratios among key radionuclides to represent them, a graphical analysis of the frequency of occurrence of the ratios for each of items i) through m) was done. Figures C-1 through C-5 show the probability plots for ratios developed in Tables C-1 through C-5 to be lognormally distributed. Tables C-1 through C-5 also include some statistical properties of the concentration ratios.

C.3.2 <u>Results</u>

The geometric mean of each distribution shown in Figures C-1 through C-5 is presented as the best estimate of the ratio of the respective key radionuclides. The mean ratios are summarized as:

- Th-230/U-238 = 1.1 (apply to items b and c, above),
- Ra-226/U-238 = 2.8 (apply to item d, above),
- Ra-228/Th-232 = 1.6 (apply to items e and f, above),
- Th-228/Th-232 = 1.3 (apply to items g, above), and
- Th-228/Ra-228 = 0.8 (apply to items h, above).

Fifteen years since cessation of C-T processing is enough to allow thorium series nuclides to grow or decay within about 0.20 of radioactive equilibrium. Considering uncertainty in alpha spectrometry of separate radioelements at low concentration, the thorium series might rationally be assumed to be in radioactive equilibrium in Plant 5 soil samples.

C.4 CONCLUSION

In samples in which the concentration of a key radionuclide is not available, it was estimated as the product of a concentration of another key radionuclide in that sample and the relevant mean ratio. For example, in the case of a sample without an analytical result for Th-230, the Th-230 concentration will be estimated by multiplying the U-238 concentration in that sample by 1.1. Also, in the case of a sample without an analytical result for U-238, the U-238 concentration will be estimated by multiplying the Th-230 concentration by 1/1.1 (*i.e.*, 0.91). This will allow a best estimate of the sum-of-fractions value to be calculated for each characterization sample.

The results of this appendix were applied to interpretation of characterization data for the purpose of estimating the volume of subsurface soil with radionuclide concentrations that exceed the $DCGL_w$ and may be subject to excavation.

Table C-1. Distribution Analysis: Th-230 / U-238 Concentration Ratio of Subsurface Soil

Count 46

Estimation Method: Least Squares (X on Y)
Distribution: Lognormal base e

Parameter Estimates

Parameter	Estimate	Standard Error	95.00% Normal CL Lower	95.00% Normal CL Upper
Location	0.0613	0.1203	-0.1745	0.2972
Scale	0.8162	0.0861	0.6638	1.0035

Goodness-of-Fit
Correlation Coefficient = 0.9768 (Pearson correlation coefficient, r)

Characteristics of Distribution

	Estimate	Standard Error	95.00% Normal CL Lower	95.00% Normal CL Upper
Mean	1.4835	0.2067	1.1290	1.9493
Standard Deviation	1.4434	0.3552	0.8911	2.3381
Median	1.0633	0.1279	0.8399	1.3461
First Quartile	0.6131	0.0819	0.4719	0.7967
Third Quartile	1.8438	0.2463	1.4190	2.3957
Interquartile Range	1.2307	0.2056	0.8870	1.7074

	Sample Depth (ft)		Radionuclide Concentration		
Location ID	Top	Bottom	U-238 (pCi/g)	Th-230 (pCi/g)	Th-230 / U-238
BH-010	0	2.5	21.5	262	12.1860
BH-010	0	4.5	20	18	0.9000
BH-011	0	9.5	30.4	24.8	0.8158
BH-012	0	5.5	10.4	24.3	2.3365
BH-012	0	9.5	10	16.3	1.6300
BH-014	0	4.5	28.7	20.2	0.7038
BH-015	0	5.5	16.3	98.8	6.0613
BH-015	0	9.5	71.7	261.9	3.6527
BH-021	0	2.5	16.6	10.4	0.6265
BH-022	0	5.5	34.8	54.3	1.5603
BH-022	0	9.5	13	17.3	1.3308
BH-026	0	4.5	17.8	24.9	1.3989
BH-029	0	2.5	53.4	16.9	0.3165

(continued next page)

Table C-1 (continued)

Location ID	Sample Depth (ft) Top	Bottom	Radionuclide Concentration U-238 (pCi/g)	Th-230 (pCi/g)	Th-230 / U-238
BH-038	0	1	56.9	138.6	2.4359
BH-038	0	6.5	10.3	22.4	2.1748
BH-039	0	1.5	29.7	23.3	0.7845
BH-041	0	3.5	17.5	61.5	3.5143
BH-042	0	1	11.1	32	2.8829
BH-052	0	4	28.5	29.4	1.0316
BH-054	0	1.5	30.8	25.2	0.8182
BH-066	0	1.5	66.01	77.9	1.1801
BH-083	0.5	1.5	23.9	24.4	1.0209
BH-087	1	1.5	31.6	13.3	0.4209
BH-088	3	4.5	18.8	11.7	0.6223
BH-091	12	13.5	36.5	28	0.7671
BH-092	12	13.5	18	10.8	0.6000
BH-112	0	2	26.54	11.5	0.4333
BH-114	0	2	19.17	10.03	0.5232
BH-114	2	4	36.74	30.43	0.8283
BH-Z-22	0	3	11.48	11.14	0.9704
JA-01	0	5	216.06	43.72	0.2024
JA-02	0	1	89.96	60.72	0.6750
JA-03	0	1	28.39	41.14	1.4491
JA-04	0	1	33.46	79.74	2.3831
JA-05	0	1	26.87	50.32	1.8727
JA-06	0	1	36.27	53.73	1.4814
JA-07	0	1	51.91	60.64	1.1682
JA-08	0	1	33.08	32.39	0.9791
JA-09	0	1	69.76	50.47	0.7235
JA-10	0	1	70.7	81.27	1.1495
JA-11	0	1	172.48	123.1	0.7137
JA-12	0	1	166.5	19.3	0.1159
JA-17A	0	3	14.5	19.6	1.3517

Table C-2. Distribution Analysis: Ra-226 / U-238 Concentration Ratio of Subsurface Soil

Count 22

Estimation Method: Least Squares (X on Y)
Distribution: Lognormal base e

Parameter Estimates

Parameter	Estimate	Standard Error	95.00% Normal CL Lower	95.00% Normal CL Upper
Location	1.0135	0.3429	0.3414	1.6855
Scale	1.6082	0.2620	1.1687	2.2131

Goodness-of-Fit
Correlation Coefficient = 0.9922 (Pearson correlation coefficient, r)

Characteristics of Distribution

	Estimate	Standard Error	95.00% Normal CL Lower	95.00% Normal CL Upper
Mean	10.0405	5.4538	3.4626	29.1145
Standard Deviation	35.1865	33.1290	5.5584	222.7429
Median	2.7551	0.9446	1.4070	5.3950
First Quartile	0.9312	0.3592	0.4372	1.9832
Third Quartile	8.1513	3.1441	3.8274	17.3601
Interquartile Range	7.2201	2.9502	3.2414	16.0825

	Sample Depth (ft)		Radionuclide Concentration		
Location ID	Top	Bottom	U-238 (pCi/g)	Ra-226 (pCi/g)	Ra-226 / U-238
BH-010	0	2.5	21.5	239.3	11.1302
BH-010	0	4.5	20	31.8	1.5900
BH-011	0	9.5	30.4	40.4	1.3289
BH-012	0	5.5	10.4	250.2	24.0577
BH-012	0	9.5	10	208.7	20.8700
BH-014	0	4.5	28.7	16.4	0.5714
BH-015	0	5.5	16.3	327.4	20.0859
BH-015	0	9.5	71.7	744.6	10.3849
BH-015	0	11.5	210	667	3.1762
BH-026	0	4.5	17.8	21.9	1.2303
BH-038	0	1	56.9	16.7	0.2935
BH-039	0	1.5	29.7	21.1	0.7104
BH-043	0	2.5	10.2	24.8	2.4314
BH-052	0	4	28.5	1511	53.0175
BH-054	0	1.5	30.8	192	6.2338
BH-055	0	15	18.7	60.7	3.2460
BH-090	12	13.5	18	11.1	0.6167
BH-091	12	13.5	36.5	24.3	0.6658
JA-02	0	1	89.96	13.44	0.1494
JA-03	0	1	28.39	28.08	0.9891
JA-04	0	1	33.46	132.8	3.9689
JA-06	0	1	36.27	242.7	6.6915

Table C-3. Distribution Analysis: Ra-228 / Th-232 Concentration Ratio of Subsurface Soil

Count 15

Estimation Method: Least Squares (X on Y)
Distribution: Lognormal base e

Parameter Estimates

Parameter	Estimate	Standard Error	95.00% Normal CL Lower	95.00% Normal CL Upper
Location	0.5006	0.1732	0.1612	0.8400
Scale	0.6707	0.1348	0.4523	0.9946

Goodness-of-Fit
Correlation Coefficient = 0.9817 (Pearson correlation coefficient, r)

Characteristics of Distribution

	Estimate	Standard Error	95.00% Normal CL Lower	95.00% Normal CL Upper
Mean	2.0658	0.4036	1.4087	3.0296
Standard Deviation	1.5570	0.5941	0.7370	3.2893
Median	1.6498	0.2857	1.1749	2.3164
First Quartile	1.0494	0.2053	0.7153	1.5397
Third Quartile	2.5935	0.5073	1.7676	3.8051
Interquartile Range	1.5440	0.4257	0.8994	2.6506

	Sample Depth (ft)		Radionuclide Concentration		
Location ID	Top	Bottom	Th-232 (pCi/g)	Ra-228 (pCi/g)	Ra-228 / Th-232
BH-009	0	2.5	5.5	6.3	1.1455
BH-010	0	2.5	51.1	81.5	1.5949
BH-010A	0	6.5	10.8	28.2	2.6111
BH-011	0	3.5	25.9	47.4	1.8301
BH-011	0	9.5	15.3	33.3	2.1765
BH-012	0	5.5	33.8	40.3	1.1923
BH-012	0	9.5	8.3	23	2.7711
BH-012	0	11.5	5.95	5.99	1.0067
BH-014	0	4.5	11.9	8.5	0.7143
BH-015	0	5.5	11.1	78	7.0270
BH-015	0	9.5	48.2	193.3	4.0104
BH-020	0	9.5	9.4	11.3	1.2021
BH-031	0	9	6.86	6.97	1.0160
BH-052	0	4	7	13.3	1.9000
BH-086	6	7.5	27.5	17	0.6182

Table C-4. Distribution Analysis: Th-228 / Th-232 Concentration Ratio of Subsurface Soil

Count 19

Estimation Method: Least Squares (X on Y)
Distribution: Lognormal base e

Parameter Estimates

Parameter	Estimate	Standard Error	95.00% Normal CL Lower	95.00% Normal CL Upper
Location	0.22483	0.07084	0.08599	0.36367
Scale	0.30878	0.04775	0.22805	0.41809

Goodness-of-Fit
Correlation Coefficient = 0.9065 (Pearson correlation coefficient, r)

Characteristics of Distribution

	Estimate	Standard Error	95.00% Normal CL Lower	95.00% Normal CL Upper
Mean	1.3132	0.0950	1.1396	1.5133
Standard Deviation	0.4154	0.0791	0.2859	0.6034
Median	1.2521	0.0887	1.0898	1.4386
First Quartile	1.0167	0.0791	0.8729	1.1842
Third Quartile	1.5420	0.1200	1.3239	1.7961
Interquartile Range	0.5253	0.0904	0.3749	0.7361

Location ID	Sample Depth (ft) Top	Sample Depth (ft) Bottom	Radionuclide Concentration Th-232 (pCi/g)	Th-228 (pCi/g)	Th-228 / Th-232
BH-009	0	2.5	5.5	6.4	1.1636
BH-010	0	2.5	51.1	64.6	1.2642
BH-010A	0	6.5	10.8	14.2	1.3148
BH-011	0	3.5	25.9	28.1	1.0849
BH-011	0	9.5	15.3	19.3	1.2614
BH-012	0	5.5	33.8	38.3	1.1331
BH-012	0	9.5	8.3	12.5	1.5060
BH-014	0	4.5	11.9	16.9	1.4202
BH-015	0	5.5	11.1	32	2.8829
BH-015	0	9.5	48.2	60.9	1.2635
BH-020	0	9.5	9.4	8.3	0.8830
BH-052	0	4	7	19	2.7143
BH-086	3	4.5	8.6	7.9	0.9186
BH-086	6	7.5	27.5	29.2	1.0618
BH-088	6	7.5	7.4	6.7	0.9054
BH-091	12	13.5	7.7	7.3	0.9481
BH-099	0	3	6.49	7.06	1.0878
BH-100	3	6	6.12	9.04	1.4771
BH-101	0	3	8.15	7.75	0.9509

Table C-5. Distribution Analysis: Th-228 / Ra-228 Concentration Ratio of Subsurface Soil

Count 13

Estimation Method: Least Squares (X on Y)
Distribution: Lognormal base e

Parameter Estimates

Parameter	Estimate	Standard Error	95.00% Normal CL Lower	95.00% Normal CL Upper
Location	-0.2616	0.1601	-0.5754	0.0521
Scale	0.5772	0.1282	0.3735	0.8920

Goodness-of-Fit
Correlation Coefficient = 0.9883 (Pearson correlation coefficient, r)

Characteristics of Distribution

	Estimate	Standard Error	95.00% Normal CL Lower	95.00% Normal CL Upper
Mean	0.9093	0.1604	0.6436	1.2848
Standard Deviation	0.5718	0.2123	0.2761	1.1840
Median	0.7698	0.1232	0.5625	1.0535
First Quartile	0.5215	0.0949	0.3651	0.7450
Third Quartile	1.1362	0.2067	0.7954	1.6230
Interquartile Range	0.6146	0.1738	0.3531	1.0700

	Sample Depth (ft)		Radionuclide Concentration		
Location ID	Top	Bottom	Ra-228 (pCi/g)	Th-228 (pCi/g)	Th-228 / Ra-228
BH-009	0	2.5	6.3	6.4	1.0159
BH-010	0	2.5	81.5	64.6	0.7926
BH-010A	0	6.5	28.2	14.2	0.5035
BH-011	0	3.5	47.4	28.1	0.5928
BH-011	0	9.5	33.3	19.3	0.5796
BH-012	0	5.5	40.3	38.3	0.9504
BH-012	0	9.5	23	12.5	0.5435
BH-014	0	4.5	8.5	16.9	1.9882
BH-015	0	5.5	78	32	0.4103
BH-015	0	9.5	193.3	60.9	0.3151
BH-020	0	9.5	11.3	8.3	0.7345
BH-052	0	4	13.3	19	1.4286
BH-086	6	7.5	17	29.2	1.7176

Figure C-1

Distribution Analysis: Th-230 / U-238 concentration ratio of cinder/fill

Lognormal base e Distribution - Least Squares X on Y Estimates - 95.0% CI

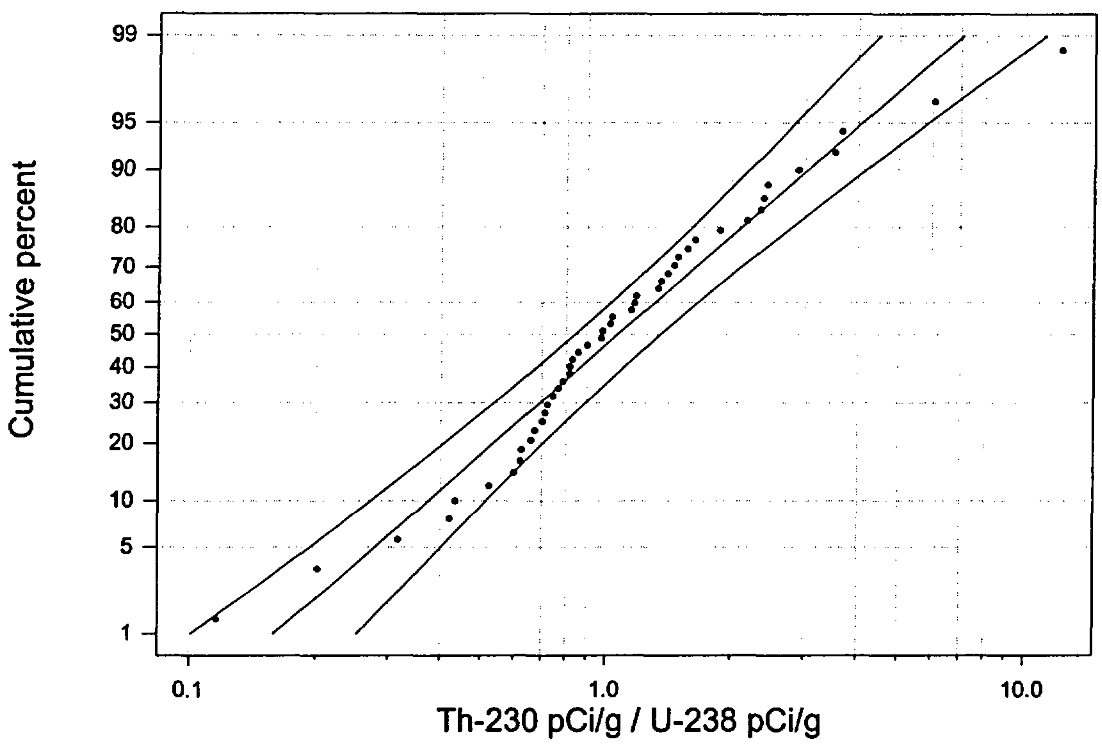


Figure C-2

Distribution Analysis: Ra-226 / U-238 concentration ratio of cinder/fill

Lognormal base e Distribution - Least Squares X on Y Estimates - 95.0% CI

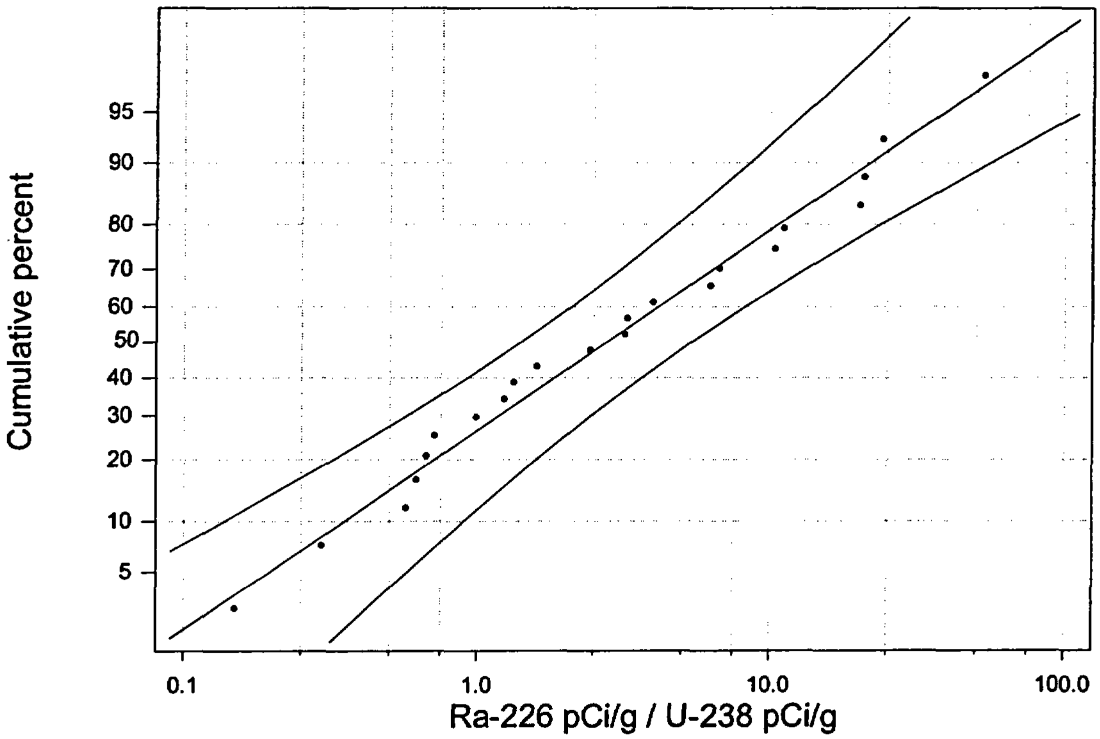


Figure C-3

Distribution Analysis: Ra-228 / Th-232 concentration ratio of cinder/fill

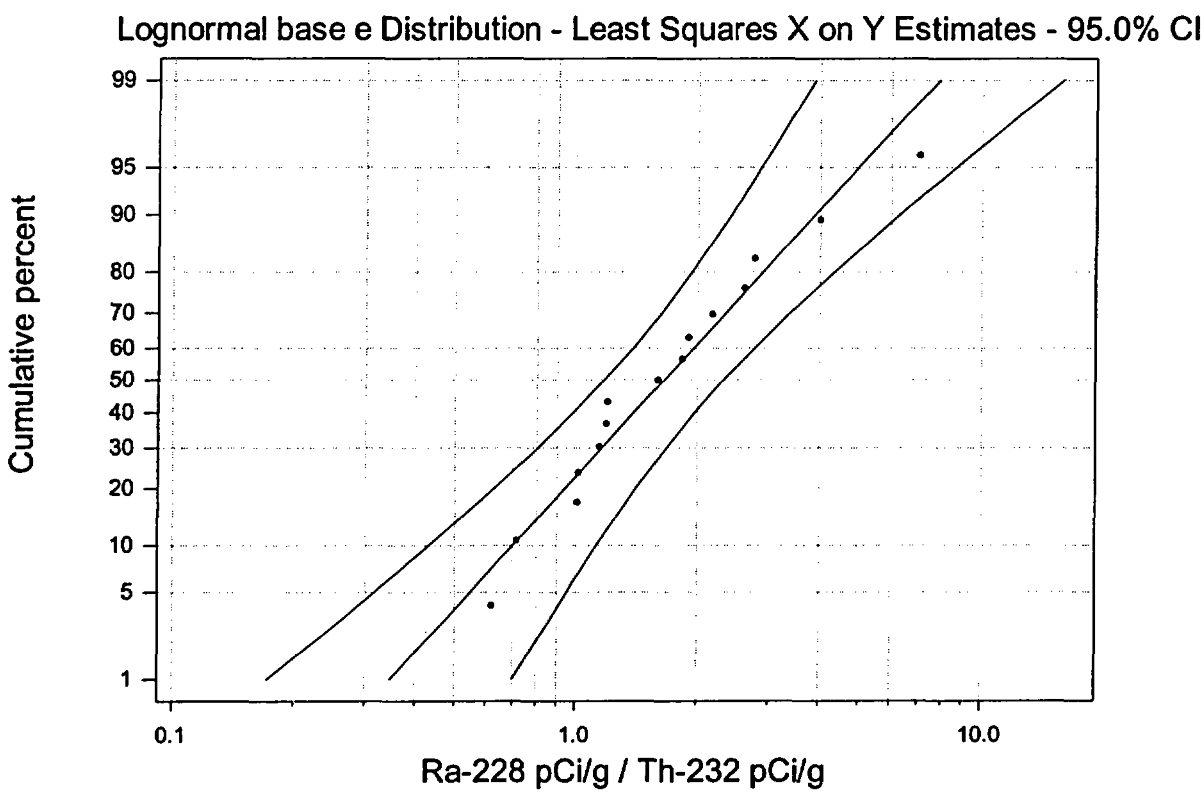


Figure C-4

Distribution Analysis: Th-228 / Th-232 concentration ratio of cinder/fill

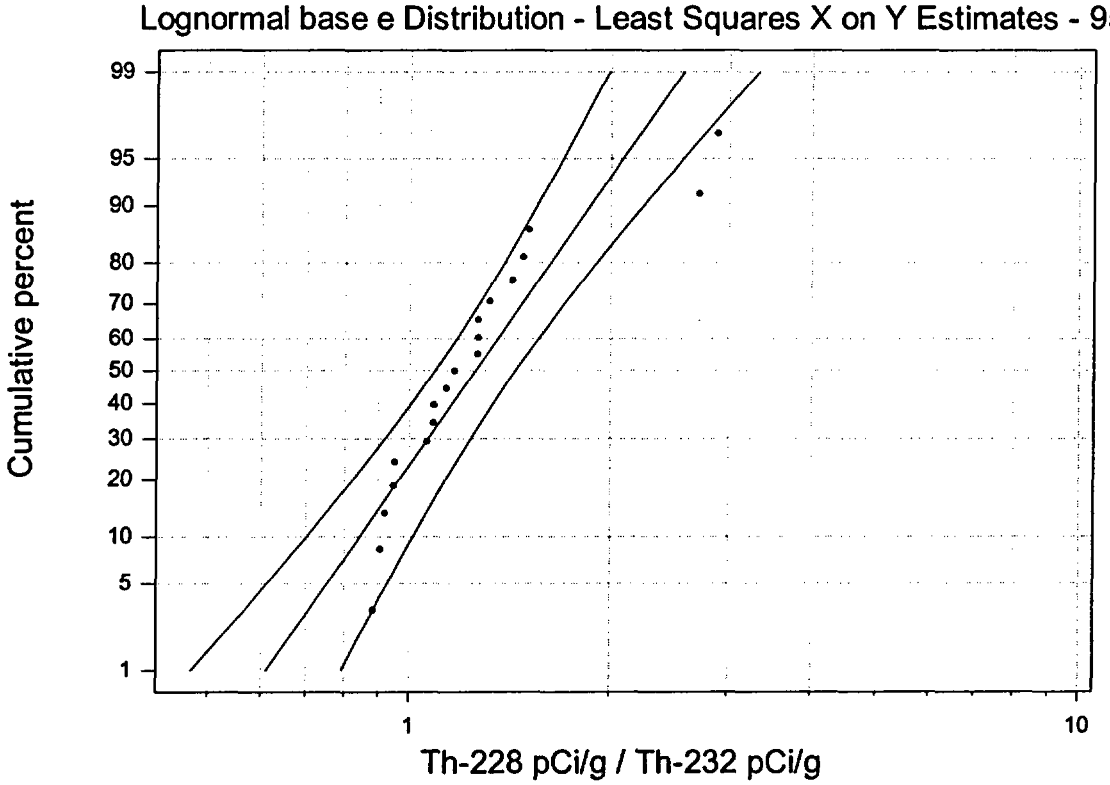
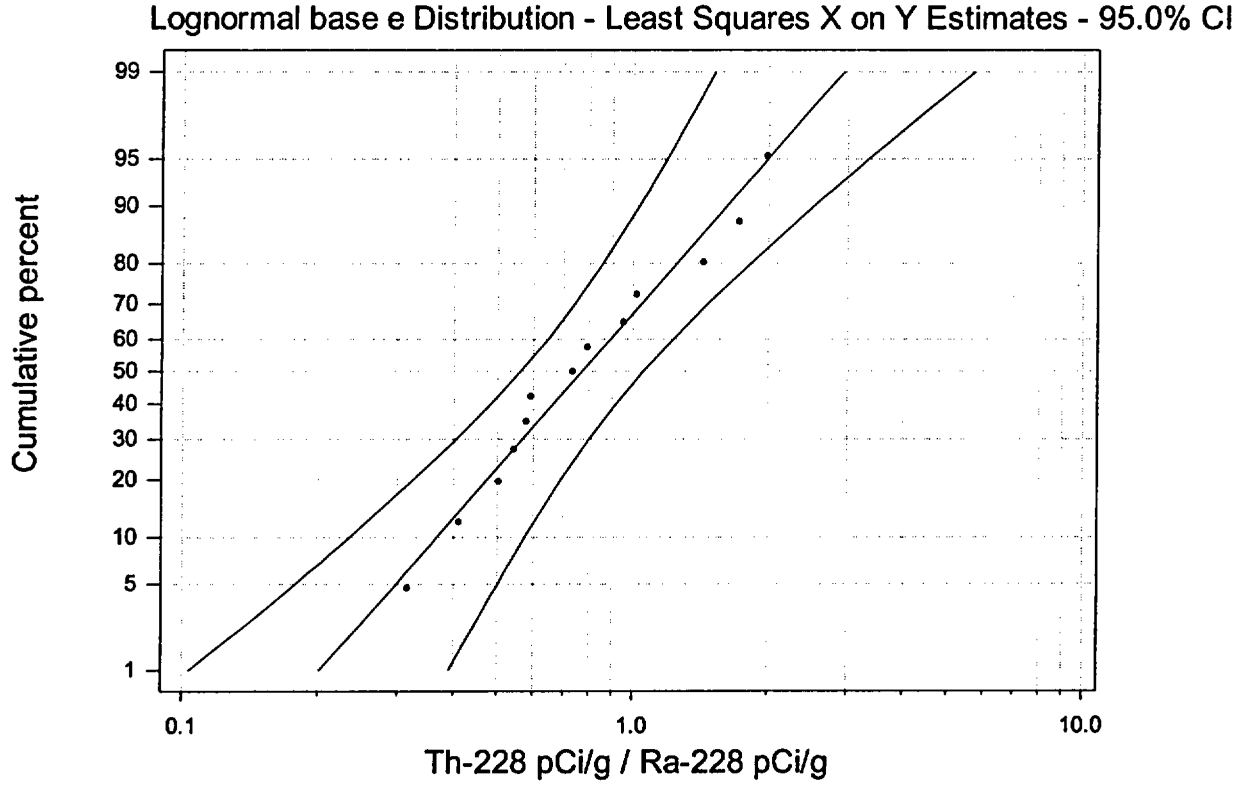


Figure C-5

Distribution Analysis: Th-228 / Ra-228 concentration ratio of cinder/fill



APPENDIX D

RECORD OF RESRAD COMPUTATIONS FOR DCGL DERIVATION

Mallinckrodt Inc.

C-T Phase II Decomissioning Plan
May 15, 2003

NRC Docket: 40-06563
NRC License: STB-401

Basis of U Series and Actinium Series in Table 5-1

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

Nuclide (i)	t= 0.000E+00	1.000E+00	3.000E+00	1.000E+01	3.000E+01	1.000E+02	3.000E+02	1.000E+03
Ac-227	8.187E+01	8.453E+01	9.012E+01	1.127E+02	2.138E+02	2.008E+03	1.208E+06	*7.230E+13
Pa-231	2.176E+02	2.010E+02	1.754E+02	1.266E+02	8.337E+01	6.340E+01	6.619E+01	8.587E+01
Pb-210	4.153E+02	4.285E+02	4.560E+02	5.670E+02	1.057E+03	9.348E+03	4.736E+06	*7.631E+13
Ra-226	3.047E+01	3.042E+01	3.032E+01	3.003E+01	2.958E+01	2.983E+01	3.267E+01	4.543E+01
Th-230	3.663E+03	3.481E+03	3.167E+03	2.403E+03	1.415E+03	5.783E+02	2.228E+02	8.192E+01
U-234	7.830E+03	7.838E+03	7.855E+03	7.912E+03	8.074E+03	8.640E+03	1.012E+04	1.145E+04
U-235	4.296E+02	4.300E+02	4.309E+02	4.339E+02	4.424E+02	4.716E+02	5.631E+02	1.015E+03
U-238	1.944E+03	1.946E+03	1.950E+03	1.965E+03	2.007E+03	2.161E+03	2.668E+03	5.586E+03

*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	4.550E-02	0.000E+00	3.054E-01	8.187E+01	3.054E-01	8.187E+01
Pa-231	4.550E-02	130.8 ± 0.3	3.976E-01	6.288E+01	1.149E-01	2.176E+02
Pb-210	1.000E+00	0.000E+00	6.019E-02	4.153E+02	6.019E-02	4.153E+02
Ra-226	1.000E+00	49.65 ± 0.10	8.480E-01	2.948E+01	8.204E-01	3.047E+01
Th-230	1.000E+00	1.000E+03	3.052E-01	8.192E+01	6.826E-03	3.663E+03
U-234	1.000E+00	0.000E+00	3.193E-03	7.830E+03	3.193E-03	7.830E+03
U-235	4.550E-02	0.000E+00	5.819E-02	4.296E+02	5.819E-02	4.296E+02
U-238	1.000E+00	0.000E+00	1.286E-02	1.944E+03	1.286E-02	1.944E+03

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-Nuclide	Ground		Inhalation		Radon		Plant		Meat		Milk		Soil	
	mrem/yr	fract.	mrem/yr	fract.	mrem/yr	fract.	mrem/yr	fract.	mrem/yr	fract.	mrem/yr	fract.	mrem/yr	fr
Ac-227	6.328E-03	0.0068	1.784E-03	0.0019	0.000E+00	0.0000	0.000E+00	0.0000	0.000E+00	0.0000	0.000E+00	0.0000	5.345E-03	0.
Pa-231	9.418E-04	0.0010	4.435E-04	0.0005	0.000E+00	0.0000	0.000E+00	0.0000	0.000E+00	0.0000	0.000E+00	0.0000	4.275E-03	0.
Pb-210	4.386E-04	0.0005	1.356E-04	0.0001	0.000E+00	0.0000	0.000E+00	0.0000	0.000E+00	0.0000	0.000E+00	0.0000	5.778E-02	0.
Ra-226	8.079E-01	0.8733	5.908E-05	0.0001	0.000E+00	0.0000	0.000E+00	0.0000	0.000E+00	0.0000	0.000E+00	0.0000	1.382E-02	0.
Th-230	6.143E-04	0.0007	1.996E-03	0.0022	0.000E+00	0.0000	0.000E+00	0.0000	0.000E+00	0.0000	0.000E+00	0.0000	4.571E-03	0.
U-234	2.983E-05	0.0000	8.069E-04	0.0009	0.000E+00	0.0000	0.000E+00	0.0000	0.000E+00	0.0000	0.000E+00	0.0000	2.353E-03	0.
U-235	2.510E-03	0.0027	3.422E-05	0.0000	0.000E+00	0.0000	0.000E+00	0.0000	0.000E+00	0.0000	0.000E+00	0.0000	1.011E-04	0.
U-238	9.888E-03	0.0107	7.213E-04	0.0008	0.000E+00	0.0000	0.000E+00	0.0000	0.000E+00	0.0000	0.000E+00	0.0000	2.236E-03	0.
Total	8.287E-01	0.8957	5.981E-03	0.0065	0.000E+00	0.0000	0.000E+00	0.0000	0.000E+00	0.0000	0.000E+00	0.0000	9.048E-02	0.

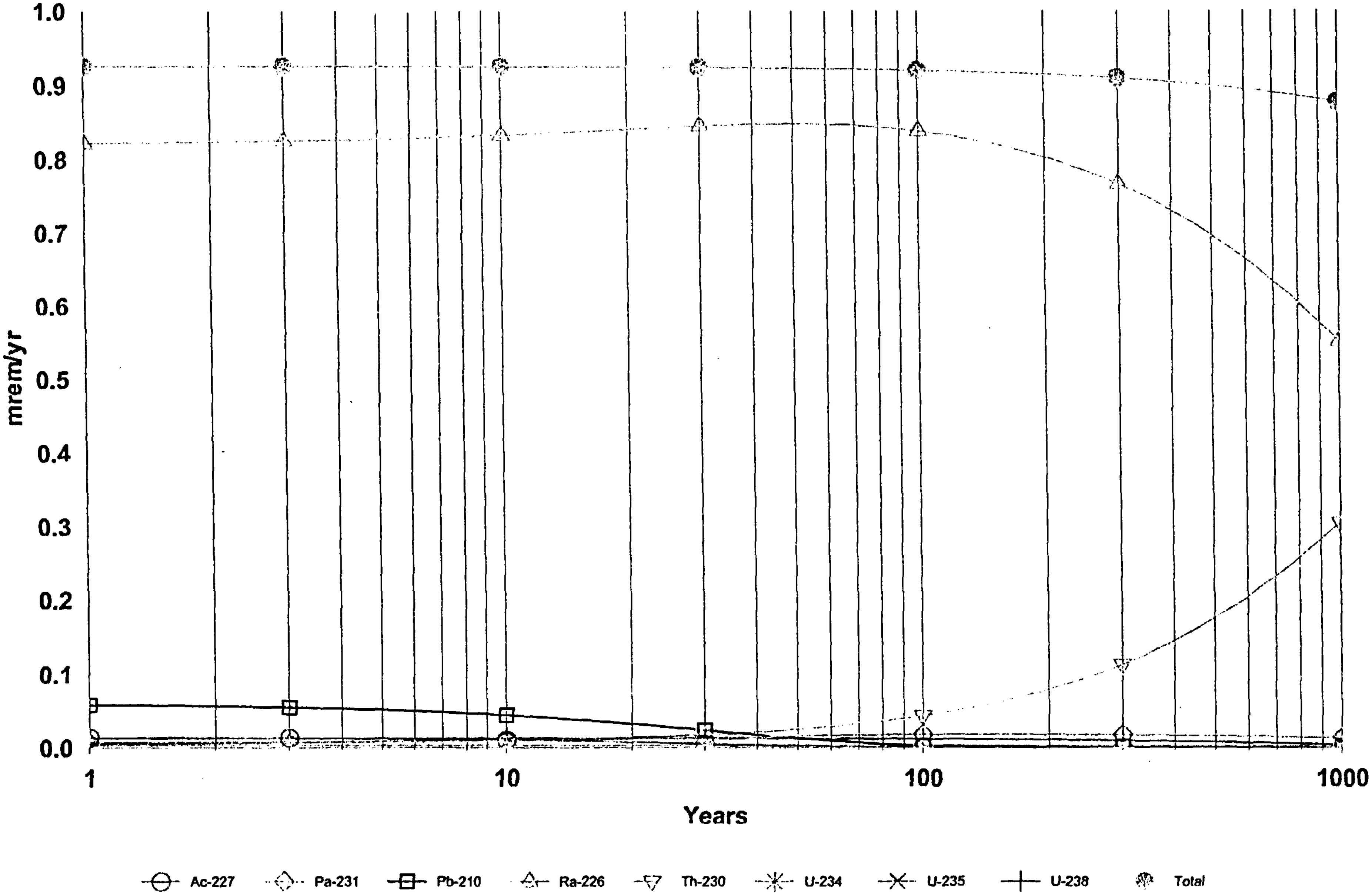
Total Dose Contributions TDOSE(i,p,t) for Individual Radionuclides (i) and Pathways (p)
As mrem/yr and Fraction of Total Dose At t = 1.000E+00 years

Water Dependent Pathways

Radio-Nuclide	Water		Fish		Radon		Plant		Meat		Milk		All Pathwa	
	mrem/yr	fract.	mrem/yr	fract.	mrem/yr	fract.	mrem/yr	fract.	mrem/yr	fract.	mrem/yr	fract.	mrem/yr	fr
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	1.346E-02	0.
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	5.660E-03	0.
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	5.835E-02	0.
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	8.218E-01	0.
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	7.181E-03	0.
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	3.189E-03	0.
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	2.645E-03	0.
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	1.285E-02	0.
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	9.252E-01	1.

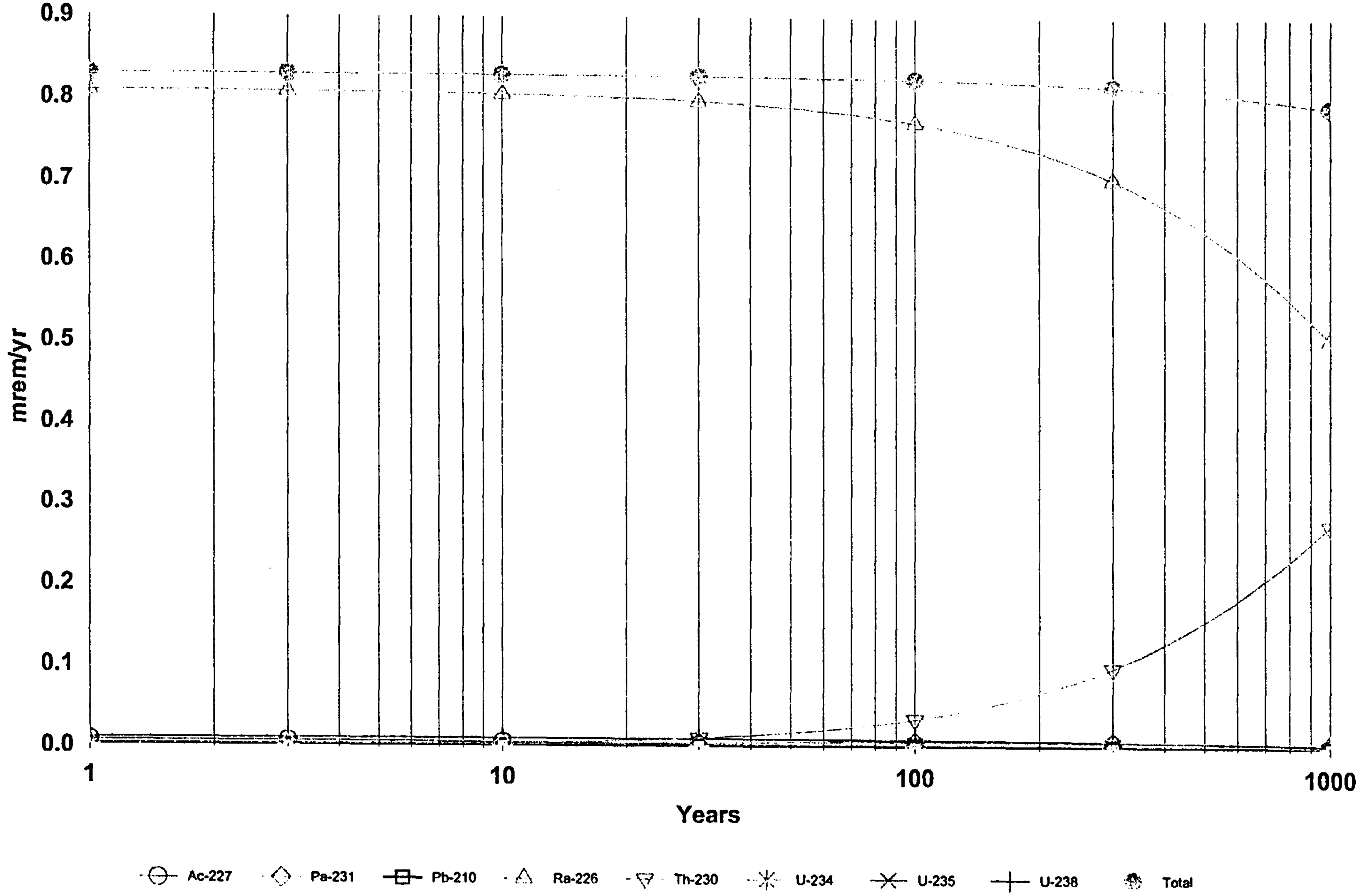
*Sum of all water independent and dependent pathways.

DOSE: All Nuclides Summed, All Pathways Summed



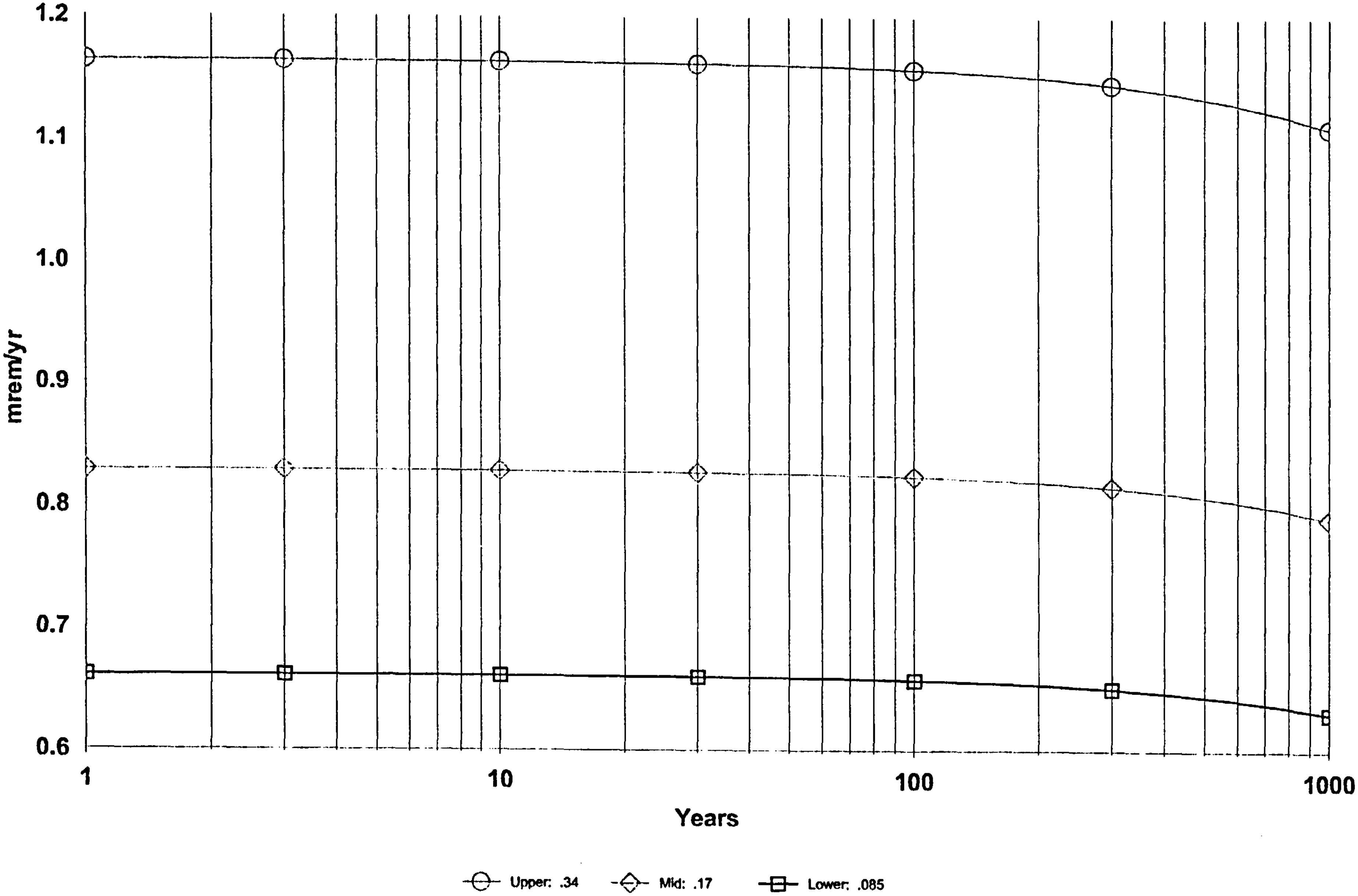
13gui.RAD 06/14/2002 11:23 Includes All Pathways

DOSE: All Nuclides Summed, External



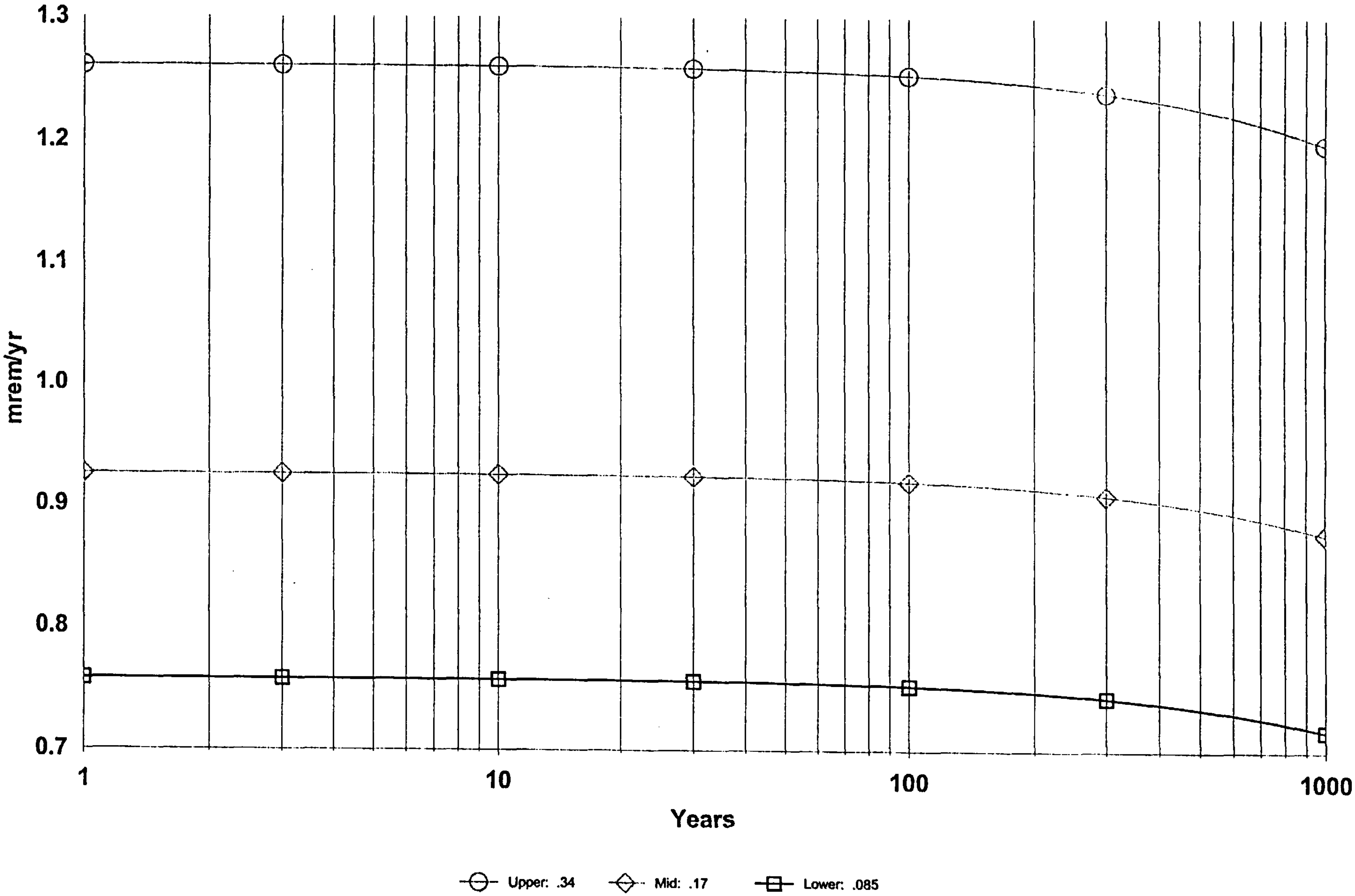
13gui.RAD 06/14/2002 11:23 Pathways: External

DOSE: All Nuclides Summed, External With SA on External Gamma Shielding factor



13gui.RAD 06/14/2002 11:35 Pathways: External

DOSE: All Nuclides Summed, All Pathways Summed With SA on External Gamma Shielding factor



13gui.RAD 06/14/2002 11:35 Includes All Pathways

Basis of Thorium Series
In Table 5-1

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

Parent (i)	Product (j)	Branch Fraction*	t= 0.000E+00	1.000E+00	3.000E+00	1.000E+01	3.000E+01	1.000E+02	3.000E+02	1.000E+03
			DSR(j,t) (mrem/yr)/(pCi/g)							
Ra-228	Ra-228	1.000E+00	4.176E-01	3.694E-01	2.892E-01	1.227E-01	1.060E-02	2.009E-06	4.649E-17	0.000E+00
Ra-228	Th-228	1.000E+00	1.153E-01	2.803E-01	4.157E-01	2.864E-01	2.691E-02	5.101E-06	1.181E-16	0.000E+00
Ra-228	∑DSR(j)		5.328E-01	6.498E-01	7.049E-01	4.092E-01	3.751E-02	7.110E-06	1.646E-16	0.000E+00
Th-228	Th-228	1.000E+00	6.257E-01	4.355E-01	2.110E-01	1.670E-02	1.191E-05	1.151E-16	0.000E+00	0.000E+00
Th-232	Th-232	1.000E+00	3.281E-02	3.281E-02	3.281E-02	3.281E-02	3.281E-02	3.280E-02	3.279E-02	3.274E-02
Th-232	Ra-228	1.000E+00	2.568E-02	7.306E-02	1.521E-01	3.159E-01	4.263E-01	4.367E-01	4.365E-01	4.358E-01
Th-232	Th-228	1.000E+00	4.820E-03	2.956E-02	1.174E-01	4.359E-01	7.078E-01	7.342E-01	7.338E-01	7.327E-01
Th-232	∑DSR(j)		6.331E-02	1.354E-01	3.022E-01	7.846E-01	1.167E+00	1.204E+00	1.203E+00	1.201E+00

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

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

Nuclide (i)	t= 0.000E+00	1.000E+00	3.000E+00	1.000E+01	3.000E+01	1.000E+02	3.000E+02	1.000E+03
Ra-228	4.692E+01	3.848E+01	3.547E+01	6.110E+01	6.665E+02	3.516E+06	*2.726E+14	*2.726E+14
Th-228	3.995E+01	5.740E+01	1.185E+02	1.497E+03	2.100E+06	*8.192E+14	*8.192E+14	*8.192E+14
Th-232	3.949E+02	1.846E+02	8.272E+01	3.186E+01	2.142E+01	2.077E+01	2.078E+01	2.081E+01

*At specific activity limit

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

Nuclide (i)	Initial (pCi/g)	tmin (years)	DSR(i,tmin)	G(i,tmin) (pCi/g)	DSR(i,tmax)	G(i,tmax) (pCi/g)
Ra-228	1.000E+00	2.659 ± 0.005	7.066E-01	3.538E+01	5.328E-01	4.692E+01
Th-228	1.000E+00	0.000E+00	6.257E-01	3.995E+01	6.257E-01	3.995E+01
Th-232	1.000E+00	91.0 ± 0.2	1.204E+00	2.077E+01	6.331E-02	3.949E+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 Independent Pathways (Inhalation excludes radon)

Radio-Nuclide	Ground		Inhalation		Radon		Plant		Meat		Milk		Soil	
	mrem/yr	fract.	mrem/yr	fract.	mrem/yr	fract.	mrem/yr	fract.	mrem/yr	fract.	mrem/yr	fract.	mrem/yr	fract.
Ra-228	5.202E-01	0.4257	3.557E-04	0.0003	0.000E+00	0.0000	0.000E+00	0.0000	0.000E+00	0.0000	0.000E+00	0.0000	1.233E-02	0.0101
Th-228	6.183E-01	0.5060	1.772E-03	0.0015	0.000E+00	0.0000	0.000E+00	0.0000	0.000E+00	0.0000	0.000E+00	0.0000	5.644E-03	0.0046
Th-232	2.979E-02	0.0244	1.006E-02	0.0082	0.000E+00	0.0000	0.000E+00	0.0000	0.000E+00	0.0000	0.000E+00	0.0000	2.347E-02	0.0192
Total	1.168E+00	0.9561	1.218E-02	0.0100	0.000E+00	0.0000	0.000E+00	0.0000	0.000E+00	0.0000	0.000E+00	0.0000	4.144E-02	0.0339

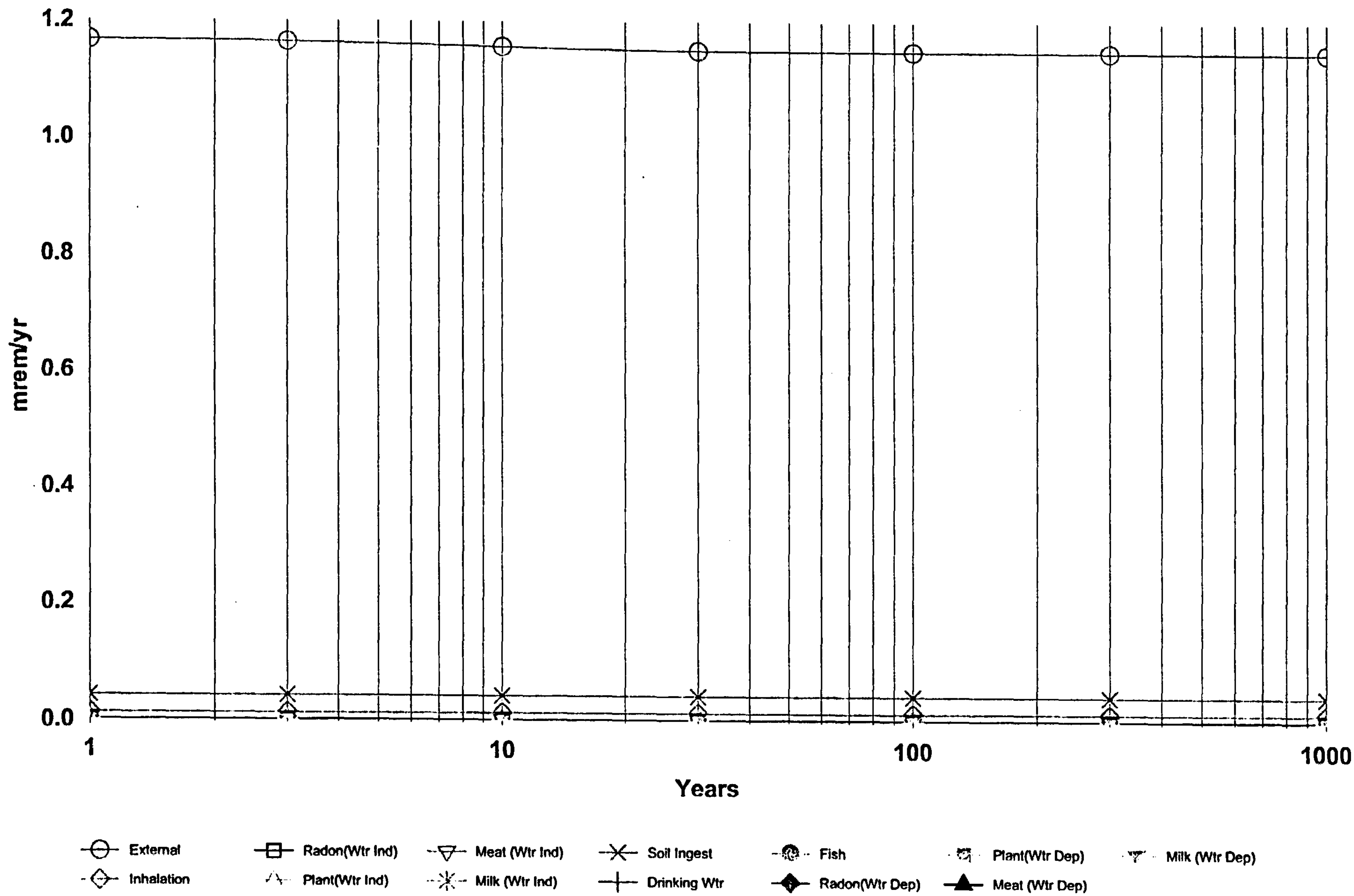
Total Dose Contributions TDOSE(i,p,t) for Individual Radionuclides (i) and Pathways (p)
As mrem/yr and Fraction of Total Dose At t = 0.000E+00 years

Water Dependent Pathways

Radio-Nuclide	Water		Fish		Radon		Plant		Meat		Milk		All Pathways*	
	mrem/yr	fract.	mrem/yr	fract.	mrem/yr	fract.	mrem/yr	fract.	mrem/yr	fract.	mrem/yr	fract.	mrem/yr	fract.
Ra-228	0.000E+00	0.0000	0.000E+00	0.0000	0.000E+00	0.0000	0.000E+00	0.0000	0.000E+00	0.0000	0.000E+00	0.0000	5.328E-01	0.4361
Th-228	0.000E+00	0.0000	0.000E+00	0.0000	0.000E+00	0.0000	0.000E+00	0.0000	0.000E+00	0.0000	0.000E+00	0.0000	6.257E-01	0.5121
Th-232	0.000E+00	0.0000	0.000E+00	0.0000	0.000E+00	0.0000	0.000E+00	0.0000	0.000E+00	0.0000	0.000E+00	0.0000	6.331E-02	0.0518
Total	0.000E+00	0.0000	0.000E+00	0.0000	0.000E+00	0.0000	0.000E+00	0.0000	0.000E+00	0.0000	0.000E+00	0.0000	1.222E+00	1.0000

*Sum of all water independent and dependent pathways.

DOSE: All Nuclides Summed, Component Pathways



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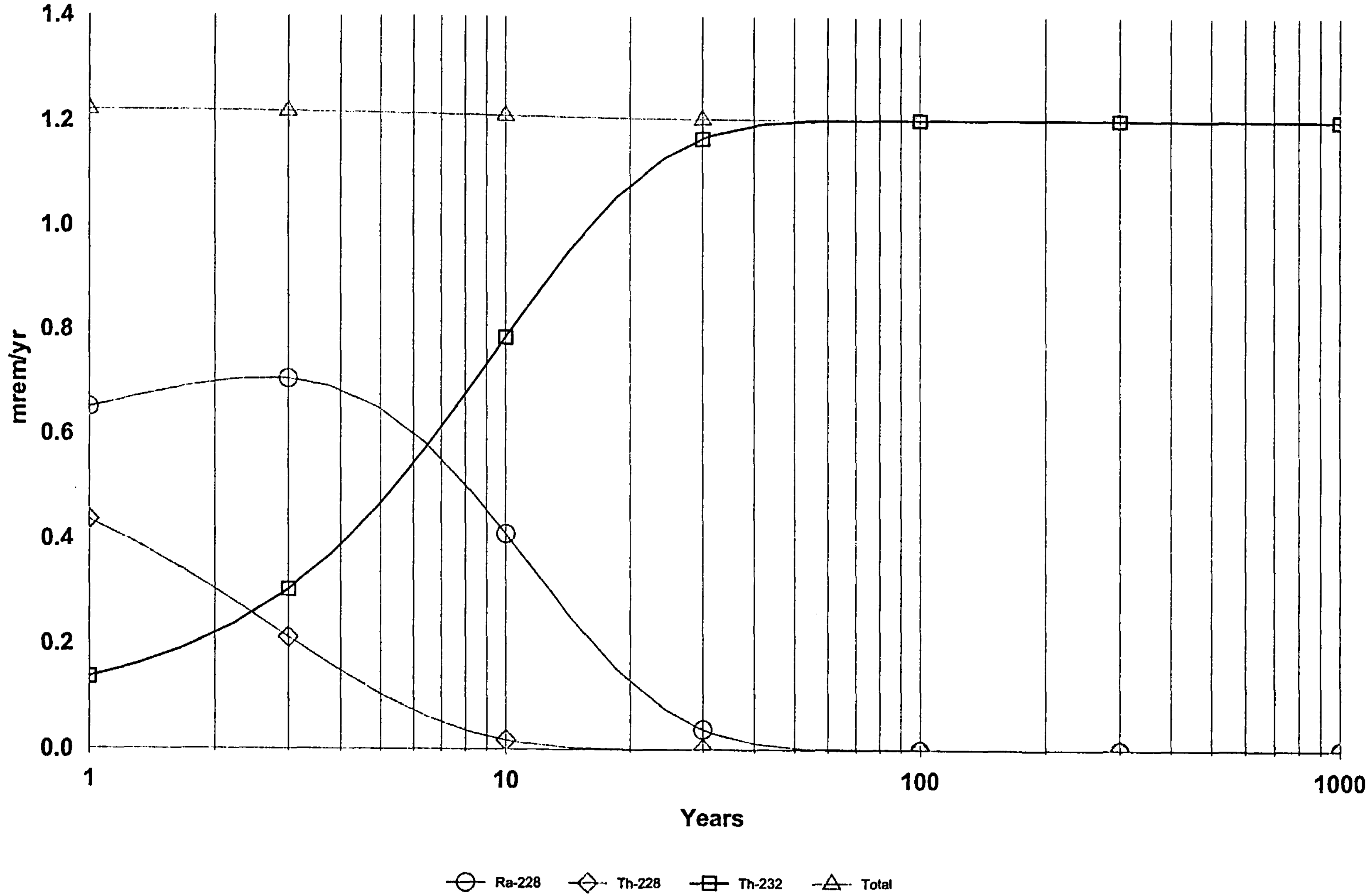
DOSE: All Nuclides Summed, All Pathways Summed



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Industrial Worker Scenario – Basis for Table 5-1

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

Nuclide (i)	t= 0.000E+00	1.000E+00	3.000E+00	1.000E+01	3.000E+01	1.000E+02	3.000E+02	1.000E+03
Ac-227	8.187E+01	8.453E+01	9.012E+01	1.127E+02	2.138E+02	2.008E+03	1.208E+06	*7.230E+13
Pa-231	2.176E+02	2.010E+02	1.754E+02	1.266E+02	8.337E+01	6.340E+01	6.619E+01	8.587E+01
Pb-210	4.153E+02	4.285E+02	4.560E+02	5.670E+02	1.057E+03	9.348E+03	4.736E+06	*7.631E+13
Ra-226	3.047E+01	3.042E+01	3.032E+01	3.003E+01	2.958E+01	2.983E+01	3.267E+01	4.543E+01
Ra-228	4.692E+01	3.848E+01	3.547E+01	6.110E+01	6.665E+02	3.516E+06	*2.726E+14	*2.726E+14
Th-228	3.995E+01	5.740E+01	1.185E+02	1.497E+03	2.100E+06	*8.192E+14	*8.192E+14	*8.192E+14
Th-230	3.663E+03	3.481E+03	3.167E+03	2.403E+03	1.415E+03	5.783E+02	2.228E+02	8.192E+01
Th-232	3.949E+02	1.846E+02	8.272E+01	3.186E+01	2.142E+01	2.077E+01	2.078E+01	2.081E+01
U-234	7.830E+03	7.838E+03	7.855E+03	7.912E+03	8.074E+03	8.640E+03	1.012E+04	1.145E+04
U-235	4.296E+02	4.300E+02	4.309E+02	4.339E+02	4.424E+02	4.716E+02	5.631E+02	1.015E+03
U-238	1.944E+03	1.946E+03	1.950E+03	1.965E+03	2.007E+03	2.161E+03	2.668E+03	5.586E+03

*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	4.550E-02	0.000E+00	3.054E-01	8.187E+01	3.054E-01	8.187E+01
Pa-231	4.550E-02	130.8 ± 0.3	3.976E-01	6.288E+01	1.149E-01	2.176E+02
Pb-210	1.000E+00	0.000E+00	6.019E-02	4.153E+02	6.019E-02	4.153E+02
Ra-226	1.000E+00	49.65 ± 0.10	8.480E-01	2.948E+01	8.204E-01	3.047E+01
Ra-228	1.000E+00	2.659 ± 0.005	7.066E-01	3.538E+01	5.328E-01	4.692E+01
Th-228	1.000E+00	0.000E+00	6.257E-01	3.995E+01	6.257E-01	3.995E+01
Th-230	1.000E+00	1.000E+03	3.052E-01	8.192E+01	6.826E-03	3.663E+03
Th-232	1.000E+00	91.0 ± 0.2	1.204E+00	2.077E+01	6.331E-02	3.949E+02
U-234	1.000E+00	0.000E+00	3.193E-03	7.830E+03	3.193E-03	7.830E+03
U-235	4.550E-02	0.000E+00	5.819E-02	4.296E+02	5.819E-02	4.296E+02
U-238	1.000E+00	0.000E+00	1.286E-02	1.944E+03	1.286E-02	1.944E+03

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

Water Independent Pathways (Inhalation excludes radon)

Radio-Nuclide	Ground		Inhalation		Radon		Plant		Meat		Milk		Soil	
	mrem/yr	fract.	mrem/yr	fract.	mrem/yr	fract.	mrem/yr	fract.	mrem/yr	fract.	mrem/yr	fract.	mrem/yr	fract.
Ac-227	6.534E-03	0.0030	1.842E-03	0.0009	0.000E+00	0.0000	0.000E+00	0.0000	0.000E+00	0.0000	0.000E+00	0.0000	5.518E-03	0.0026
Pa-231	7.374E-04	0.0003	3.860E-04	0.0002	0.000E+00	0.0000	0.000E+00	0.0000	0.000E+00	0.0000	0.000E+00	0.0000	4.104E-03	0.0019
Pb-210	4.525E-04	0.0002	1.398E-04	0.0001	0.000E+00	0.0000	0.000E+00	0.0000	0.000E+00	0.0000	0.000E+00	0.0000	5.960E-02	0.0278
Ra-226	8.083E-01	0.3765	5.482E-05	0.0000	0.000E+00	0.0000	0.000E+00	0.0000	0.000E+00	0.0000	0.000E+00	0.0000	1.200E-02	0.0056
Ra-228	5.202E-01	0.2423	3.557E-04	0.0002	0.000E+00	0.0000	0.000E+00	0.0000	0.000E+00	0.0000	0.000E+00	0.0000	1.233E-02	0.0057
Th-228	6.183E-01	0.2880	1.772E-03	0.0008	0.000E+00	0.0000	0.000E+00	0.0000	0.000E+00	0.0000	0.000E+00	0.0000	5.644E-03	0.0026
Th-230	2.642E-04	0.0001	1.996E-03	0.0009	0.000E+00	0.0000	0.000E+00	0.0000	0.000E+00	0.0000	0.000E+00	0.0000	4.566E-03	0.0021
Th-232	2.979E-02	0.0139	1.006E-02	0.0047	0.000E+00	0.0000	0.000E+00	0.0000	0.000E+00	0.0000	0.000E+00	0.0000	2.347E-02	0.0109
U-234	2.985E-05	0.0000	8.077E-04	0.0004	0.000E+00	0.0000	0.000E+00	0.0000	0.000E+00	0.0000	0.000E+00	0.0000	2.355E-03	0.0011
U-235	2.512E-03	0.0012	3.425E-05	0.0000	0.000E+00	0.0000	0.000E+00	0.0000	0.000E+00	0.0000	0.000E+00	0.0000	1.011E-04	0.0000
U-238	9.899E-03	0.0046	7.220E-04	0.0003	0.000E+00	0.0000	0.000E+00	0.0000	0.000E+00	0.0000	0.000E+00	0.0000	2.239E-03	0.0010
Total	1.997E+00	0.9301	1.817E-02	0.0085	0.000E+00	0.0000	0.000E+00	0.0000	0.000E+00	0.0000	0.000E+00	0.0000	1.319E-01	0.0614

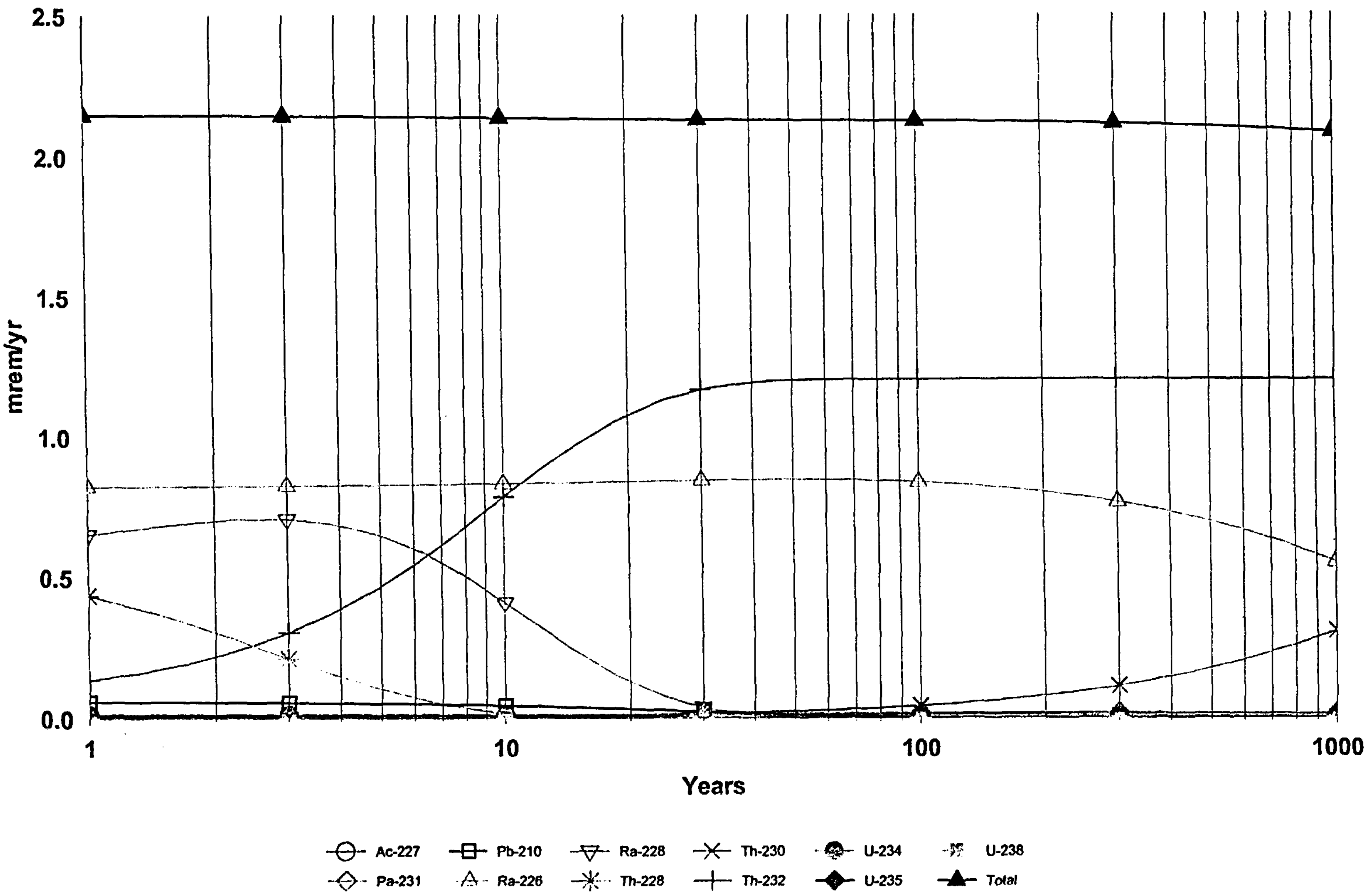
Total Dose Contributions TDOSE(i,p,t) for Individual Radionuclides (i) and Pathways (p)
As mrem/yr and Fraction of Total Dose At t = 0.000E+00 years

Water Dependent Pathways

Radio-Nuclide	Water		Fish		Radon		Plant		Meat		Milk		All Pathways*	
	mrem/yr	fract.	mrem/yr	fract.	mrem/yr	fract.	mrem/yr	fract.	mrem/yr	fract.	mrem/yr	fract.	mrem/yr	fract.
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	1.389E-02	0.0065
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	5.227E-03	0.0024
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	6.019E-02	0.0280
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	8.204E-01	0.3821
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	5.328E-01	0.2482
Th-228	0.000E+00	0.0000	0.000E+00	0.0000	0.000E+00	0.0000	0.000E+00	0.0000	0.000E+00	0.0000	0.000E+00	0.0000	6.257E-01	0.2914
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	6.826E-03	0.0032
Th-232	0.000E+00	0.0000	0.000E+00	0.0000	0.000E+00	0.0000	0.000E+00	0.0000	0.000E+00	0.0000	0.000E+00	0.0000	6.331E-02	0.0295
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	3.193E-03	0.0015
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	2.648E-03	0.0012
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	1.286E-02	0.0060
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	2.147E+00	1.0000

*Sum of all water independent and dependent pathways.

DOSE: All Nuclides Summed, All Pathways Summed



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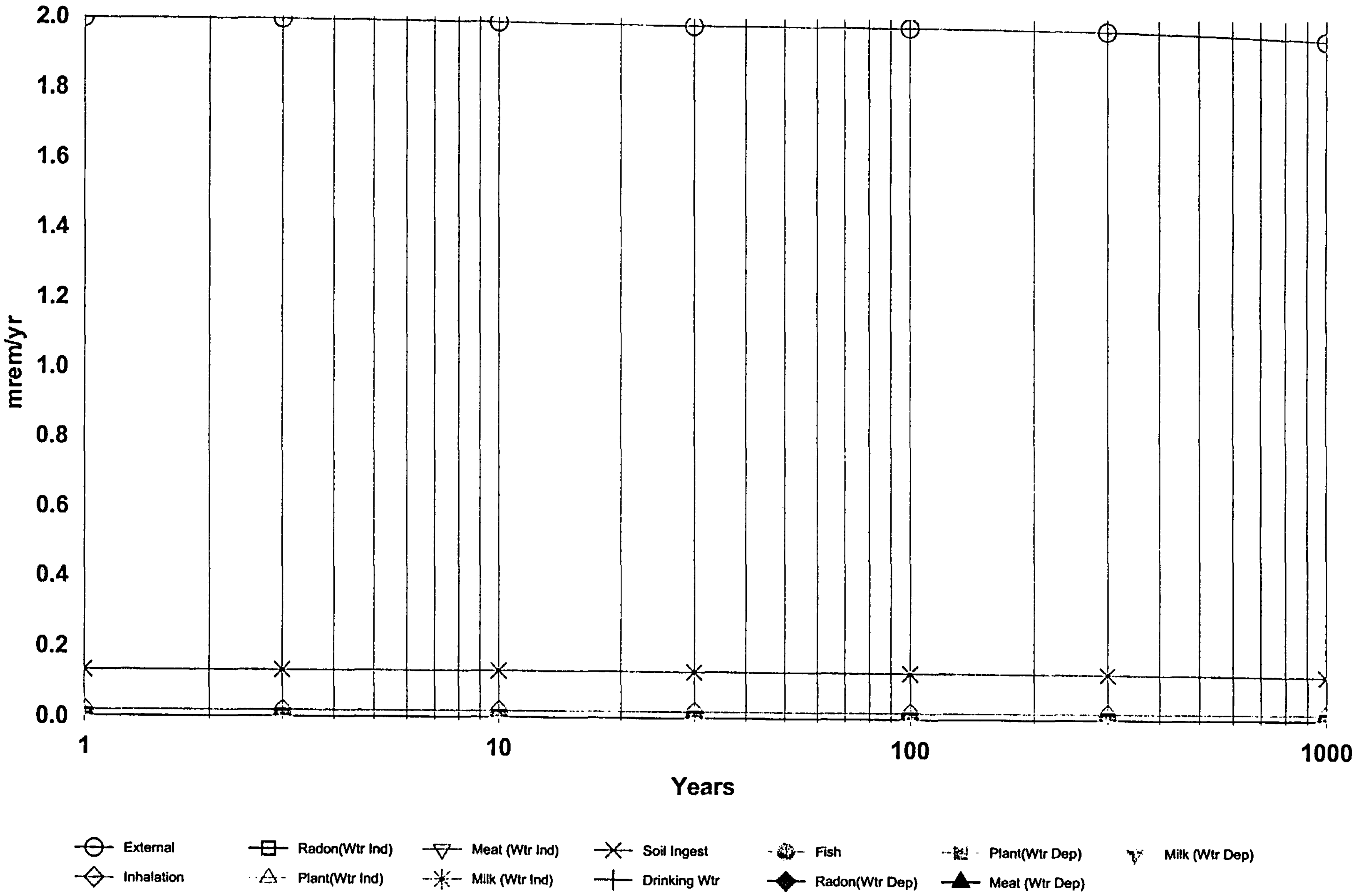
DOSE: All Nuclides Summed, Component Pathways



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Area Factors for Soil –
Basis for Figure 5-1

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

Water Independent Pathways (Inhalation excludes radon)

Radio-	Ground		Inhalation		Radon		Plant		Meat		Milk		Soil	
Nuclide	mrem/yr	fract.	mrem/yr	fract.	mrem/yr	fract.	mrem/yr	fract.	mrem/yr	fract.	mrem/yr	fract.	mrem/yr	fract.
Ac-227	6.534E-03	0.0030	1.842E-03	0.0009	0.000E+00	0.0000	0.000E+00	0.0000	0.000E+00	0.0000	0.000E+00	0.0000	5.518E-03	0.0026
Pa-231	7.374E-04	0.0003	3.860E-04	0.0002	0.000E+00	0.0000	0.000E+00	0.0000	0.000E+00	0.0000	0.000E+00	0.0000	4.104E-03	0.0019
Pb-210	4.525E-04	0.0002	1.398E-04	0.0001	0.000E+00	0.0000	0.000E+00	0.0000	0.000E+00	0.0000	0.000E+00	0.0000	5.960E-02	0.0278
Ra-226	8.083E-01	0.3765	5.482E-05	0.0000	0.000E+00	0.0000	0.000E+00	0.0000	0.000E+00	0.0000	0.000E+00	0.0000	1.200E-02	0.0056
Ra-228	5.202E-01	0.2423	3.557E-04	0.0002	0.000E+00	0.0000	0.000E+00	0.0000	0.000E+00	0.0000	0.000E+00	0.0000	1.233E-02	0.0057
Th-228	6.183E-01	0.2880	1.772E-03	0.0008	0.000E+00	0.0000	0.000E+00	0.0000	0.000E+00	0.0000	0.000E+00	0.0000	5.644E-03	0.0026
Th-230	2.642E-04	0.0001	1.996E-03	0.0009	0.000E+00	0.0000	0.000E+00	0.0000	0.000E+00	0.0000	0.000E+00	0.0000	4.566E-03	0.0021
Th-232	2.979E-02	0.0139	1.006E-02	0.0047	0.000E+00	0.0000	0.000E+00	0.0000	0.000E+00	0.0000	0.000E+00	0.0000	2.347E-02	0.0109
U-234	2.985E-05	0.0000	8.077E-04	0.0004	0.000E+00	0.0000	0.000E+00	0.0000	0.000E+00	0.0000	0.000E+00	0.0000	2.355E-03	0.0011
U-235	2.512E-03	0.0012	3.425E-05	0.0000	0.000E+00	0.0000	0.000E+00	0.0000	0.000E+00	0.0000	0.000E+00	0.0000	1.011E-04	0.0000
U-238	9.899E-03	0.0046	7.220E-04	0.0003	0.000E+00	0.0000	0.000E+00	0.0000	0.000E+00	0.0000	0.000E+00	0.0000	2.239E-03	0.0010
Total	1.997E+00	0.9301	1.817E-02	0.0085	0.000E+00	0.0000	0.000E+00	0.0000	0.000E+00	0.0000	0.000E+00	0.0000	1.319E-01	0.0614

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

Water Dependent Pathways

Radio-	Water		Fish		Radon		Plant		Meat		Milk		All Pathways*	
Nuclide	mrem/yr	fract.	mrem/yr	fract.	mrem/yr	fract.	mrem/yr	fract.	mrem/yr	fract.	mrem/yr	fract.	mrem/yr	fract.
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	1.389E-02	0.0065
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	5.227E-03	0.0024
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	6.019E-02	0.0280
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	8.204E-01	0.3821
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	5.328E-01	0.2482
Th-228	0.000E+00	0.0000	0.000E+00	0.0000	0.000E+00	0.0000	0.000E+00	0.0000	0.000E+00	0.0000	0.000E+00	0.0000	6.257E-01	0.2914
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	6.826E-03	0.0032
Th-232	0.000E+00	0.0000	0.000E+00	0.0000	0.000E+00	0.0000	0.000E+00	0.0000	0.000E+00	0.0000	0.000E+00	0.0000	6.331E-02	0.0295
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	3.193E-03	0.0015
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	2.648E-03	0.0012
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	1.286E-02	0.0060
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	2.147E+00	1.0000

*Sum of all water independent and dependent pathways.

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

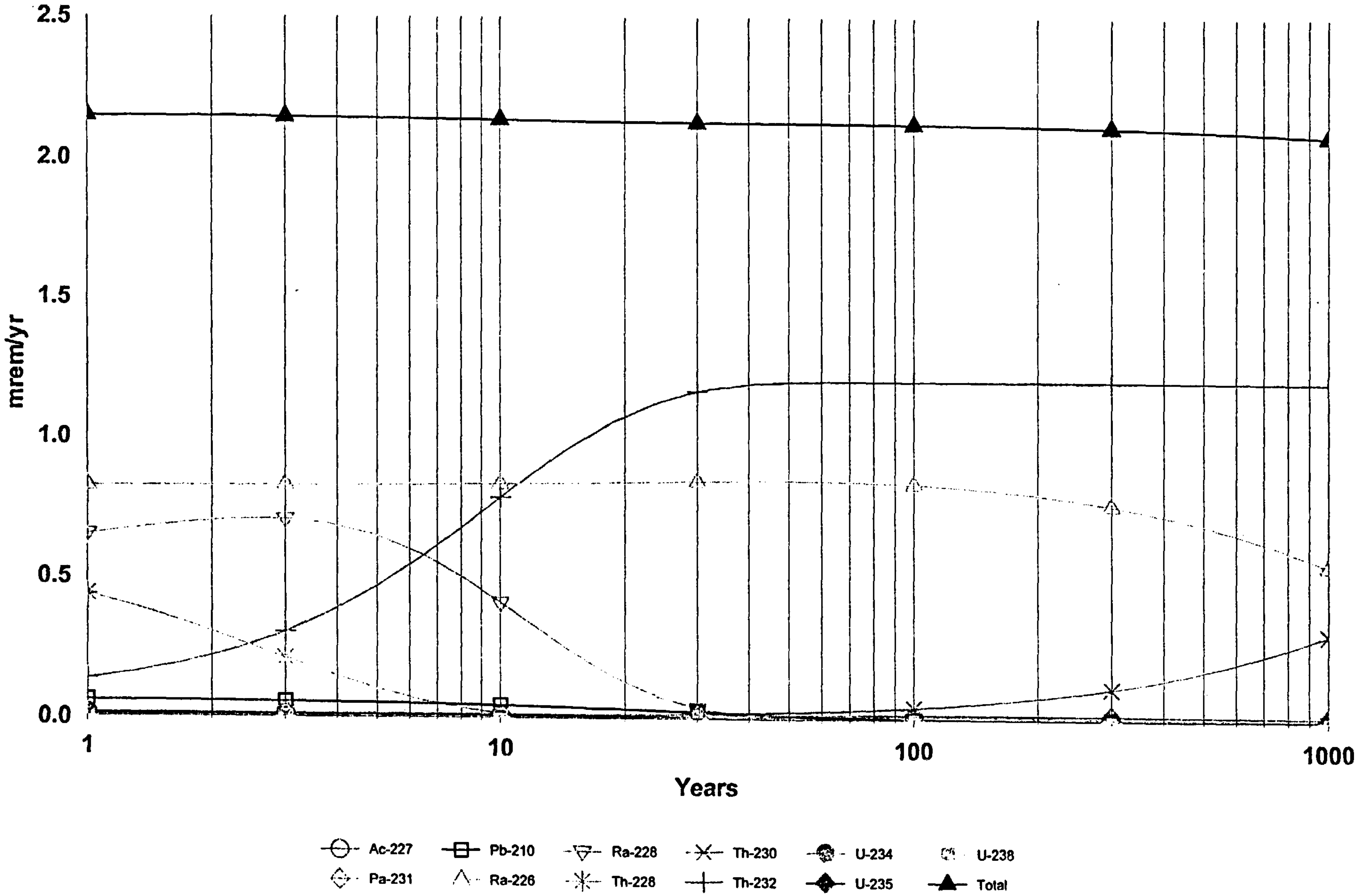
Nuclide (i)	t= 0.000E+00	1.000E+00	3.000E+00	1.000E+01	3.000E+01	1.000E+02	3.000E+02	1.000E+03
Ac-227	8.187E+01	8.453E+01	9.012E+01	1.127E+02	2.138E+02	2.008E+03	1.208E+06	*7.230E+13
Pa-231	2.176E+02	2.010E+02	1.754E+02	1.266E+02	8.337E+01	6.340E+01	6.619E+01	8.587E+01
Pb-210	4.153E+02	4.285E+02	4.560E+02	5.670E+02	1.057E+03	9.348E+03	4.736E+06	*7.631E+13
Ra-226	3.047E+01	3.042E+01	3.032E+01	3.003E+01	2.958E+01	2.983E+01	3.267E+01	4.543E+01
Ra-228	4.692E+01	3.848E+01	3.547E+01	6.110E+01	6.665E+02	3.516E+06	*2.726E+14	*2.726E+14
Th-228	3.995E+01	5.740E+01	1.185E+02	1.497E+03	2.100E+06	*8.192E+14	*8.192E+14	*8.192E+14
Th-230	3.663E+03	3.481E+03	3.167E+03	2.403E+03	1.415E+03	5.783E+02	2.228E+02	8.192E+01
Th-232	3.949E+02	1.846E+02	8.272E+01	3.186E+01	2.142E+01	2.077E+01	2.078E+01	2.081E+01
U-234	7.830E+03	7.838E+03	7.855E+03	7.912E+03	8.074E+03	8.640E+03	1.012E+04	1.145E+04
U-235	4.296E+02	4.300E+02	4.309E+02	4.339E+02	4.424E+02	4.716E+02	5.631E+02	1.015E+03
U-238	1.944E+03	1.946E+03	1.950E+03	1.965E+03	2.007E+03	2.161E+03	2.668E+03	5.586E+03

*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	4.550E-02	0.000E+00	3.054E-01	8.187E+01	3.054E-01	8.187E+01
Pa-231	4.550E-02	130.8 ± 0.3	3.976E-01	6.288E+01	1.149E-01	2.176E+02
Pb-210	1.000E+00	0.000E+00	6.019E-02	4.153E+02	6.019E-02	4.153E+02
Ra-226	1.000E+00	49.65 ± 0.10	8.480E-01	2.948E+01	8.204E-01	3.047E+01
Ra-228	1.000E+00	2.659 ± 0.005	7.066E-01	3.538E+01	5.328E-01	4.692E+01
Th-228	1.000E+00	0.000E+00	6.257E-01	3.995E+01	6.257E-01	3.995E+01
Th-230	1.000E+00	1.000E+03	3.052E-01	8.192E+01	6.826E-03	3.663E+03
Th-232	1.000E+00	91.0 ± 0.2	1.204E+00	2.077E+01	6.331E-02	3.949E+02
U-234	1.000E+00	0.000E+00	3.193E-03	7.830E+03	3.193E-03	7.830E+03
U-235	4.550E-02	0.000E+00	5.819E-02	4.296E+02	5.819E-02	4.296E+02
U-238	1.000E+00	0.000E+00	1.286E-02	1.944E+03	1.286E-02	1.944E+03

DOSE: All Nuclides Summed, All Pathways Summed



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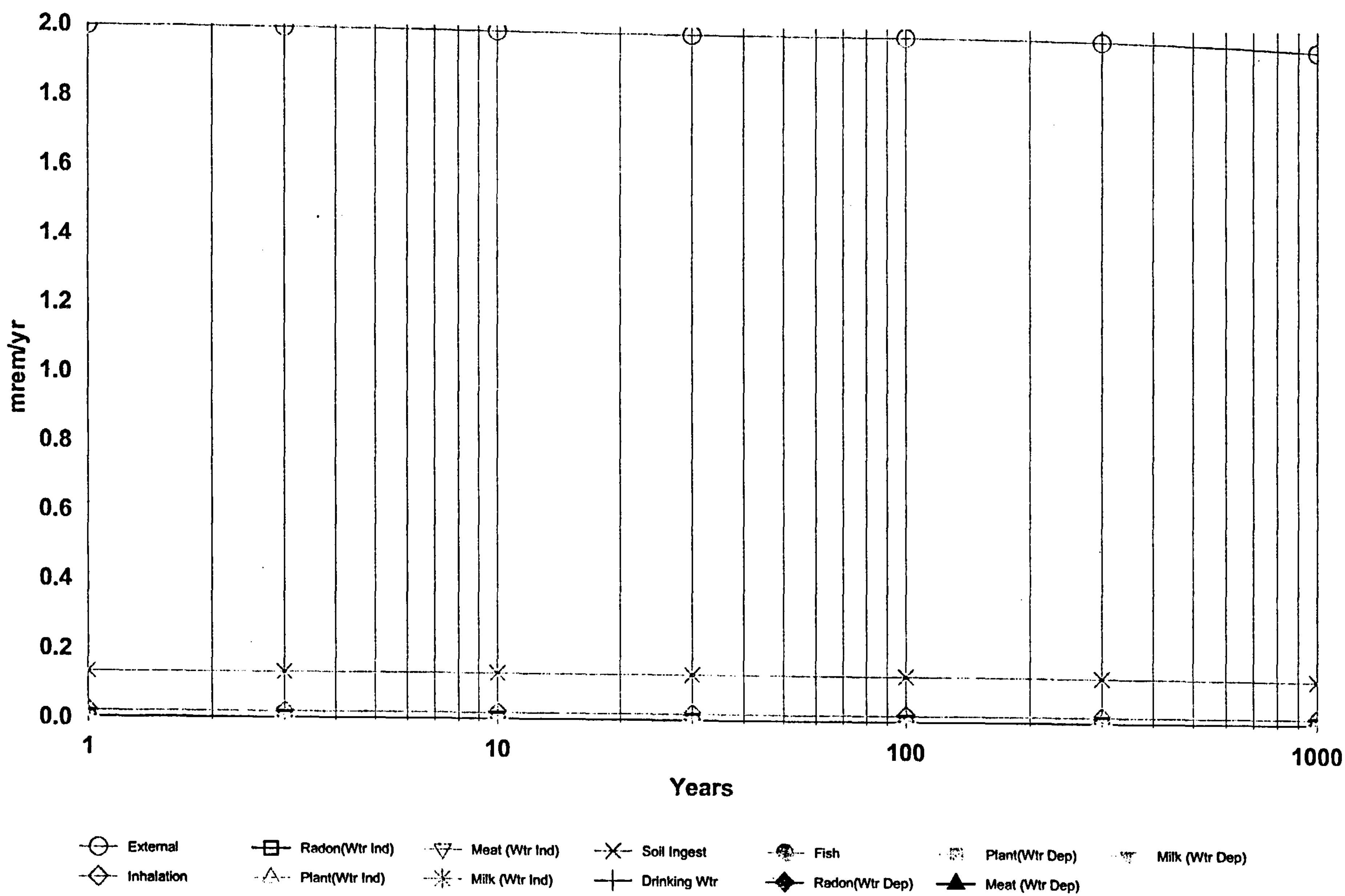
DOSE: All Nuclides Summed, Component Pathways



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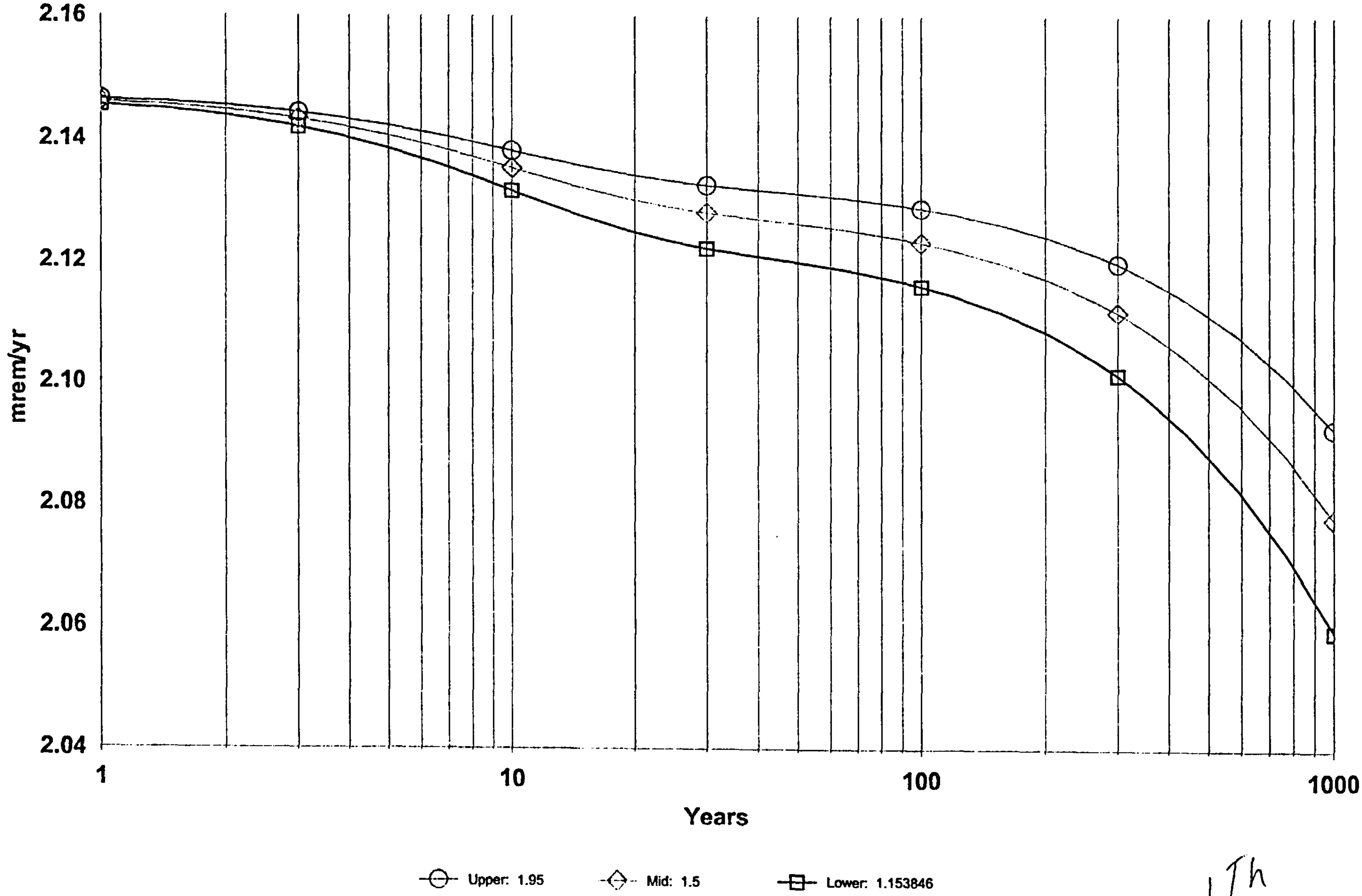
DOSE: All Nuclides Summed, All Pathways Summed With SA on Density of contaminated zone



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1U to 1Th

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

Nuclide (i)	t= 0.000E+00	1.000E+00	3.000E+00	1.000E+01	3.000E+01	1.000E+02	3.000E+02	1.000E+03
Ac-227	8.427E+01	8.701E+01	9.276E+01	1.160E+02	2.201E+02	2.067E+03	1.243E+06	*7.230E+13
Pa-231	2.203E+02	2.037E+02	1.781E+02	1.291E+02	8.527E+01	6.495E+01	6.783E+01	8.799E+01
Pb-210	4.155E+02	4.287E+02	4.562E+02	5.673E+02	1.058E+03	9.353E+03	4.738E+06	*7.631E+13
Ra-226	3.133E+01	3.127E+01	3.116E+01	3.085E+01	3.038E+01	3.061E+01	3.352E+01	4.661E+01
Ra-228	4.824E+01	3.955E+01	3.645E+01	6.278E+01	6.848E+02	3.613E+06	*2.726E+14	*2.726E+14
Th-228	4.104E+01	5.895E+01	1.217E+02	1.537E+03	2.156E+06	*8.192E+14	*8.192E+14	*8.192E+14
Th-230	3.800E+03	3.610E+03	3.281E+03	2.484E+03	1.459E+03	5.946E+02	2.288E+02	8.408E+01
Th-232	4.080E+02	1.902E+02	8.512E+01	3.276E+01	2.202E+01	2.135E+01	2.136E+01	2.139E+01
U-234	8.076E+03	8.085E+03	8.102E+03	8.161E+03	8.329E+03	8.912E+03	1.044E+04	1.178E+04
U-235	4.400E+02	4.405E+02	4.414E+02	4.444E+02	4.531E+02	4.830E+02	5.767E+02	1.040E+03
U-238	2.000E+03	2.002E+03	2.006E+03	2.021E+03	2.064E+03	2.223E+03	2.745E+03	5.747E+03

*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	4.550E-02	0.000E+00	2.967E-01	8.427E+01	2.967E-01	8.427E+01
Pa-231	4.550E-02	130.8 ± 0.3	3.880E-01	6.443E+01	1.135E-01	2.203E+02
Pb-210	1.000E+00	0.000E+00	6.016E-02	4.155E+02	6.016E-02	4.155E+02
Ra-226	1.000E+00	50.4 ± 0.1	8.262E-01	3.026E+01	7.980E-01	3.133E+01
Ra-228	1.000E+00	2.660 ± 0.005	6.876E-01	3.636E+01	5.182E-01	4.824E+01
Th-228	1.000E+00	0.000E+00	6.092E-01	4.104E+01	6.092E-01	4.104E+01
Th-230	1.000E+00	1.000E+03	2.973E-01	8.408E+01	6.580E-03	3.800E+03
Th-232	1.000E+00	91.3 ± 0.2	1.171E+00	2.135E+01	6.127E-02	4.080E+02
U-234	1.000E+00	0.000E+00	3.095E-03	8.076E+03	3.095E-03	8.076E+03
U-235	4.550E-02	0.000E+00	5.682E-02	4.400E+02	5.682E-02	4.400E+02
U-238	1.000E+00	0.000E+00	1.250E-02	2.000E+03	1.250E-02	2.000E+03

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-Nuclide	Ground		Inhalation		Radon		Plant		Meat		Milk		Soil	
	mrem/yr	fract.	mrem/yr	fract.	mrem/yr	fract.	mrem/yr	fract.	mrem/yr	fract.	mrem/yr	fract.	mrem/yr	fr
Ac-227	6.158E-03	0.0029	1.571E-03	0.0008	0.000E+00	0.0000	0.000E+00	0.0000	0.000E+00	0.0000	0.000E+00	0.0000	5.345E-03	0.
Pa-231	9.182E-04	0.0004	3.905E-04	0.0002	0.000E+00	0.0000	0.000E+00	0.0000	0.000E+00	0.0000	0.000E+00	0.0000	4.275E-03	0.
Pb-210	4.247E-04	0.0002	1.193E-04	0.0001	0.000E+00	0.0000	0.000E+00	0.0000	0.000E+00	0.0000	0.000E+00	0.0000	5.778E-02	0.
Ra-226	7.856E-01	0.3760	5.201E-05	0.0000	0.000E+00	0.0000	0.000E+00	0.0000	0.000E+00	0.0000	0.000E+00	0.0000	1.382E-02	0.
Ra-228	6.189E-01	0.2962	7.216E-04	0.0003	0.000E+00	0.0000	0.000E+00	0.0000	0.000E+00	0.0000	0.000E+00	0.0000	1.251E-02	0.
Th-228	4.190E-01	0.2006	1.086E-03	0.0005	0.000E+00	0.0000	0.000E+00	0.0000	0.000E+00	0.0000	0.000E+00	0.0000	3.929E-03	0.
Th-230	5.976E-04	0.0003	1.757E-03	0.0008	0.000E+00	0.0000	0.000E+00	0.0000	0.000E+00	0.0000	0.000E+00	0.0000	4.571E-03	0.
Th-232	9.753E-02	0.0467	8.917E-03	0.0043	0.000E+00	0.0000	0.000E+00	0.0000	0.000E+00	0.0000	0.000E+00	0.0000	2.497E-02	0.
U-234	2.909E-05	0.0000	7.103E-04	0.0003	0.000E+00	0.0000	0.000E+00	0.0000	0.000E+00	0.0000	0.000E+00	0.0000	2.353E-03	0.
U-235	2.451E-03	0.0012	3.013E-05	0.0000	0.000E+00	0.0000	0.000E+00	0.0000	0.000E+00	0.0000	0.000E+00	0.0000	1.011E-04	0.
U-238	9.616E-03	0.0046	6.350E-04	0.0003	0.000E+00	0.0000	0.000E+00	0.0000	0.000E+00	0.0000	0.000E+00	0.0000	2.236E-03	0.
Total	1.941E+00	0.9292	1.599E-02	0.0077	0.000E+00	0.0000	0.000E+00	0.0000	0.000E+00	0.0000	0.000E+00	0.0000	1.319E-01	0.

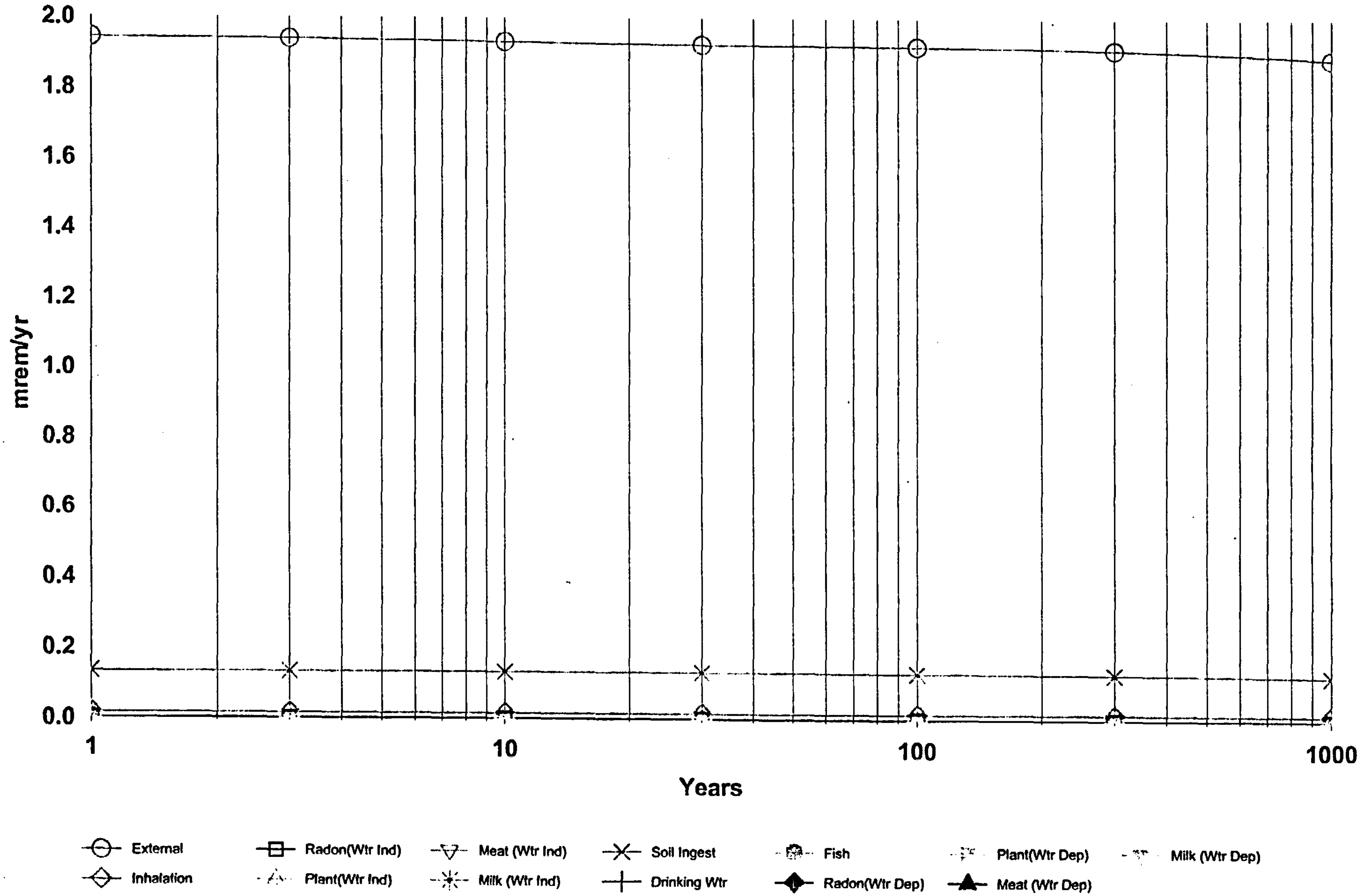
Total Dose Contributions TDOSE(i,p,t) for Individual Radionuclides (i) and Pathways (p)
As mrem/yr and Fraction of Total Dose At t = 1.000E+00 years

Water Dependent Pathways

Radio-Nuclide	Water		Fish		Radon		Plant		Meat		Milk		All Pathwa	
	mrem/yr	fract.	mrem/yr	fract.	mrem/yr	fract.	mrem/yr	fract.	mrem/yr	fract.	mrem/yr	fract.	mrem/yr	fr
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	1.307E-02	0.
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	5.584E-03	0.
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	5.832E-02	0.
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	7.995E-01	0.
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	6.321E-01	0.
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	4.241E-01	0.
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	6.925E-03	0.
Th-232	0.000E+00	0.0000	0.000E+00	0.0000	0.000E+00	0.0000	0.000E+00	0.0000	0.000E+00	0.0000	0.000E+00	0.0000	1.314E-01	0.
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	3.092E-03	0.
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	2.583E-03	0.
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	1.249E-02	0.
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	2.089E+00	1.

*Sum of all water independent and dependent pathways.

DOSE: All Nuclides Summed, Component Pathways



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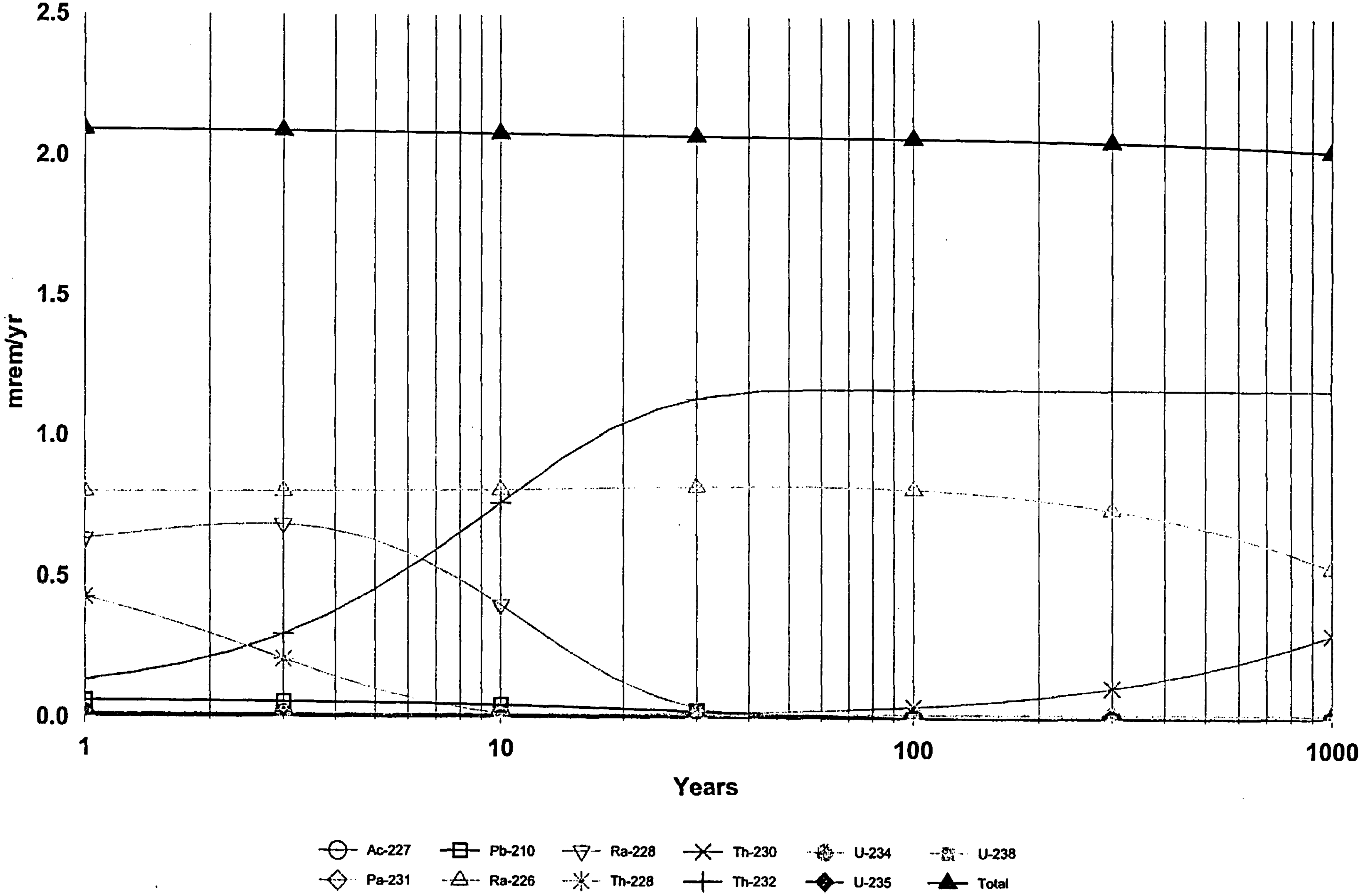
DOSE: All Nuclides Summed, All Pathways Summed



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

Nuclide (i)	t= 0.000E+00	1.000E+00	3.000E+00	1.000E+01	3.000E+01	1.000E+02	3.000E+02	1.000E+03
Ac-227	8.621E+01	8.902E+01	9.490E+01	1.187E+02	2.251E+02	2.114E+03	1.272E+06	*7.230E+13
Pa-231	2.225E+02	2.059E+02	1.803E+02	1.310E+02	8.681E+01	6.621E+01	6.914E+01	8.969E+01
Pb-210	4.157E+02	4.289E+02	4.564E+02	5.676E+02	1.058E+03	9.356E+03	4.740E+06	*7.631E+13
Ra-226	3.196E+01	3.190E+01	3.179E+01	3.147E+01	3.097E+01	3.119E+01	3.415E+01	4.749E+01
Ra-228	4.923E+01	4.036E+01	3.720E+01	6.407E+01	6.989E+02	3.687E+06	*2.726E+14	*2.726E+14
Th-228	4.188E+01	6.017E+01	1.242E+02	1.569E+03	2.201E+06	*8.192E+14	*8.192E+14	*8.192E+14
Th-230	3.919E+03	3.721E+03	3.379E+03	2.553E+03	1.494E+03	6.072E+02	2.333E+02	8.570E+01
Th-232	4.188E+02	1.947E+02	8.697E+01	3.345E+01	2.248E+01	2.180E+01	2.180E+01	2.184E+01
U-234	8.289E+03	8.298E+03	8.315E+03	8.375E+03	8.548E+03	9.146E+03	1.071E+04	1.205E+04
U-235	4.474E+02	4.478E+02	4.487E+02	4.518E+02	4.606E+02	4.911E+02	5.864E+02	1.058E+03
U-238	2.044E+03	2.046E+03	2.050E+03	2.065E+03	2.110E+03	2.271E+03	2.805E+03	5.873E+03

*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	4.550E-02	0.000E+00	2.900E-01	8.621E+01	2.900E-01	8.621E+01
Pa-231	4.550E-02	130.7 ± 0.3	3.806E-01	6.568E+01	1.124E-01	2.225E+02
Pb-210	1.000E+00	0.000E+00	6.014E-02	4.157E+02	6.014E-02	4.157E+02
Ra-226	1.000E+00	51.1 ± 0.1	8.106E-01	3.084E+01	7.821E-01	3.196E+01
Ra-228	1.000E+00	2.660 ± 0.005	6.737E-01	3.711E+01	5.078E-01	4.923E+01
Th-228	1.000E+00	0.000E+00	5.969E-01	4.188E+01	5.969E-01	4.188E+01
Th-230	1.000E+00	1.000E+03	2.917E-01	8.570E+01	6.380E-03	3.919E+03
Th-232	1.000E+00	90.5 ± 0.2	1.147E+00	2.180E+01	5.969E-02	4.188E+02
U-234	1.000E+00	0.000E+00	3.016E-03	8.289E+03	3.016E-03	8.289E+03
U-235	4.550E-02	0.000E+00	5.588E-02	4.474E+02	5.588E-02	4.474E+02
U-238	1.000E+00	0.000E+00	1.223E-02	2.044E+03	1.223E-02	2.044E+03

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	fr
Ac-227	6.037E-03	0.0029	1.396E-03	0.0007	0.000E+00	0.0000	0.000E+00	0.0000	0.000E+00	0.0000	0.000E+00	0.0000	5.345E-03	0.
Pa-231	9.017E-04	0.0004	3.471E-04	0.0002	0.000E+00	0.0000	0.000E+00	0.0000	0.000E+00	0.0000	0.000E+00	0.0000	4.275E-03	0.
Pb-210	4.140E-04	0.0002	1.061E-04	0.0001	0.000E+00	0.0000	0.000E+00	0.0000	0.000E+00	0.0000	0.000E+00	0.0000	5.778E-02	0.
Ra-226	7.697E-01	0.3758	4.624E-05	0.0000	0.000E+00	0.0000	0.000E+00	0.0000	0.000E+00	0.0000	0.000E+00	0.0000	1.382E-02	0.
Ra-228	6.063E-01	0.2960	6.416E-04	0.0003	0.000E+00	0.0000	0.000E+00	0.0000	0.000E+00	0.0000	0.000E+00	0.0000	1.251E-02	0.
Th-228	4.106E-01	0.2005	9.653E-04	0.0005	0.000E+00	0.0000	0.000E+00	0.0000	0.000E+00	0.0000	0.000E+00	0.0000	3.929E-03	0.
Th-230	5.858E-04	0.0003	1.562E-03	0.0008	0.000E+00	0.0000	0.000E+00	0.0000	0.000E+00	0.0000	0.000E+00	0.0000	4.571E-03	0.
Th-232	9.553E-02	0.0466	7.928E-03	0.0039	0.000E+00	0.0000	0.000E+00	0.0000	0.000E+00	0.0000	0.000E+00	0.0000	2.497E-02	0.
U-234	2.858E-05	0.0000	6.315E-04	0.0003	0.000E+00	0.0000	0.000E+00	0.0000	0.000E+00	0.0000	0.000E+00	0.0000	2.353E-03	0.
U-235	2.412E-03	0.0012	2.678E-05	0.0000	0.000E+00	0.0000	0.000E+00	0.0000	0.000E+00	0.0000	0.000E+00	0.0000	1.011E-04	0.
U-238	9.418E-03	0.0046	5.645E-04	0.0003	0.000E+00	0.0000	0.000E+00	0.0000	0.000E+00	0.0000	0.000E+00	0.0000	2.236E-03	0.
Total	1.902E+00	0.9287	1.422E-02	0.0069	0.000E+00	0.0000	0.000E+00	0.0000	0.000E+00	0.0000	0.000E+00	0.0000	1.319E-01	0.

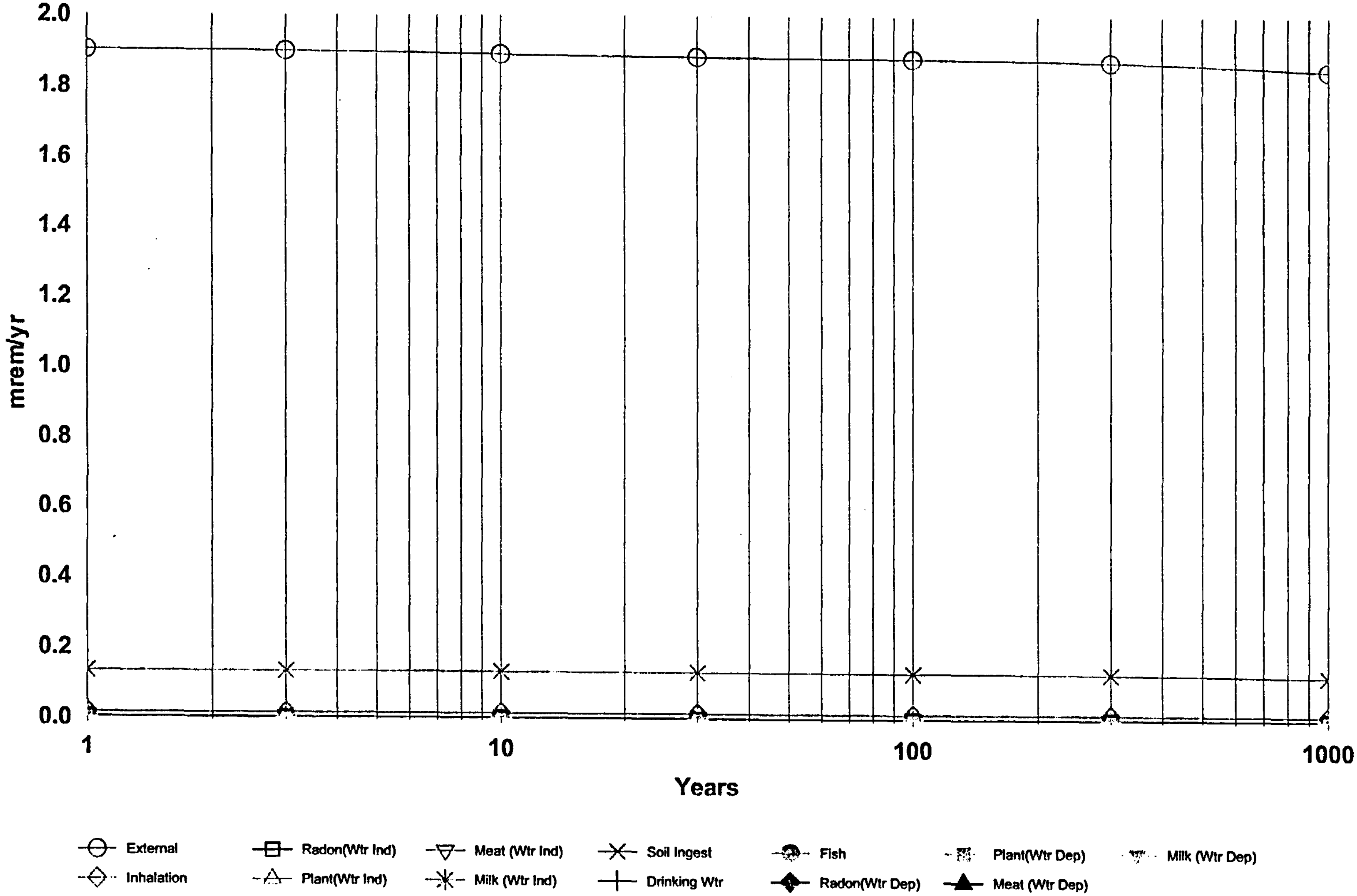
Total Dose Contributions TDOSE(i,p,t) for Individual Radionuclides (i) and Pathways (p)
As mrem/yr and Fraction of Total Dose At t = 1.000E+00 years

Water Dependent Pathways

Radio-	Water		Fish		Radon		Plant		Meat		Milk		All Pathwa	
Nuclide	mrem/yr	fract.	mrem/yr	fract.	mrem/yr	fract.	mrem/yr	fract.	mrem/yr	fract.	mrem/yr	fract.	mrem/yr	fr
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	1.278E-02	0.
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	5.524E-03	0.
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	5.830E-02	0.
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	7.836E-01	0.
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	6.194E-01	0.
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	4.155E-01	0.
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	6.719E-03	0.
Th-232	0.000E+00	0.0000	0.000E+00	0.0000	0.000E+00	0.0000	0.000E+00	0.0000	0.000E+00	0.0000	0.000E+00	0.0000	1.284E-01	0.
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	3.013E-03	0.
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	2.540E-03	0.
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	1.222E-02	0.
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	2.048E+00	1.

*Sum of all water independent and dependent pathways.

DOSE: All Nuclides Summed, Component Pathways



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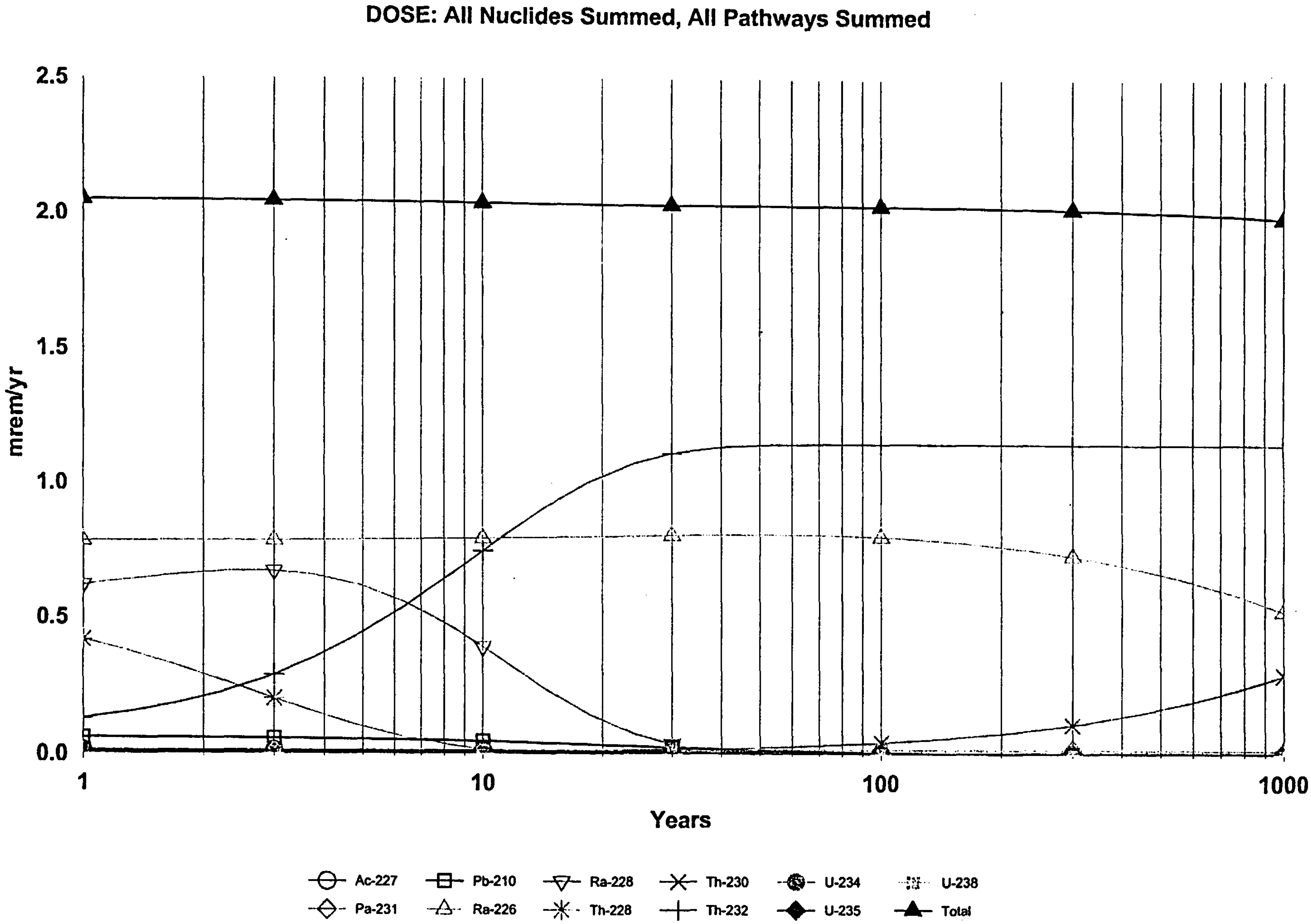

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Single Radionuclide Soil Guidelines G(i,t) in pCi/g
Basic Radiation Dose Limit = 2.500E+01 mrem/yr

Nuclide (i)	t= 0.000E+00	1.000E+00	3.000E+00	1.000E+01	3.000E+01	1.000E+02	3.000E+02	1.000E+03
Ac-227	1.275E+02	1.316E+02	1.403E+02	1.755E+02	3.328E+02	3.126E+03	1.880E+06	*7.230E+13
Pa-231	5.223E+02	4.631E+02	3.807E+02	2.475E+02	1.497E+02	1.095E+02	1.139E+02	1.478E+02
Pb-210	1.360E+03	1.403E+03	1.493E+03	1.856E+03	3.461E+03	3.060E+04	1.550E+07	*7.631E+13
Ra-226	3.383E+01	3.382E+01	3.380E+01	3.377E+01	3.380E+01	3.463E+01	3.801E+01	5.285E+01
Ra-228	5.258E+01	4.301E+01	3.958E+01	6.811E+01	7.428E+02	3.919E+06	*2.726E+14	*2.726E+14
Th-228	4.439E+01	6.378E+01	1.316E+02	1.663E+03	2.333E+06	*8.192E+14	*8.192E+14	*8.192E+14
Th-230	8.380E+03	7.568E+03	6.339E+03	4.041E+03	1.985E+03	7.197E+02	2.657E+02	9.616E+01
Th-232	6.104E+02	2.372E+02	9.813E+01	3.637E+01	2.426E+01	2.351E+01	2.352E+01	2.356E+01
U-234	1.939E+04	1.941E+04	1.945E+04	1.959E+04	1.998E+04	2.126E+04	2.362E+04	1.840E+04
U-235	4.765E+02	4.770E+02	4.780E+02	4.814E+02	4.911E+02	5.255E+02	6.349E+02	1.203E+03
U-238	2.455E+03	2.458E+03	2.463E+03	2.481E+03	2.534E+03	2.729E+03	3.370E+03	7.057E+03

*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	4.550E-02	0.000E+00	1.962E-01	1.275E+02	1.962E-01	1.275E+02
Pa-231	4.550E-02	134.0 ± 0.3	2.307E-01	1.084E+02	4.786E-02	5.223E+02
Pb-210	1.000E+00	0.000E+00	1.839E-02	1.360E+03	1.839E-02	1.360E+03
Ra-226	1.000E+00	15.91 ± 0.03	7.406E-01	3.376E+01	7.390E-01	3.383E+01
Ra-228	1.000E+00	2.671 ± 0.005	6.330E-01	3.949E+01	4.755E-01	5.258E+01
Th-228	1.000E+00	0.000E+00	5.632E-01	4.439E+01	5.632E-01	4.439E+01
Th-230	1.000E+00	1.000E+03	2.600E-01	9.616E+01	2.983E-03	8.380E+03
Th-232	1.000E+00	91.1 ± 0.2	1.063E+00	2.351E+01	4.096E-02	6.104E+02
U-234	1.000E+00	1.000E+03	1.359E-03	1.840E+04	1.289E-03	1.939E+04
U-235	4.550E-02	0.000E+00	5.247E-02	4.765E+02	5.247E-02	4.765E+02
U-238	1.000E+00	0.000E+00	1.018E-02	2.455E+03	1.018E-02	2.455E+03

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

Water Independent Pathways (Inhalation excludes radon)

Radio-Nuclide	Ground mrem/yr	Ground fract.	Inhalation mrem/yr	Inhalation fract.	Radon mrem/yr	Radon fract.	Plant mrem/yr	Plant fract.	Meat mrem/yr	Meat fract.	Milk mrem/yr	Milk fract.	Soil mrem/yr	Soil fr
Ac-227	6.003E-03	0.0032	1.266E-03	0.0007	0.000E+00	0.0000	0.000E+00	0.0000	0.000E+00	0.0000	0.000E+00	0.0000	1.656E-03	0.
Pa-231	6.814E-04	0.0004	2.652E-04	0.0001	0.000E+00	0.0000	0.000E+00	0.0000	0.000E+00	0.0000	0.000E+00	0.0000	1.231E-03	0.
Pb-210	4.093E-04	0.0002	9.610E-05	0.0001	0.000E+00	0.0000	0.000E+00	0.0000	0.000E+00	0.0000	0.000E+00	0.0000	1.788E-02	0.
Ra-226	7.353E-01	0.3943	3.767E-05	0.0000	0.000E+00	0.0000	0.000E+00	0.0000	0.000E+00	0.0000	0.000E+00	0.0000	3.601E-03	0.
Ra-228	4.716E-01	0.2529	2.445E-04	0.0001	0.000E+00	0.0000	0.000E+00	0.0000	0.000E+00	0.0000	0.000E+00	0.0000	3.698E-03	0.
Th-228	5.603E-01	0.3004	1.218E-03	0.0007	0.000E+00	0.0000	0.000E+00	0.0000	0.000E+00	0.0000	0.000E+00	0.0000	1.693E-03	0.
Th-230	2.422E-04	0.0001	1.372E-03	0.0007	0.000E+00	0.0000	0.000E+00	0.0000	0.000E+00	0.0000	0.000E+00	0.0000	1.370E-03	0.
Th-232	2.701E-02	0.0145	6.910E-03	0.0037	0.000E+00	0.0000	0.000E+00	0.0000	0.000E+00	0.0000	0.000E+00	0.0000	7.041E-03	0.
U-234	2.771E-05	0.0000	5.551E-04	0.0003	0.000E+00	0.0000	0.000E+00	0.0000	0.000E+00	0.0000	0.000E+00	0.0000	7.066E-04	0.
U-235	2.333E-03	0.0013	2.354E-05	0.0000	0.000E+00	0.0000	0.000E+00	0.0000	0.000E+00	0.0000	0.000E+00	0.0000	3.034E-05	0.
U-238	9.015E-03	0.0048	4.962E-04	0.0003	0.000E+00	0.0000	0.000E+00	0.0000	0.000E+00	0.0000	0.000E+00	0.0000	6.716E-04	0.
Total	1.813E+00	0.9721	1.248E-02	0.0067	0.000E+00	0.0000	0.000E+00	0.0000	0.000E+00	0.0000	0.000E+00	0.0000	3.958E-02	0.

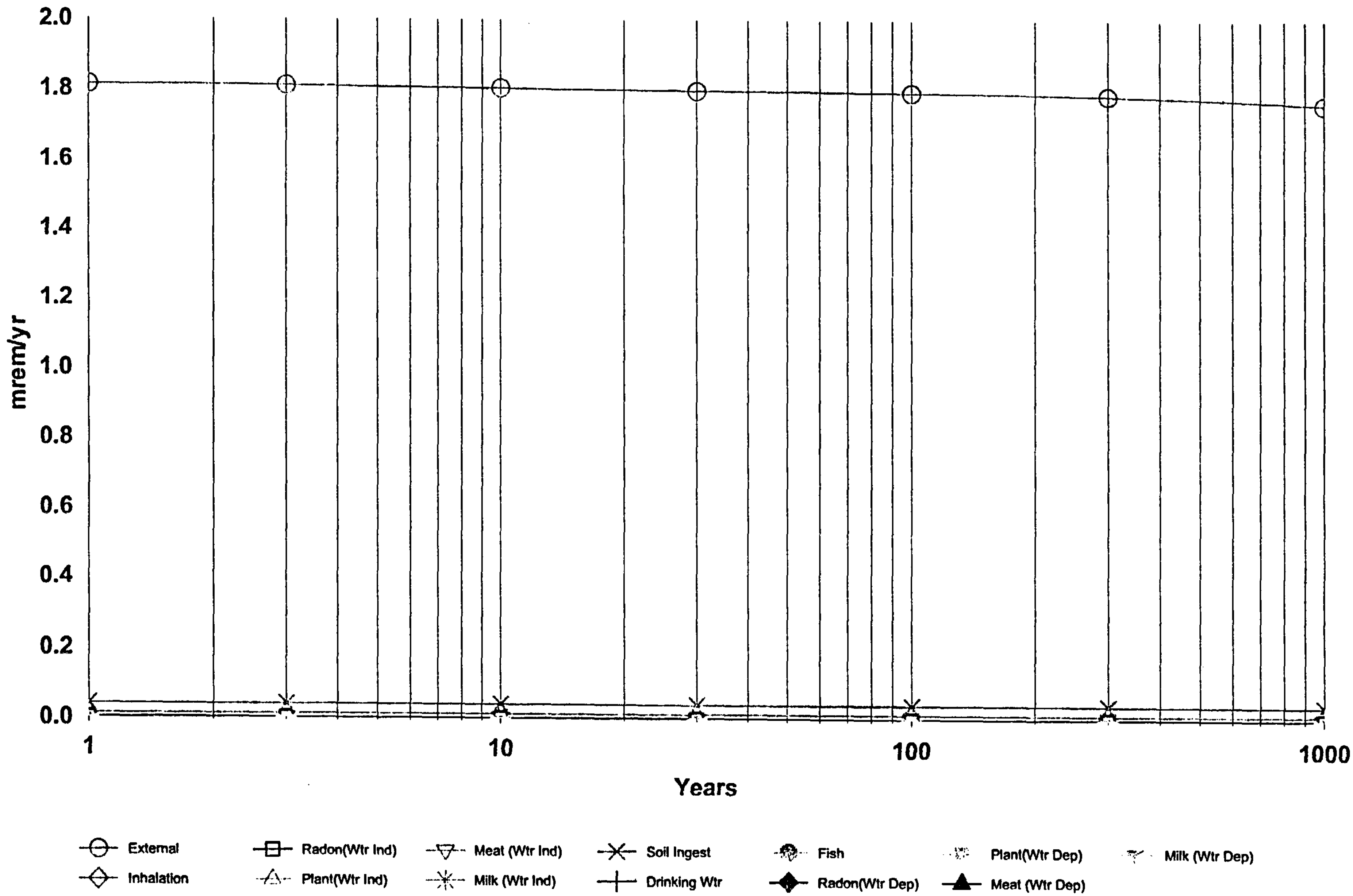
Total Dose Contributions TDOSE(i,p,t) for Individual Radionuclides (i) and Pathways (p)
As mrem/yr and Fraction of Total Dose At t = 0.000E+00 years

Water Dependent Pathways

Radio-Nuclide	Water mrem/yr	Water fract.	Fish mrem/yr	Fish fract.	Radon mrem/yr	Radon fract.	Plant mrem/yr	Plant fract.	Meat mrem/yr	Meat fract.	Milk mrem/yr	Milk fract.	All Pathwa mrem/yr	All Pathwa fr
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	8.925E-03	0.
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	2.178E-03	0.
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	1.839E-02	0.
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	7.390E-01	0.
Ra-228	0.000E+00	0.0000	0.000E+00	0.0000	0.000E+00	0.0000	0.000E+00	0.0000	0.000E+00	0.0000	0.000E+00	0.0000	4.755E-01	0.
Th-228	0.000E+00	0.0000	0.000E+00	0.0000	0.000E+00	0.0000	0.000E+00	0.0000	0.000E+00	0.0000	0.000E+00	0.0000	5.632E-01	0.
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	2.983E-03	0.
Th-232	0.000E+00	0.0000	0.000E+00	0.0000	0.000E+00	0.0000	0.000E+00	0.0000	0.000E+00	0.0000	0.000E+00	0.0000	4.096E-02	0.
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	1.289E-03	0.
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	2.387E-03	0.
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	1.018E-02	0.
Total	0.000E+00	0.0000	0.000E+00	0.0000	0.000E+00	0.0000	0.000E+00	0.0000	0.000E+00	0.0000	0.000E+00	0.0000	1.865E+00	1.

*Sum of all water independent and dependent pathways.

DOSE: All Nuclides Summed, Component Pathways



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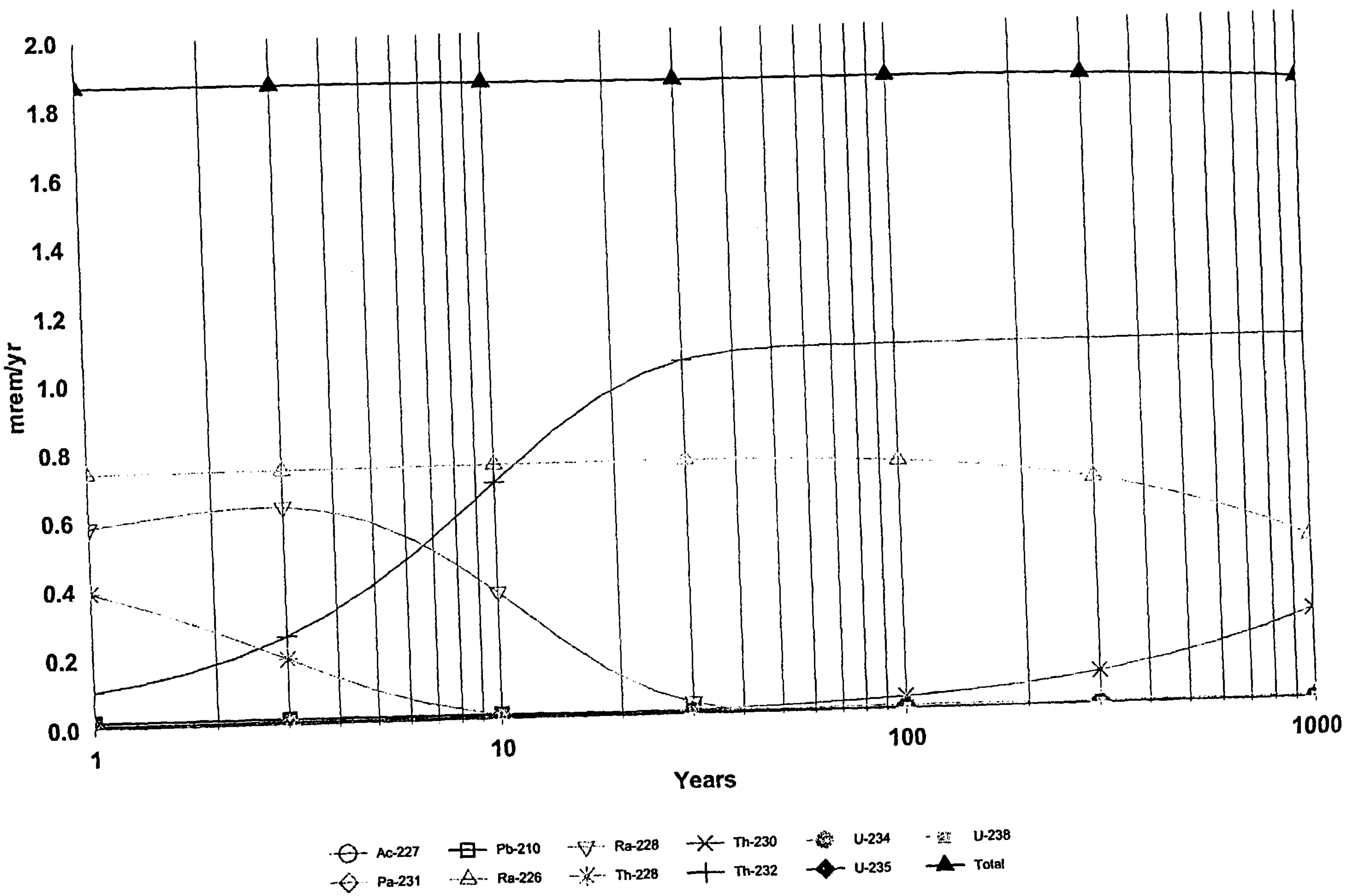
DOSE: All Nuclides Summed, All Pathways Summed



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

Nuclide (i)	t= 0.000E+00	1.000E+00	3.000E+00	1.000E+01	3.000E+01	1.000E+02	3.000E+02	1.000E+03
Ac-227	1.568E+02	1.619E+02	1.726E+02	2.160E+02	4.096E+02	3.846E+03	2.313E+06	*7.230E+13
Pa-231	8.882E+02	7.546E+02	5.866E+02	3.502E+02	1.999E+02	1.427E+02	1.482E+02	1.923E+02
Pb-210	3.888E+03	4.011E+03	4.269E+03	5.309E+03	9.896E+03	8.752E+04	4.434E+07	*7.631E+13
Ra-226	3.675E+01	3.675E+01	3.677E+01	3.683E+01	3.706E+01	3.817E+01	4.192E+01	5.829E+01
Ra-228	5.712E+01	4.673E+01	4.301E+01	7.400E+01	8.071E+02	4.258E+06	*2.726E+14	*2.726E+14
Th-228	4.824E+01	6.930E+01	1.430E+02	1.807E+03	2.535E+06	*8.192E+14	*8.192E+14	*8.192E+14
Th-230	1.317E+04	1.140E+04	8.988E+03	5.164E+03	2.336E+03	8.110E+02	2.954E+02	1.064E+02
Th-232	7.470E+02	2.694E+02	1.086E+02	3.979E+01	2.648E+01	2.566E+01	2.567E+01	2.571E+01
U-234	3.316E+04	3.319E+04	3.326E+04	3.349E+04	3.415E+04	3.610E+04	3.810E+04	2.305E+04
U-235	5.151E+02	5.156E+02	5.167E+02	5.204E+02	5.311E+02	5.689E+02	6.898E+02	1.328E+03
U-238	2.773E+03	2.776E+03	2.782E+03	2.803E+03	2.863E+03	3.082E+03	3.807E+03	7.973E+03

*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	4.550E-02	0.000E+00	1.594E-01	1.568E+02	1.594E-01	1.568E+02
Pa-231	4.550E-02	135.8 ± 0.3	1.772E-01	1.411E+02	2.815E-02	8.882E+02
Pb-210	1.000E+00	0.000E+00	6.430E-03	3.888E+03	6.430E-03	3.888E+03
Ra-226	1.000E+00	0.000E+00	6.803E-01	3.675E+01	6.803E-01	3.675E+01
Ra-228	1.000E+00	2.671 ± 0.005	5.826E-01	4.291E+01	4.377E-01	5.712E+01
Th-228	1.000E+00	0.000E+00	5.182E-01	4.824E+01	5.182E-01	4.824E+01
Th-230	1.000E+00	1.000E+03	2.350E-01	1.064E+02	1.898E-03	1.317E+04
Th-232	1.000E+00	91.1 ± 0.2	9.744E-01	2.566E+01	3.347E-02	7.470E+02
U-234	1.000E+00	1.000E+03	1.085E-03	2.305E+04	7.540E-04	3.316E+04
U-235	4.550E-02	0.000E+00	4.854E-02	5.151E+02	4.854E-02	5.151E+02
U-238	1.000E+00	0.000E+00	9.014E-03	2.773E+03	9.014E-03	2.773E+03

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

Water Independent Pathways (Inhalation excludes radon)

Radio-Nuclide	Ground		Inhalation		Radon		Plant		Meat		Milk		Soil	
	mrem/yr	fract.	mrem/yr	fract.	mrem/yr	fract.	mrem/yr	fract.	mrem/yr	fract.	mrem/yr	fract.	mrem/yr	fr
Ac-227	5.578E-03	0.0033	1.123E-03	0.0007	0.000E+00	0.0000	0.000E+00	0.0000	0.000E+00	0.0000	0.000E+00	0.0000	5.518E-04	0.
Pa-231	6.350E-04	0.0004	2.353E-04	0.0001	0.000E+00	0.0000	0.000E+00	0.0000	0.000E+00	0.0000	0.000E+00	0.0000	4.104E-04	0.
Pb-210	3.840E-04	0.0002	8.526E-05	0.0001	0.000E+00	0.0000	0.000E+00	0.0000	0.000E+00	0.0000	0.000E+00	0.0000	5.960E-03	0.
Ra-226	6.791E-01	0.3998	3.342E-05	0.0000	0.000E+00	0.0000	0.000E+00	0.0000	0.000E+00	0.0000	0.000E+00	0.0000	1.200E-03	0.
Ra-228	4.362E-01	0.2568	2.169E-04	0.0001	0.000E+00	0.0000	0.000E+00	0.0000	0.000E+00	0.0000	0.000E+00	0.0000	1.233E-03	0.
Th-228	5.166E-01	0.3041	1.080E-03	0.0006	0.000E+00	0.0000	0.000E+00	0.0000	0.000E+00	0.0000	0.000E+00	0.0000	5.644E-04	0.
Th-230	2.245E-04	0.0001	1.217E-03	0.0007	0.000E+00	0.0000	0.000E+00	0.0000	0.000E+00	0.0000	0.000E+00	0.0000	4.566E-04	0.
Th-232	2.499E-02	0.0147	6.131E-03	0.0036	0.000E+00	0.0000	0.000E+00	0.0000	0.000E+00	0.0000	0.000E+00	0.0000	2.347E-03	0.
U-234	2.608E-05	0.0000	4.924E-04	0.0003	0.000E+00	0.0000	0.000E+00	0.0000	0.000E+00	0.0000	0.000E+00	0.0000	2.355E-04	0.
U-235	2.177E-03	0.0013	2.088E-05	0.0000	0.000E+00	0.0000	0.000E+00	0.0000	0.000E+00	0.0000	0.000E+00	0.0000	1.011E-05	0.
U-238	8.350E-03	0.0049	4.402E-04	0.0003	0.000E+00	0.0000	0.000E+00	0.0000	0.000E+00	0.0000	0.000E+00	0.0000	2.239E-04	0.
Total	1.674E+00	0.9857	1.108E-02	0.0065	0.000E+00	0.0000	0.000E+00	0.0000	0.000E+00	0.0000	0.000E+00	0.0000	1.319E-02	0.

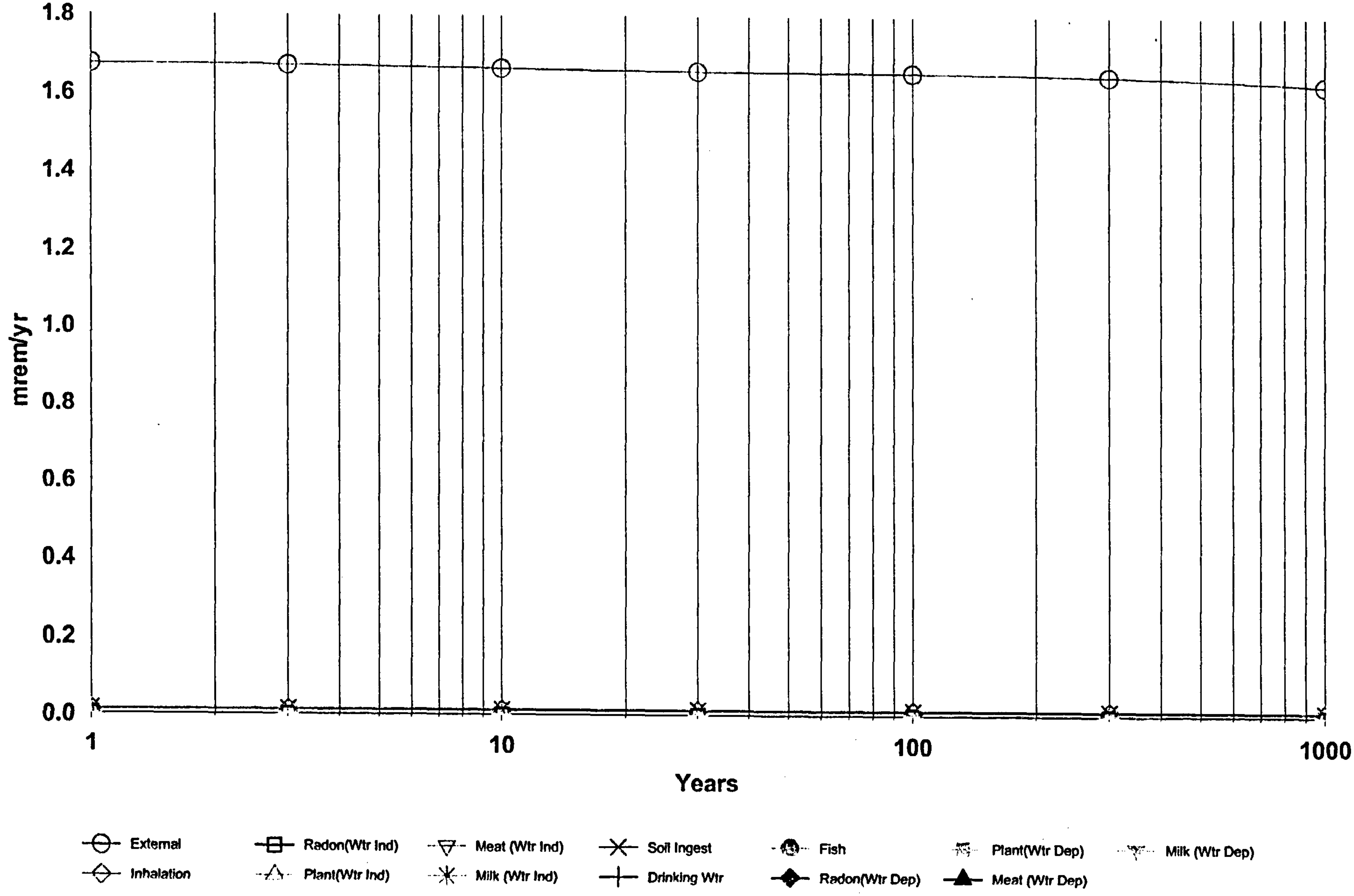
Total Dose Contributions TDOSE(i,p,t) for Individual Radionuclides (i) and Pathways (p)
As mrem/yr and Fraction of Total Dose At t = 0.000E+00 years

Water Dependent Pathways

Radio-Nuclide	Water		Fish		Radon		Plant		Meat		Milk		All Pathwa	
	mrem/yr	fract.	mrem/yr	fract.	mrem/yr	fract.	mrem/yr	fract.	mrem/yr	fract.	mrem/yr	fract.	mrem/yr	fr
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	7.253E-03	0.
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	1.281E-03	0.
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	6.430E-03	0.
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	6.803E-01	0.
Ra-228	0.000E+00	0.0000	0.000E+00	0.0000	0.000E+00	0.0000	0.000E+00	0.0000	0.000E+00	0.0000	0.000E+00	0.0000	4.377E-01	0.
Th-228	0.000E+00	0.0000	0.000E+00	0.0000	0.000E+00	0.0000	0.000E+00	0.0000	0.000E+00	0.0000	0.000E+00	0.0000	5.182E-01	0.
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	1.898E-03	0.
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	3.347E-02	0.
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	7.540E-04	0.
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	2.208E-03	0.
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	9.014E-03	0.
Total	0.000E+00	0.0000	0.000E+00	0.0000	0.000E+00	0.0000	0.000E+00	0.0000	0.000E+00	0.0000	0.000E+00	0.0000	1.699E+00	1.

*Sum of all water independent and dependent pathways.

DOSE: All Nuclides Summed, Component Pathways



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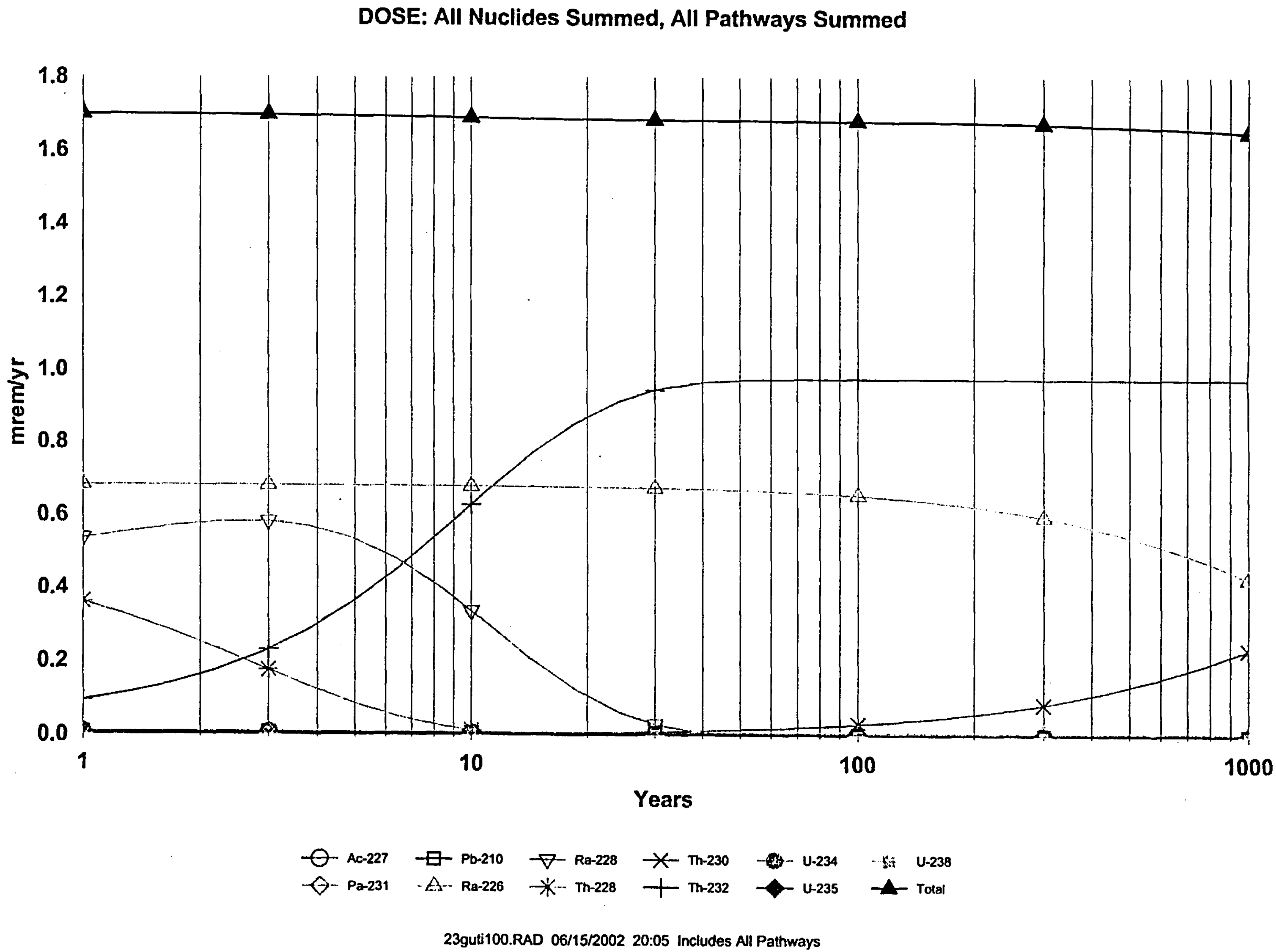
DOSE: All Nuclides Summed, All Pathways Summed
mrem/yr
1.8
1.6
1.4
1.2
1.0
0.8
0.6
0.4
0.2
0.0
1
10
100
1000
Years
Ac-227
Pb-210
Ra-228
Th-230
U-234
U-238
Pa-231
Ra-226
Th-228
Th-232
U-235
Total
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Single Radionuclide Soil Guidelines G(i,t) in pCi/g
Basic Radiation Dose Limit = 2.500E+01 mrem/yr

Nuclide (i)	t= 0.000E+00	1.000E+00	3.000E+00	1.000E+01	3.000E+01	1.000E+02	3.000E+02	1.000E+03
Ac-227	1.992E+02	2.056E+02	2.192E+02	2.743E+02	5.201E+02	4.884E+03	2.938E+06	*7.230E+13
Pa-231	1.343E+03	1.109E+03	8.326E+02	4.745E+02	2.632E+02	1.858E+02	1.928E+02	2.501E+02
Pb-210	1.145E+04	1.182E+04	1.258E+04	1.564E+04	2.915E+04	2.578E+05	1.306E+08	*7.631E+13
Ra-226	4.542E+01	4.544E+01	4.547E+01	4.559E+01	4.595E+01	4.743E+01	5.210E+01	7.245E+01
Ra-228	7.075E+01	5.794E+01	5.336E+01	9.186E+01	1.002E+03	5.286E+06	*2.726E+14	*2.726E+14
Th-228	5.996E+01	8.614E+01	1.778E+02	2.246E+03	3.151E+06	*8.192E+14	*8.192E+14	*8.192E+14
Th-230	1.804E+04	1.539E+04	1.190E+04	6.639E+03	2.943E+03	1.012E+03	3.677E+02	1.323E+02
Th-232	9.509E+02	3.371E+02	1.352E+02	4.943E+01	3.289E+01	3.187E+01	3.188E+01	3.193E+01
U-234	4.773E+04	4.778E+04	4.787E+04	4.821E+04	4.914E+04	5.181E+04	5.348E+04	2.964E+04
U-235	6.321E+02	6.328E+02	6.341E+02	6.387E+02	6.518E+02	6.984E+02	8.478E+02	1.639E+03
U-238	3.448E+03	3.452E+03	3.459E+03	3.485E+03	3.559E+03	3.832E+03	4.734E+03	9.913E+03

*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	4.550E-02	0.000E+00	1.255E-01	1.992E+02	1.255E-01	1.992E+02
Pa-231	4.550E-02	136.6 ± 0.3	1.362E-01	1.835E+02	1.862E-02	1.343E+03
Pb-210	1.000E+00	0.000E+00	2.183E-03	1.145E+04	2.183E-03	1.145E+04
Ra-226	1.000E+00	0.000E+00	5.504E-01	4.542E+01	5.504E-01	4.542E+01
Ra-228	1.000E+00	2.666 ± 0.005	4.696E-01	5.324E+01	3.533E-01	7.075E+01
Th-228	1.000E+00	0.000E+00	4.170E-01	5.996E+01	4.170E-01	5.996E+01
Th-230	1.000E+00	1.000E+03	1.890E-01	1.323E+02	1.386E-03	1.804E+04
Th-232	1.000E+00	91.1 ± 0.2	7.845E-01	3.187E+01	2.629E-02	9.509E+02
U-234	1.000E+00	1.000E+03	8.434E-04	2.964E+04	5.238E-04	4.773E+04
U-235	4.550E-02	0.000E+00	3.955E-02	6.321E+02	3.955E-02	6.321E+02
U-238	1.000E+00	0.000E+00	7.250E-03	3.448E+03	7.250E-03	3.448E+03

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)

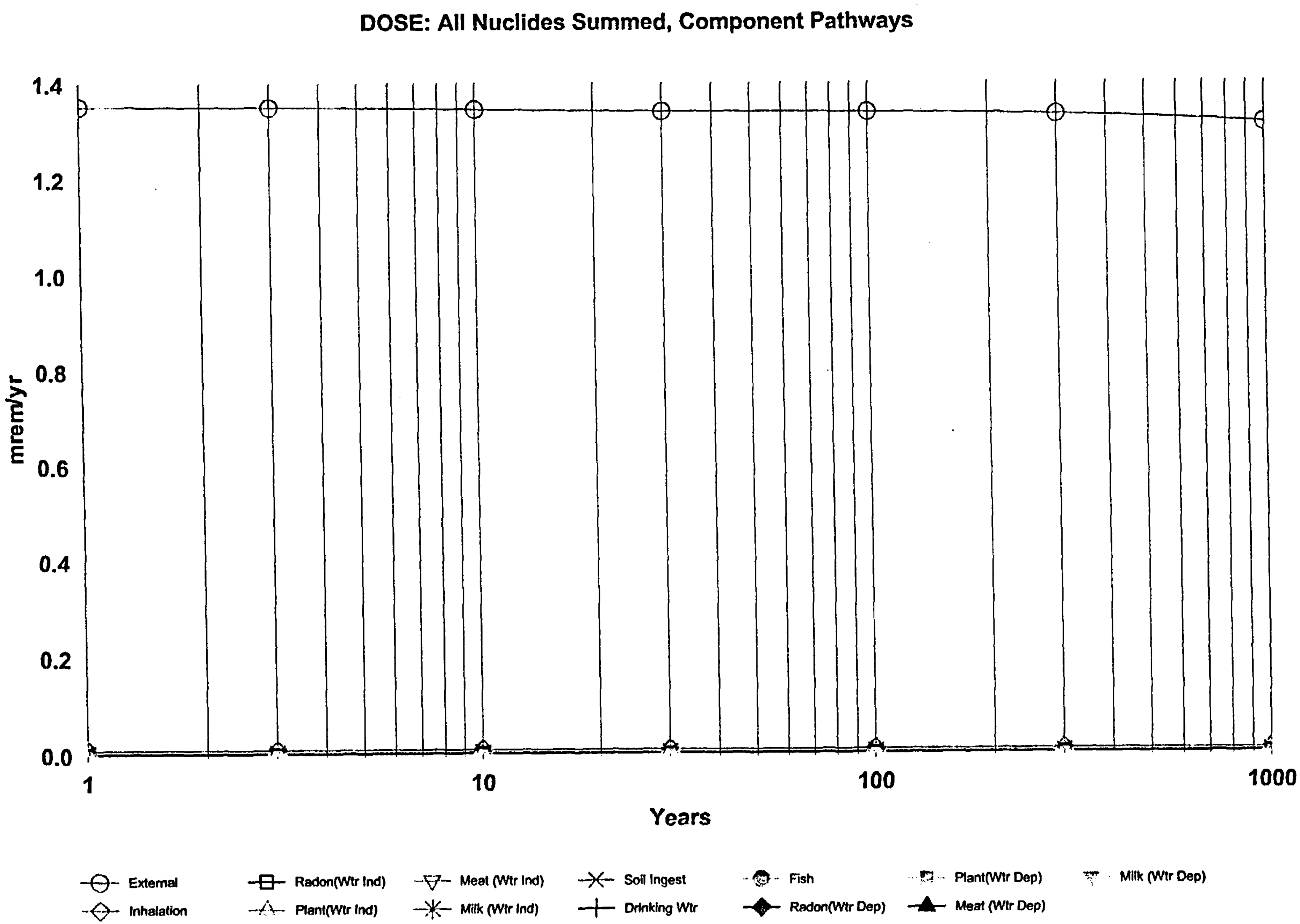
Radio-	Ground		Inhalation		Radon		Plant		Meat		Milk		Soil	
Nuclide	mrem/yr	fract.	mrem/yr	fract.	mrem/yr	fract.	mrem/yr	fract.	mrem/yr	fract.	mrem/yr	fract.	mrem/yr	fr
Ac-227	4.562E-03	0.0033	9.841E-04	0.0007	0.000E+00	0.0000	0.000E+00	0.0000	0.000E+00	0.0000	0.000E+00	0.0000	1.656E-04	0.
Pa-231	5.180E-04	0.0004	2.062E-04	0.0002	0.000E+00	0.0000	0.000E+00	0.0000	0.000E+00	0.0000	0.000E+00	0.0000	1.231E-04	0.
Pb-210	3.198E-04	0.0002	7.470E-05	0.0001	0.000E+00	0.0000	0.000E+00	0.0000	0.000E+00	0.0000	0.000E+00	0.0000	1.788E-03	0.
Ra-226	5.500E-01	0.4025	2.928E-05	0.0000	0.000E+00	0.0000	0.000E+00	0.0000	0.000E+00	0.0000	0.000E+00	0.0000	3.601E-04	0.
Ra-228	3.528E-01	0.2581	1.900E-04	0.0001	0.000E+00	0.0000	0.000E+00	0.0000	0.000E+00	0.0000	0.000E+00	0.0000	3.698E-04	0.
Th-228	4.158E-01	0.3043	9.465E-04	0.0007	0.000E+00	0.0000	0.000E+00	0.0000	0.000E+00	0.0000	0.000E+00	0.0000	1.693E-04	0.
Th-230	1.830E-04	0.0001	1.066E-03	0.0008	0.000E+00	0.0000	0.000E+00	0.0000	0.000E+00	0.0000	0.000E+00	0.0000	1.370E-04	0.
Th-232	2.022E-02	0.0148	5.372E-03	0.0039	0.000E+00	0.0000	0.000E+00	0.0000	0.000E+00	0.0000	0.000E+00	0.0000	7.041E-04	0.
U-234	2.170E-05	0.0000	4.315E-04	0.0003	0.000E+00	0.0000	0.000E+00	0.0000	0.000E+00	0.0000	0.000E+00	0.0000	7.066E-05	0.
U-235	1.778E-03	0.0013	1.829E-05	0.0000	0.000E+00	0.0000	0.000E+00	0.0000	0.000E+00	0.0000	0.000E+00	0.0000	3.034E-06	0.
U-238	6.797E-03	0.0050	3.857E-04	0.0003	0.000E+00	0.0000	0.000E+00	0.0000	0.000E+00	0.0000	0.000E+00	0.0000	6.716E-05	0.
Total	1.353E+00	0.9900	9.704E-03	0.0071	0.000E+00	0.0000	0.000E+00	0.0000	0.000E+00	0.0000	0.000E+00	0.0000	3.958E-03	0.

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 Pathwa	
Nuclide	mrem/yr	fract.	mrem/yr	fract.	mrem/yr	fract.	mrem/yr	fract.	mrem/yr	fract.	mrem/yr	fract.	mrem/yr	fr
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	5.712E-03	0.
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	8.473E-04	0.
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	2.183E-03	0.
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	5.504E-01	0.
Ra-228	0.000E+00	0.0000	0.000E+00	0.0000	0.000E+00	0.0000	0.000E+00	0.0000	0.000E+00	0.0000	0.000E+00	0.0000	3.533E-01	0.
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	4.170E-01	0.
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	1.386E-03	0.
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	2.629E-02	0.
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	5.238E-04	0.
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	1.799E-03	0.
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	7.250E-03	0.
Total	0.000E+00	0.0000	0.000E+00	0.0000	0.000E+00	0.0000	0.000E+00	0.0000	0.000E+00	0.0000	0.000E+00	0.0000	1.367E+00	1.

*Sum of all water independent and dependent pathways.



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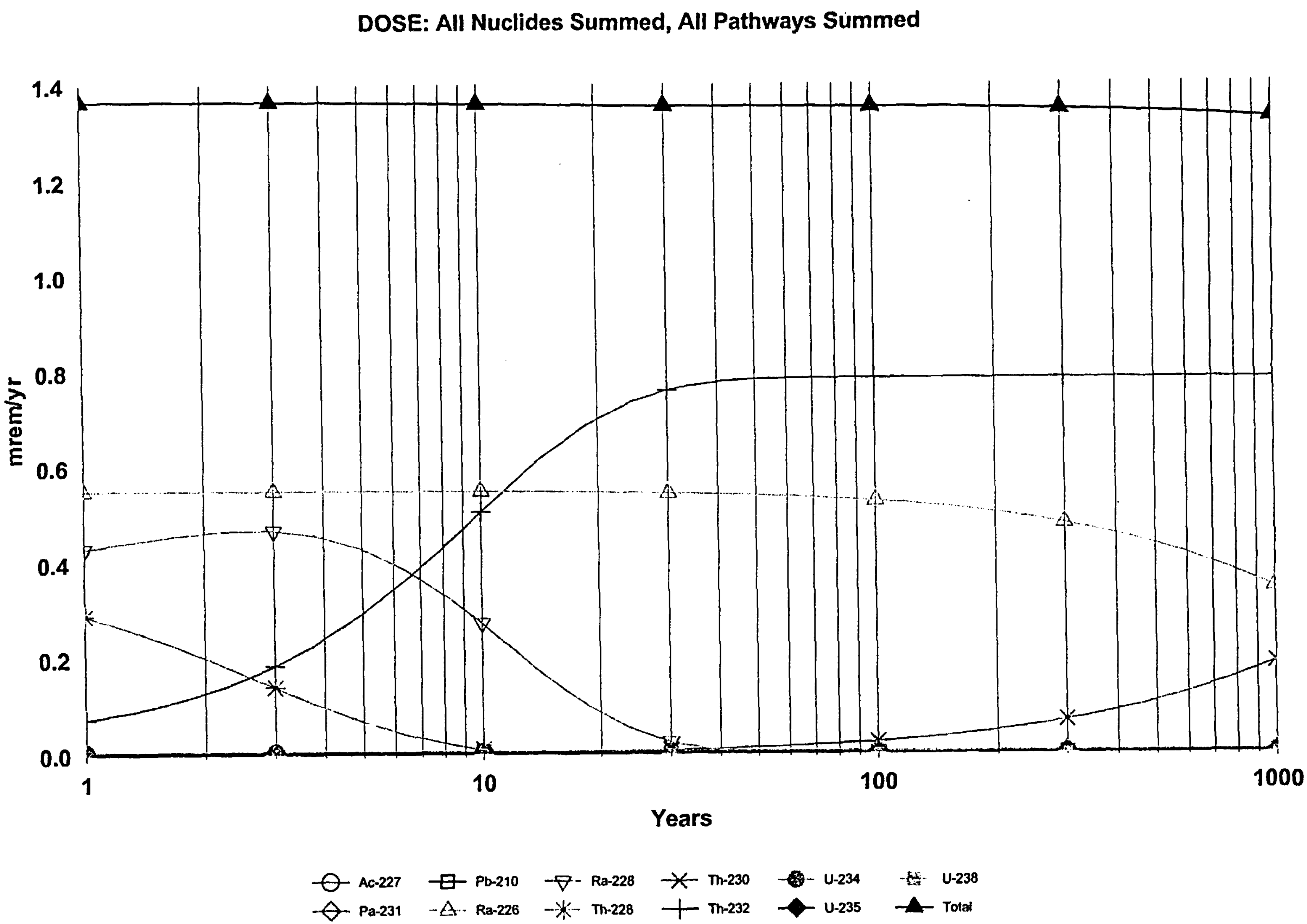

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Single Radionuclide Soil Guidelines G(i,t) in pCi/g
Basic Radiation Dose Limit = 2.500E+01 mrem/yr

Nuclide (i)	t= 0.000E+00	1.000E+00	3.000E+00	1.000E+01	3.000E+01	1.000E+02	3.000E+02	1.000E+03
Ac-227	2.669E+02	2.755E+02	2.938E+02	3.675E+02	6.969E+02	6.545E+03	3.936E+06	*7.230E+13
Pa-231	1.888E+03	1.546E+03	1.149E+03	6.466E+02	3.559E+02	2.506E+02	2.599E+02	3.372E+02
Pb-210	2.769E+04	2.856E+04	3.040E+04	3.780E+04	7.046E+04	6.231E+05	3.157E+08	*7.631E+13
Ra-226	6.303E+01	6.305E+01	6.310E+01	6.329E+01	6.384E+01	6.592E+01	7.242E+01	1.007E+02
Ra-228	9.825E+01	8.061E+01	7.433E+01	1.281E+02	1.397E+03	7.371E+06	*2.726E+14	*2.726E+14
Th-228	8.381E+01	1.204E+02	2.485E+02	3.139E+03	4.404E+06	*8.192E+14	*8.192E+14	*8.192E+14
Th-230	2.226E+04	1.931E+04	1.526E+04	8.811E+03	4.005E+03	1.396E+03	5.097E+02	1.837E+02
Th-232	1.278E+03	4.630E+02	1.871E+02	6.873E+01	4.578E+01	4.436E+01	4.438E+01	4.444E+01
U-234	5.925E+04	5.931E+04	5.943E+04	5.985E+04	6.101E+04	6.445E+04	6.767E+04	4.012E+04
U-235	8.609E+02	8.618E+02	8.636E+02	8.699E+02	8.877E+02	9.511E+02	1.154E+03	2.230E+03
U-238	4.714E+03	4.719E+03	4.729E+03	4.764E+03	4.866E+03	5.239E+03	6.471E+03	1.355E+04

*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	4.550E-02	0.000E+00	9.368E-02	2.669E+02	9.368E-02	2.669E+02
Pa-231	4.550E-02	136.7 ± 0.3	1.010E-01	2.475E+02	1.324E-02	1.888E+03
Pb-210	1.000E+00	0.000E+00	9.030E-04	2.769E+04	9.030E-04	2.769E+04
Ra-226	1.000E+00	0.000E+00	3.967E-01	6.303E+01	3.967E-01	6.303E+01
Ra-228	1.000E+00	2.656 ± 0.005	3.372E-01	7.415E+01	2.545E-01	9.825E+01
Th-228	1.000E+00	0.000E+00	2.983E-01	8.381E+01	2.983E-01	8.381E+01
Th-230	1.000E+00	1.000E+03	1.361E-01	1.837E+02	1.123E-03	2.226E+04
Th-232	1.000E+00	90.7 ± 0.2	5.636E-01	4.436E+01	1.957E-02	1.278E+03
U-234	1.000E+00	1.000E+03	6.231E-04	4.012E+04	4.220E-04	5.925E+04
U-235	4.550E-02	0.000E+00	2.904E-02	8.609E+02	2.904E-02	8.609E+02
U-238	1.000E+00	0.000E+00	5.304E-03	4.714E+03	5.304E-03	4.714E+03

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-Nuclide	Ground		Inhalation		Radon		Plant		Meat		Milk		Soil	
	mrem/yr	fract.	mrem/yr	fract.	mrem/yr	fract.	mrem/yr	fract.	mrem/yr	fract.	mrem/yr	fract.	mrem/yr	fr
Ac-227	3.231E-03	0.0033	8.441E-04	0.0009	0.000E+00	0.0000	0.000E+00	0.0000	0.000E+00	0.0000	0.000E+00	0.0000	5.345E-05	0.
Pa-231	4.831E-04	0.0005	2.098E-04	0.0002	0.000E+00	0.0000	0.000E+00	0.0000	0.000E+00	0.0000	0.000E+00	0.0000	4.275E-05	0.
Pb-210	2.334E-04	0.0002	6.413E-05	0.0001	0.000E+00	0.0000	0.000E+00	0.0000	0.000E+00	0.0000	0.000E+00	0.0000	5.778E-04	0.
Ra-226	3.963E-01	0.4035	2.795E-05	0.0000	0.000E+00	0.0000	0.000E+00	0.0000	0.000E+00	0.0000	0.000E+00	0.0000	1.382E-04	0.
Ra-228	3.096E-01	0.3152	3.878E-04	0.0004	0.000E+00	0.0000	0.000E+00	0.0000	0.000E+00	0.0000	0.000E+00	0.0000	1.251E-04	0.
Th-228	2.070E-01	0.2107	5.835E-04	0.0006	0.000E+00	0.0000	0.000E+00	0.0000	0.000E+00	0.0000	0.000E+00	0.0000	3.929E-05	0.
Th-230	3.050E-04	0.0003	9.442E-04	0.0010	0.000E+00	0.0000	0.000E+00	0.0000	0.000E+00	0.0000	0.000E+00	0.0000	4.571E-05	0.
Th-232	4.895E-02	0.0498	4.792E-03	0.0049	0.000E+00	0.0000	0.000E+00	0.0000	0.000E+00	0.0000	0.000E+00	0.0000	2.497E-04	0.
U-234	1.628E-05	0.0000	3.817E-04	0.0004	0.000E+00	0.0000	0.000E+00	0.0000	0.000E+00	0.0000	0.000E+00	0.0000	2.353E-05	0.
U-235	1.303E-03	0.0013	1.619E-05	0.0000	0.000E+00	0.0000	0.000E+00	0.0000	0.000E+00	0.0000	0.000E+00	0.0000	1.011E-06	0.
U-238	4.934E-03	0.0050	3.412E-04	0.0003	0.000E+00	0.0000	0.000E+00	0.0000	0.000E+00	0.0000	0.000E+00	0.0000	2.236E-05	0.
Total	9.724E-01	0.9899	8.593E-03	0.0087	0.000E+00	0.0000	0.000E+00	0.0000	0.000E+00	0.0000	0.000E+00	0.0000	1.319E-03	0.

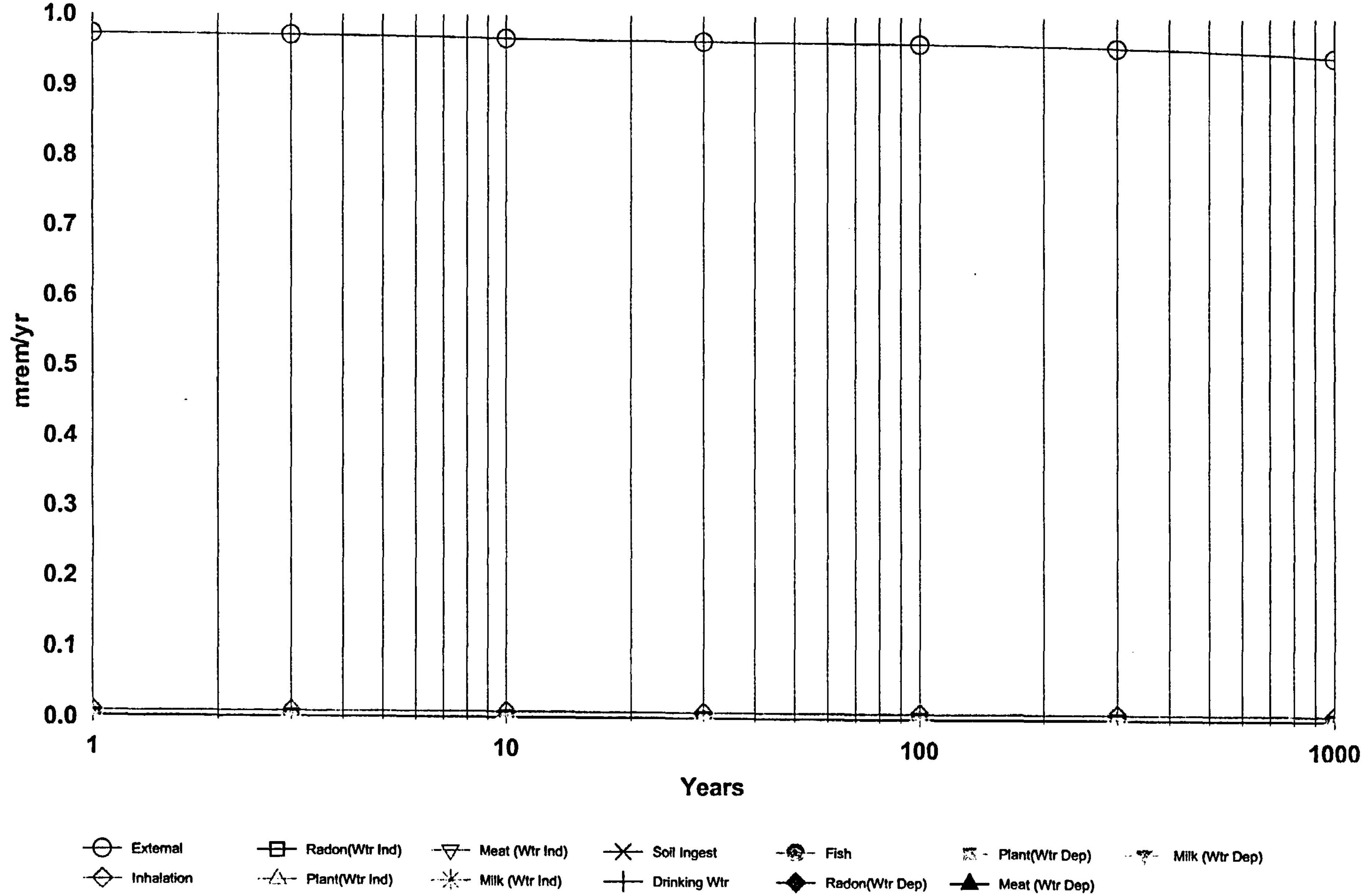
Total Dose Contributions TDOSE(i,p,t) for Individual Radionuclides (i) and Pathways (p)
As mrem/yr and Fraction of Total Dose At t = 1.000E+00 years

Water Dependent Pathways

Radio-Nuclide	Water		Fish		Radon		Plant		Meat		Milk		All Pathwa	
	mrem/yr	fract.	mrem/yr	fract.	mrem/yr	fract.	mrem/yr	fract.	mrem/yr	fract.	mrem/yr	fract.	mrem/yr	fr
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	4.128E-03	0.
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	7.357E-04	0.
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	8.753E-04	0.
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	3.965E-01	0.
Ra-228	0.000E+00	0.0000	0.000E+00	0.0000	0.000E+00	0.0000	0.000E+00	0.0000	0.000E+00	0.0000	0.000E+00	0.0000	3.101E-01	0.
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	2.076E-01	0.
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	1.295E-03	0.
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	5.399E-02	0.
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	4.215E-04	0.
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-03	0.
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	5.298E-03	0.
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	9.823E-01	1.

*Sum of all water independent and dependent pathways.

DOSE: All Nuclides Summed, Component Pathways



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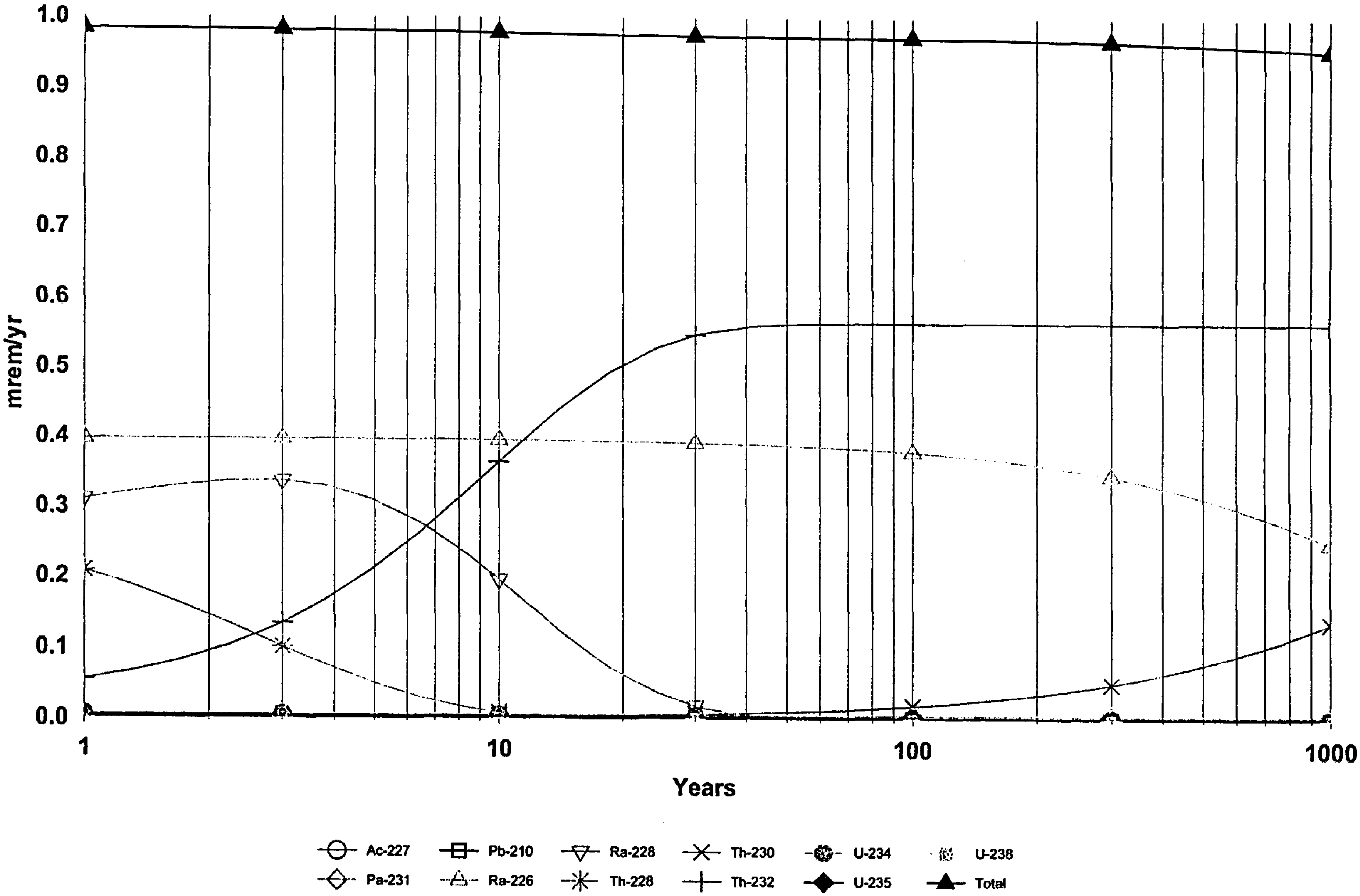
DOSE: All Nuclides Summed, All Pathways Summed



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Area Factor on Pavement –
Basis for Figure 5-2

And

Pavement Th Series –
Basis for Table 5-3

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

Parent (i)	Product (j)	Branch Fraction*	DSR(j,t) (mrem/yr)/(pCi/g) t= 0.000E+00	1.000E+00	3.000E+00	1.000E+01	3.000E+01	1.000E+02	3.000E+02	1.000E+03
Ra-228	Ra-228	1.000E+00	2.377E-03	4.723E-05	1.864E-08	2.278E-20	0.000E+00	0.000E+00	0.000E+00	0.000E+00
Ra-228	Th-228	1.000E+00	8.417E-04	8.248E-04	3.995E-04	3.066E-05	1.999E-08	1.416E-19	0.000E+00	0.000E+00
Ra-228	∑DSR(j)		3.219E-03	8.720E-04	3.995E-04	3.066E-05	1.999E-08	1.416E-19	0.000E+00	0.000E+00
Th-228	Th-228	1.000E+00	1.177E-02	8.155E-03	3.916E-03	3.005E-04	1.960E-07	1.388E-18	0.000E+00	0.000E+00
Th-232	Th-232	1.000E+00	2.228E-04	2.218E-04	2.199E-04	2.131E-04	1.950E-04	1.429E-04	5.873E-05	2.617E-06
Th-232	Ra-228	1.000E+00	2.188E-04	2.892E-04	2.881E-04	2.793E-04	2.555E-04	1.872E-04	7.696E-05	3.429E-06
Th-232	Th-228	1.000E+00	4.364E-05	1.535E-04	2.934E-04	4.030E-04	3.781E-04	2.770E-04	1.139E-04	5.073E-06
Th-232	∑DSR(j)		4.852E-04	6.646E-04	8.013E-04	8.954E-04	8.286E-04	6.071E-04	2.496E-04	1.112E-05

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

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

Nuclide (i)	t= 0.000E+00	1.000E+00	3.000E+00	1.000E+01	3.000E+01	1.000E+02	3.000E+02	1.000E+03
Ra-228	7.767E+03	2.867E+04	6.258E+04	8.155E+05	1.250E+09	*2.726E+14	*2.726E+14	*2.726E+14
Th-228	2.124E+03	3.065E+03	6.384E+03	8.318E+04	1.275E+08	*8.192E+14	*8.192E+14	*8.192E+14
Th-232	5.153E+04	3.762E+04	3.120E+04	2.792E+04	3.017E+04	4.118E+04	1.002E+05	*1.096E+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)
Ra-228	1.000E+00	0.000E+00	3.219E-03	7.767E+03	3.219E-03	7.767E+03
Th-228	1.000E+00	0.000E+00	1.177E-02	2.124E+03	1.177E-02	2.124E+03
Th-232	1.000E+00	9.80 ± 0.02	8.954E-04	2.792E+04	4.852E-04	5.153E+04

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

Water Independent Pathways (Inhalation excludes radon)

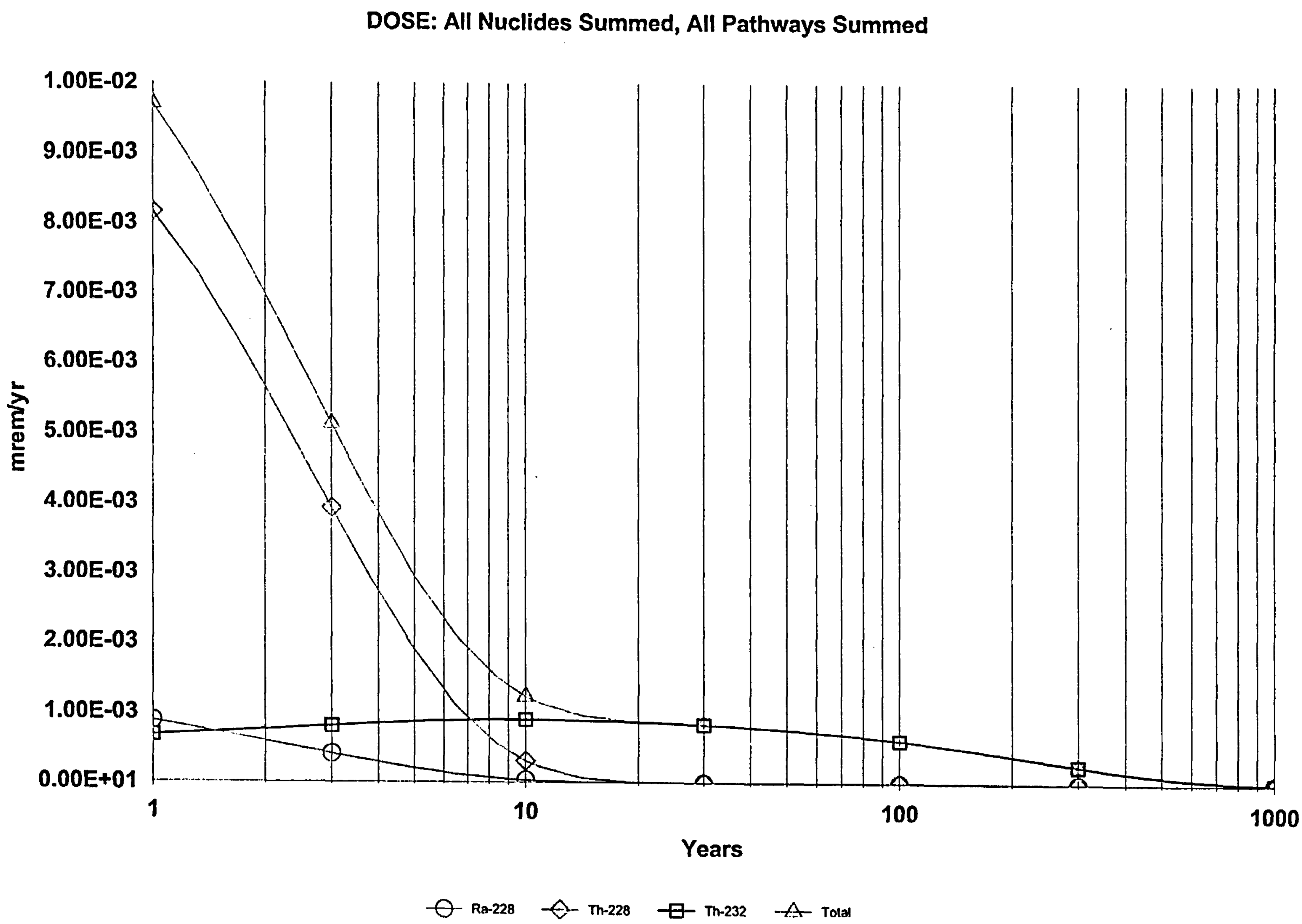
Radio-Nuclide	Ground		Inhalation		Radon		Plant		Meat		Milk		Soil	
	mrem/yr	fract.	mrem/yr	fract.	mrem/yr	fract.	mrem/yr	fract.	mrem/yr	fract.	mrem/yr	fract.	mrem/yr	fract.
Ra-228	3.195E-03	0.2065	8.949E-07	0.0001	0.000E+00	0.0000	0.000E+00	0.0000	0.000E+00	0.0000	0.000E+00	0.0000	2.269E-05	0.0015
Th-228	1.172E-02	0.7574	1.179E-05	0.0008	0.000E+00	0.0000	0.000E+00	0.0000	0.000E+00	0.0000	0.000E+00	0.0000	3.755E-05	0.0024
Th-232	2.652E-04	0.0171	6.684E-05	0.0043	0.000E+00	0.0000	0.000E+00	0.0000	0.000E+00	0.0000	0.000E+00	0.0000	1.532E-04	0.0099
Total	1.518E-02	0.9811	7.952E-05	0.0051	0.000E+00	0.0000	0.000E+00	0.0000	0.000E+00	0.0000	0.000E+00	0.0000	2.134E-04	0.0138

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

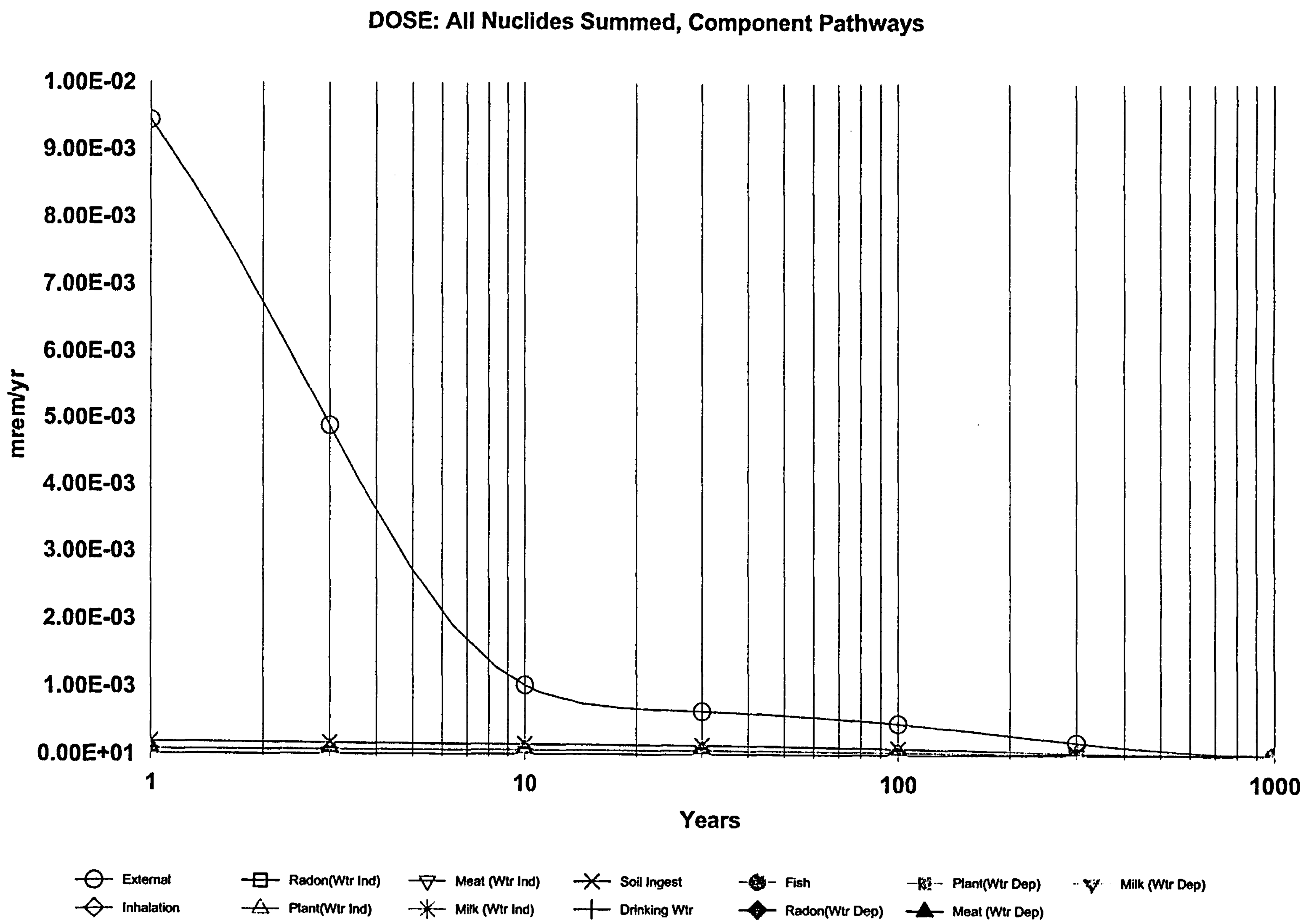
Water Dependent Pathways

Radio-Nuclide	Water		Fish		Radon		Plant		Meat		Milk		All Pathways*	
	mrem/yr	fract.	mrem/yr	fract.	mrem/yr	fract.	mrem/yr	fract.	mrem/yr	fract.	mrem/yr	fract.	mrem/yr	fract.
Ra-228	0.000E+00	0.0000	0.000E+00	0.0000	0.000E+00	0.0000	0.000E+00	0.0000	0.000E+00	0.0000	0.000E+00	0.0000	3.219E-03	0.2080
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	1.177E-02	0.7606
Th-232	0.000E+00	0.0000	0.000E+00	0.0000	0.000E+00	0.0000	0.000E+00	0.0000	0.000E+00	0.0000	0.000E+00	0.0000	4.852E-04	0.0314
Total	0.000E+00	0.0000	0.000E+00	0.0000	0.000E+00	0.0000	0.000E+00	0.0000	0.000E+00	0.0000	0.000E+00	0.0000	1.547E-02	1.0000

*Sum of all water independent and dependent pathways.

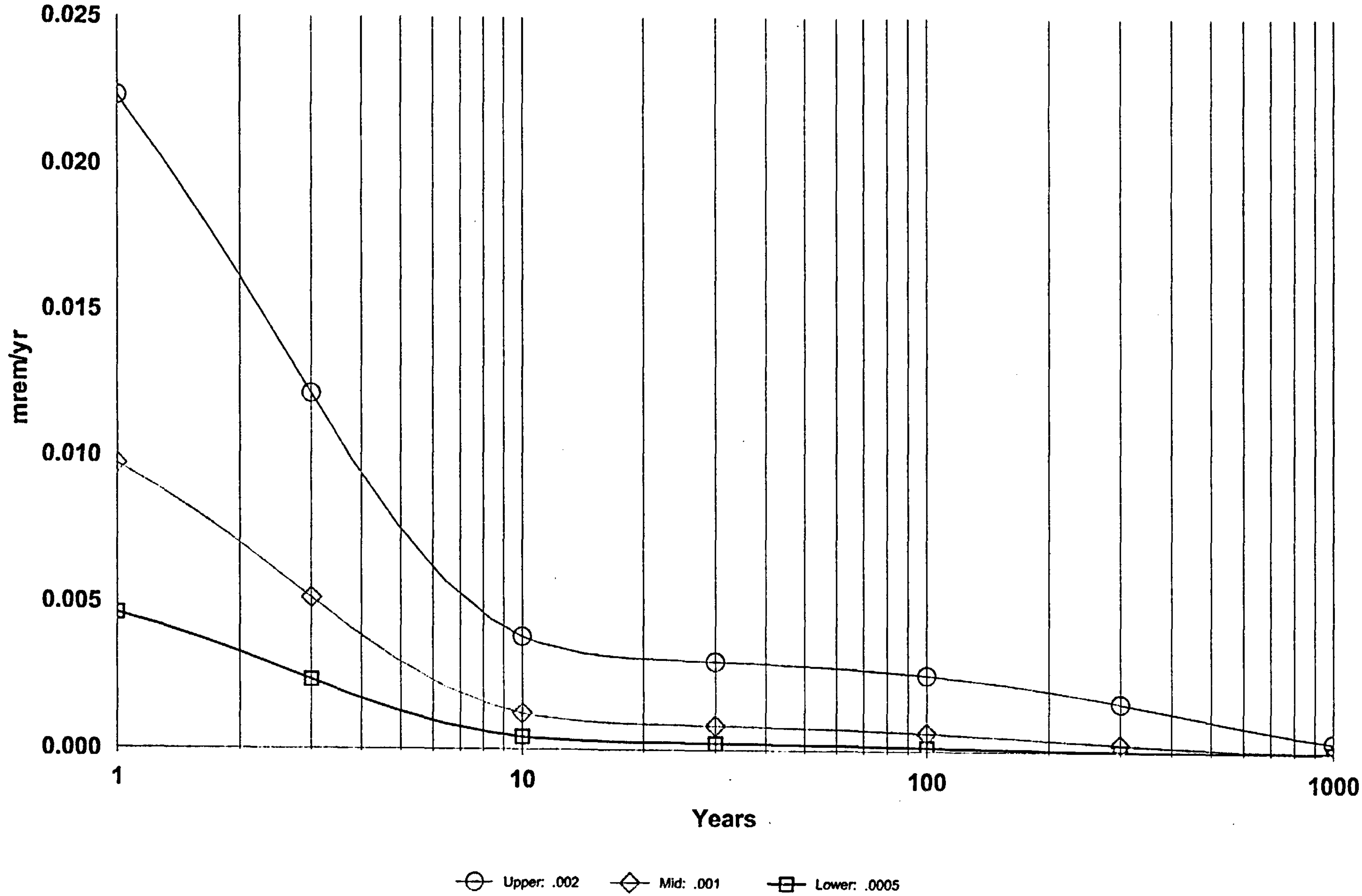


26ptp10k.RAD 07/06/2002 16:31 Includes All Pathways



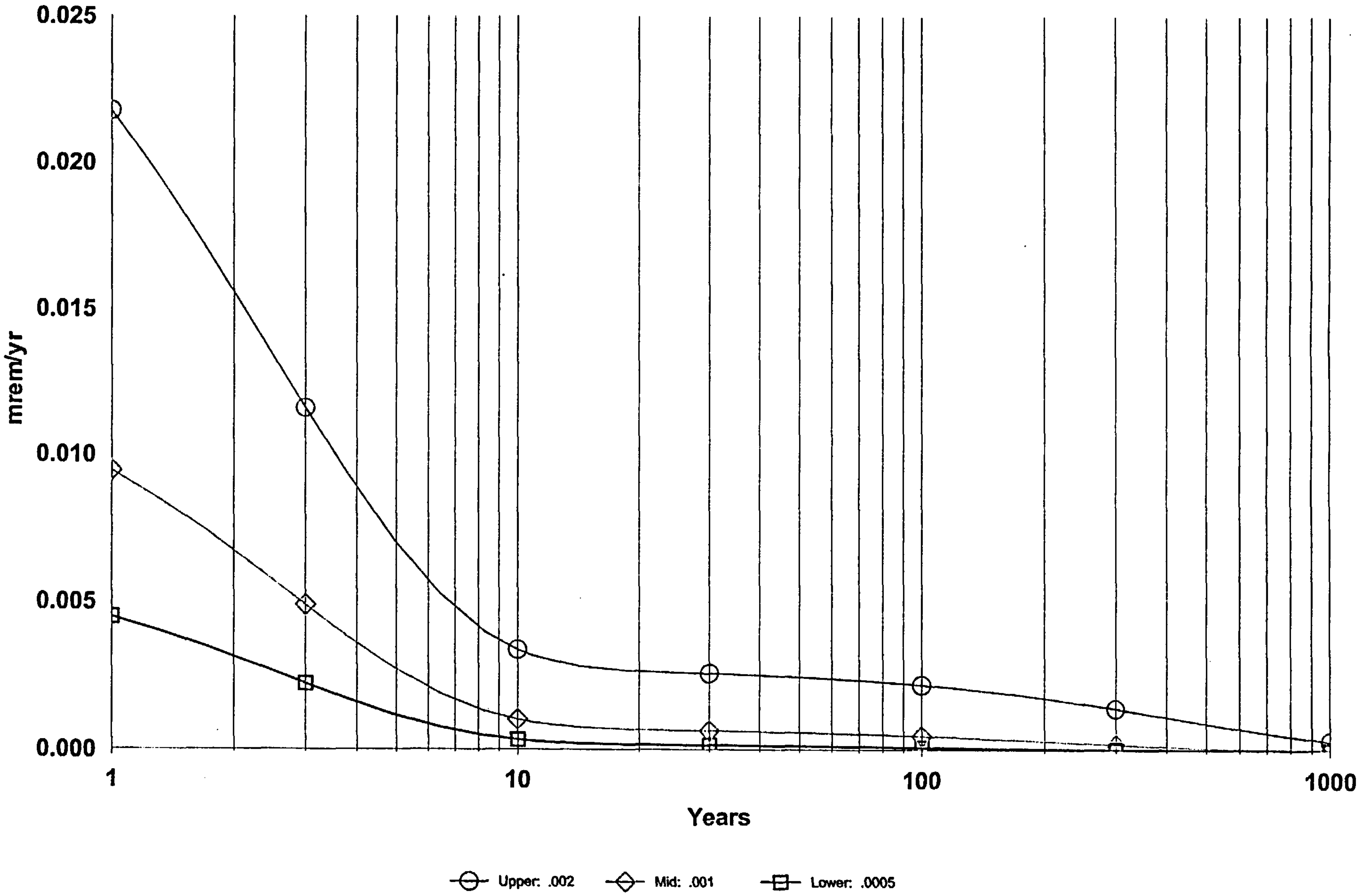
26ptp10k.RAD 07/06/2002 16:31

DOSE: All Nuclides Summed, All Pathways Summed With SA on Thickness of contaminated zone



26ptp10k.RAD 07/06/2002 16:31 Includes All Pathways

DOSE: All Nuclides Summed, External With SA on Thickness of contaminated zone



26ptp10k.RAD 07/06/2002 16:31 Pathways: External

Pavement Area = 10,000 m^2- Basis for Table 5-3

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

Nuclide (i)	t= 0.000E+00	1.000E+00	3.000E+00	1.000E+01	3.000E+01	1.000E+02	3.000E+02	1.000E+03
Ac-227	5.858E+03	8.354E+03	1.699E+04	2.039E+05	2.470E+08	*7.230E+13	*7.230E+13	*7.230E+13
Pa-231	3.093E+04	5.193E+04	1.344E+05	2.147E+06	2.688E+09	*4.722E+10	*4.722E+10	*4.722E+10
Pb-210	6.017E+04	6.938E+04	9.227E+04	2.503E+05	4.332E+06	9.343E+10	*7.631E+13	*7.631E+13
Ra-226	1.536E+03	1.655E+03	1.924E+03	3.262E+03	1.482E+04	3.004E+06	*9.882E+11	*9.882E+11
Th-230	4.720E+05	4.366E+05	3.913E+05	3.453E+05	5.065E+05	8.471E+06	*2.018E+10	*2.018E+10
U-234	2.223E+06	1.838E+07	1.241E+09	*6.245E+09	*6.245E+09	*6.245E+09	*6.245E+09	*6.245E+09
U-235	3.559E+04	2.943E+05	*2.160E+06	*2.160E+06	*2.160E+06	*2.160E+06	*2.160E+06	*2.160E+06
U-238	1.959E+05	*3.360E+05	*3.360E+05	*3.360E+05	*3.360E+05	*3.360E+05	*3.360E+05	*3.360E+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	4.550E-02	0.000E+00	4.268E-03	5.858E+03	4.268E-03	5.858E+03
Pa-231	4.550E-02	0.000E+00	8.084E-04	3.093E+04	8.084E-04	3.093E+04
Pb-210	1.000E+00	0.000E+00	4.155E-04	6.017E+04	4.155E-04	6.017E+04
Ra-226	1.000E+00	0.000E+00	1.628E-02	1.536E+03	1.628E-02	1.536E+03
Th-230	1.000E+00	10.15 ± 0.02	7.240E-05	3.453E+05	5.296E-05	4.720E+05
U-234	1.000E+00	0.000E+00	1.125E-05	2.223E+06	1.125E-05	2.223E+06
U-235	4.550E-02	0.000E+00	7.024E-04	3.559E+04	7.024E-04	3.559E+04
U-238	1.000E+00	0.000E+00	1.276E-04	1.959E+05	1.276E-04	1.959E+05

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

Water Independent Pathways (Inhalation excludes radon)

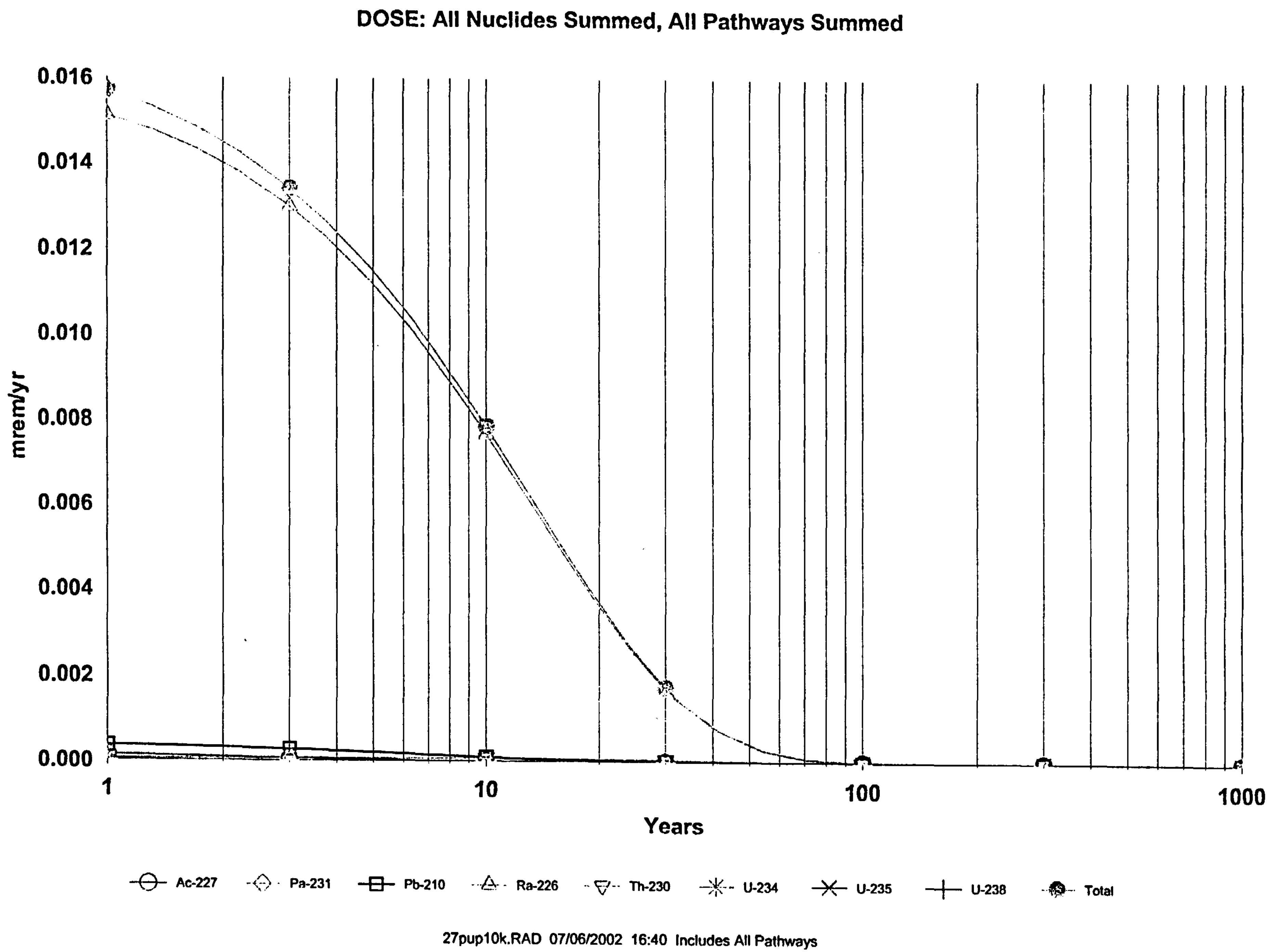
Radio-Nuclide	Ground		Inhalation		Radon		Plant		Meat		Milk		Soil	
	mrem/yr	fract.	mrem/yr	fract.	mrem/yr	fract.	mrem/yr	fract.	mrem/yr	fract.	mrem/yr	fract.	mrem/yr	fract.
Ac-227	1.522E-04	0.0089	1.050E-05	0.0006	0.000E+00	0.0000	0.000E+00	0.0000	0.000E+00	0.0000	0.000E+00	0.0000	3.147E-05	0.0018
Pa-231	1.527E-05	0.0009	1.850E-06	0.0001	0.000E+00	0.0000	0.000E+00	0.0000	0.000E+00	0.0000	0.000E+00	0.0000	1.967E-05	0.0011
Pb-210	3.852E-05	0.0022	8.825E-07	0.0001	0.000E+00	0.0000	0.000E+00	0.0000	0.000E+00	0.0000	0.000E+00	0.0000	3.761E-04	0.0219
Ra-226	1.620E-02	0.9448	3.517E-07	0.0000	0.000E+00	0.0000	0.000E+00	0.0000	0.000E+00	0.0000	0.000E+00	0.0000	7.693E-05	0.0045
Th-230	1.020E-05	0.0006	1.301E-05	0.0008	0.000E+00	0.0000	0.000E+00	0.0000	0.000E+00	0.0000	0.000E+00	0.0000	2.976E-05	0.0017
U-234	2.468E-06	0.0001	2.242E-06	0.0001	0.000E+00	0.0000	0.000E+00	0.0000	0.000E+00	0.0000	0.000E+00	0.0000	6.537E-06	0.0004
U-235	3.158E-05	0.0018	9.505E-08	0.0000	0.000E+00	0.0000	0.000E+00	0.0000	0.000E+00	0.0000	0.000E+00	0.0000	2.807E-07	0.0000
U-238	1.194E-04	0.0070	2.004E-06	0.0001	0.000E+00	0.0000	0.000E+00	0.0000	0.000E+00	0.0000	0.000E+00	0.0000	6.213E-06	0.0004
Total	1.657E-02	0.9663	3.094E-05	0.0018	0.000E+00	0.0000	0.000E+00	0.0000	0.000E+00	0.0000	0.000E+00	0.0000	5.470E-04	0.0319

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

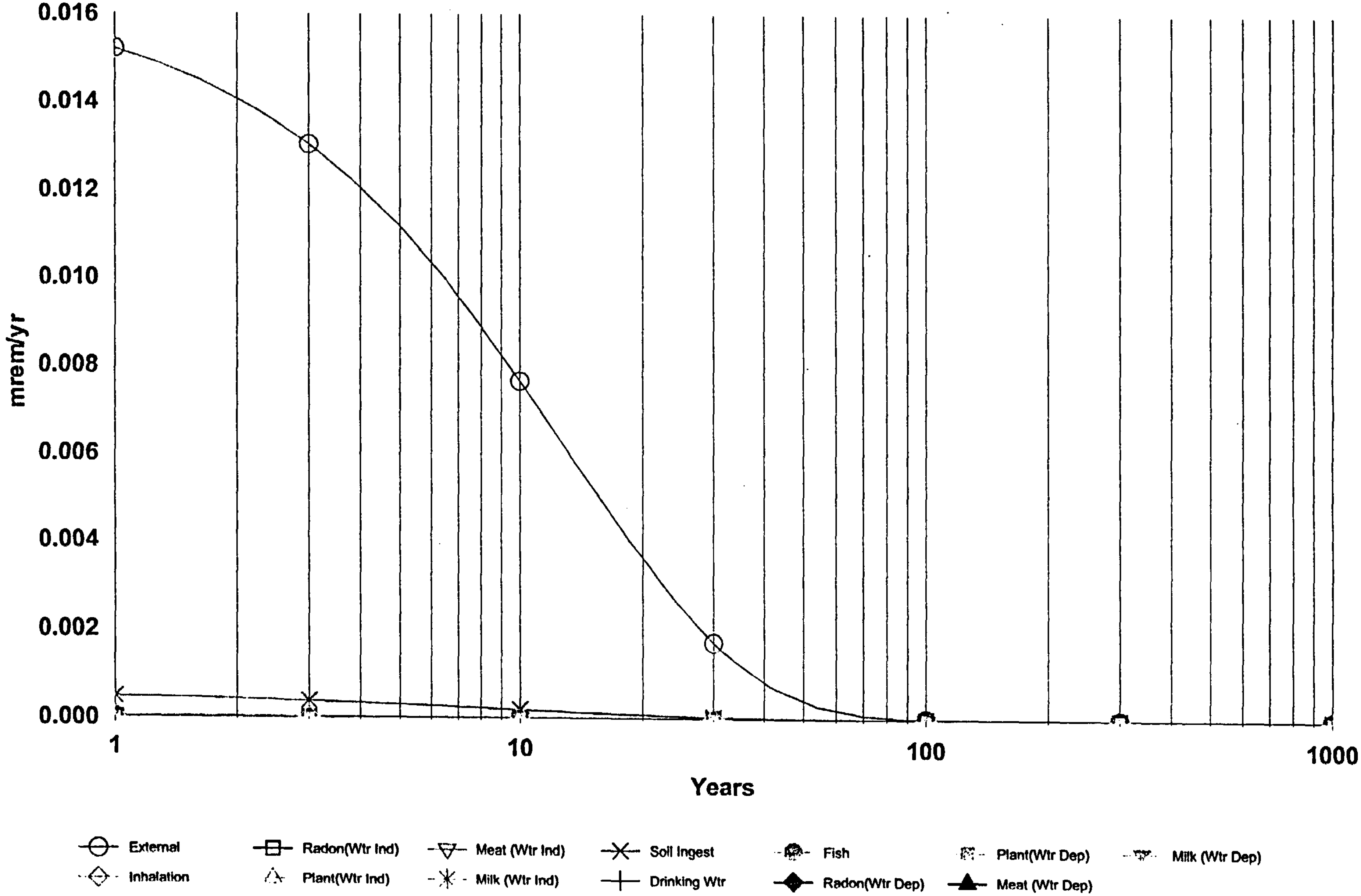
Water Dependent Pathways

Radio-Nuclide	Water		Fish		Radon		Plant		Meat		Milk		All Pathways*	
	mrem/yr	fract.	mrem/yr	fract.	mrem/yr	fract.	mrem/yr	fract.	mrem/yr	fract.	mrem/yr	fract.	mrem/yr	fract.
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	1.942E-04	0.0113
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	3.678E-05	0.0021
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	4.155E-04	0.0242
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	1.628E-02	0.9493
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	5.296E-05	0.0031
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	1.125E-05	0.0007
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	3.196E-05	0.0019
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	1.276E-04	0.0074
Total	0.000E+00	0.0000	0.000E+00	0.0000	0.000E+00	0.0000	0.000E+00	0.0000	0.000E+00	0.0000	0.000E+00	0.0000	1.715E-02	1.0000

*Sum of all water independent and dependent pathways.

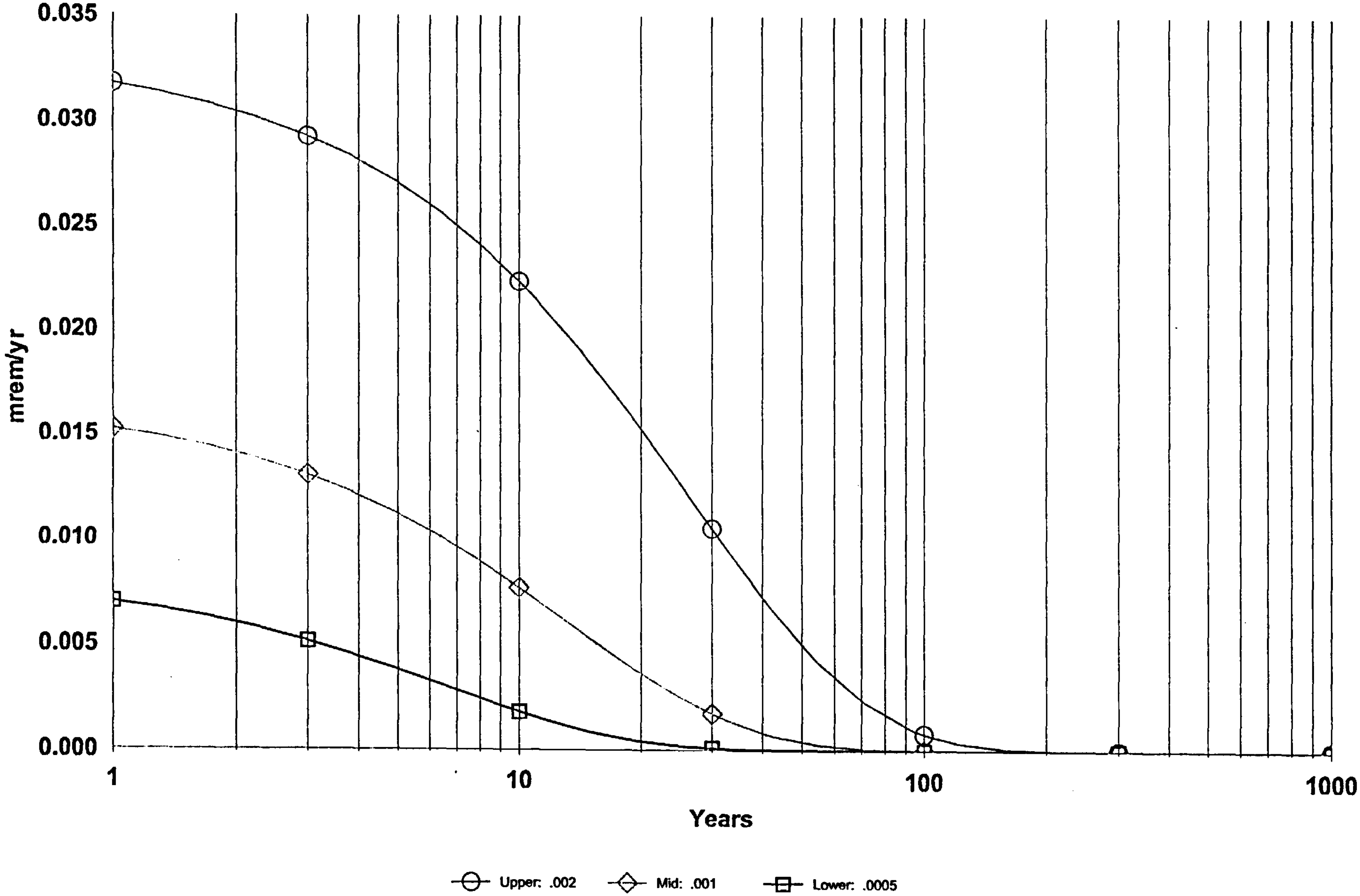

DOSE: All Nuclides Summed, All Pathways Summed
0.016
0.014
0.012
0.010
0.008
0.006
0.004
0.002
0.000
mrem/yr
1
10
100
1000
Years
Ac-227
Pa-231
Pb-210
Ra-226
Th-230
U-234
U-235
U-238
Total
27pup10k.RAD 07/06/2002 16:40 Includes All Pathways

DOSE: All Nuclides Summed, Component Pathways



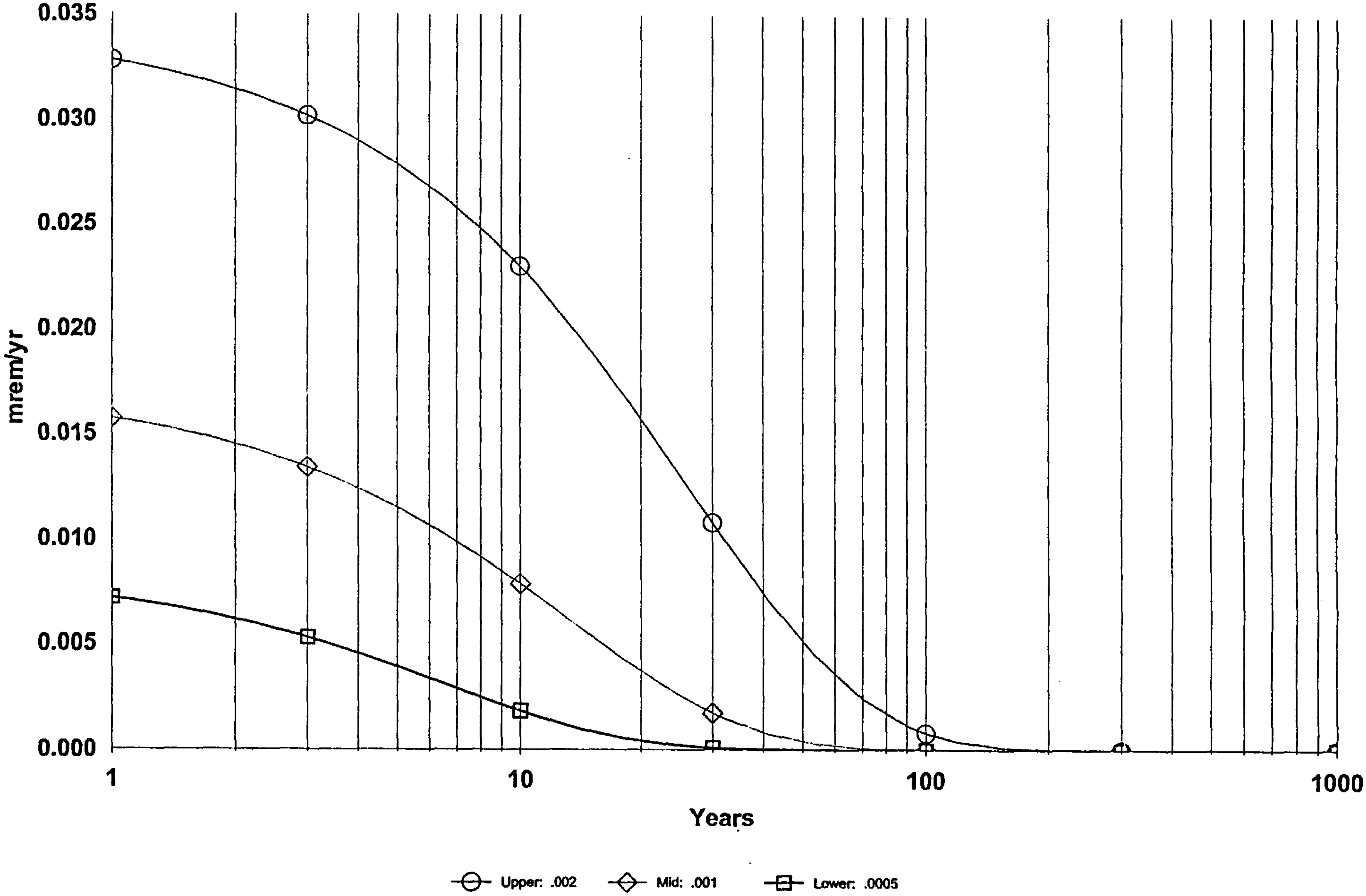
27pup10k.RAD 07/06/2002 16:40

DOSE: All Nuclides Summed, External With SA on Thickness of contaminated zone



27pup10k.RAD 07/06/2002 16:40 Pathways: External

DOSE: All Nuclides Summed, All Pathways Summed With SA on Thickness of contaminated zone



27pup10k.RAD 07/06/2002 16:40 Includes All Pathways

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

Nuclide (i)	t= 0.000E+00	1.000E+00	3.000E+00	1.000E+01	3.000E+01	1.000E+02	3.000E+02	1.000E+03
Ac-227	6.878E+03	9.809E+03	1.995E+04	2.394E+05	2.901E+08	*7.230E+13	*7.230E+13	*7.230E+13
Pa-231	3.366E+04	5.722E+04	1.515E+05	2.509E+06	3.156E+09	*4.722E+10	*4.722E+10	*4.722E+10
Pb-210	6.066E+04	6.996E+04	9.304E+04	2.524E+05	4.368E+06	9.420E+10	*7.631E+13	*7.631E+13
Ra-226	1.830E+03	1.973E+03	2.293E+03	3.884E+03	1.763E+04	3.574E+06	*9.882E+11	*9.882E+11
Ra-228	9.243E+03	3.422E+04	7.472E+04	9.737E+05	1.493E+09	*2.726E+14	*2.726E+14	*2.726E+14
Th-228	2.537E+03	3.660E+03	7.622E+03	9.932E+04	1.523E+08	*8.192E+14	*8.192E+14	*8.192E+14
Th-230	5.042E+05	4.720E+05	4.303E+05	3.904E+05	5.846E+05	9.865E+06	*2.018E+10	*2.018E+10
Th-232	5.751E+04	4.273E+04	3.575E+04	3.216E+04	3.477E+04	4.746E+04	*1.096E+05	*1.096E+05
U-234	2.332E+06	1.929E+07	1.303E+09	*6.245E+09	*6.245E+09	*6.245E+09	*6.245E+09	*6.245E+09
U-235	4.415E+04	3.652E+05	*2.160E+06	*2.160E+06	*2.160E+06	*2.160E+06	*2.160E+06	*2.160E+06
U-238	2.347E+05	*3.360E+05	*3.360E+05	*3.360E+05	*3.360E+05	*3.360E+05	*3.360E+05	*3.360E+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	4.550E-02	0.000E+00	3.635E-03	6.878E+03	3.635E-03	6.878E+03
Pa-231	4.550E-02	0.000E+00	7.428E-04	3.366E+04	7.428E-04	3.366E+04
Pb-210	1.000E+00	0.000E+00	4.121E-04	6.066E+04	4.121E-04	6.066E+04
Ra-226	1.000E+00	0.000E+00	1.366E-02	1.830E+03	1.366E-02	1.830E+03
Ra-228	1.000E+00	0.000E+00	2.705E-03	9.243E+03	2.705E-03	9.243E+03
Th-228	1.000E+00	0.000E+00	9.856E-03	2.537E+03	9.856E-03	2.537E+03
Th-230	1.000E+00	9.46 ± 0.02	6.406E-05	3.903E+05	4.959E-05	5.042E+05
Th-232	1.000E+00	9.71 ± 0.02	7.773E-04	3.216E+04	4.347E-04	5.751E+04
U-234	1.000E+00	0.000E+00	1.072E-05	2.332E+06	1.072E-05	2.332E+06
U-235	4.550E-02	0.000E+00	5.663E-04	4.415E+04	5.663E-04	4.415E+04
U-238	1.000E+00	0.000E+00	1.065E-04	2.347E+05	1.065E-04	2.347E+05

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

Water Independent Pathways (Inhalation excludes radon)

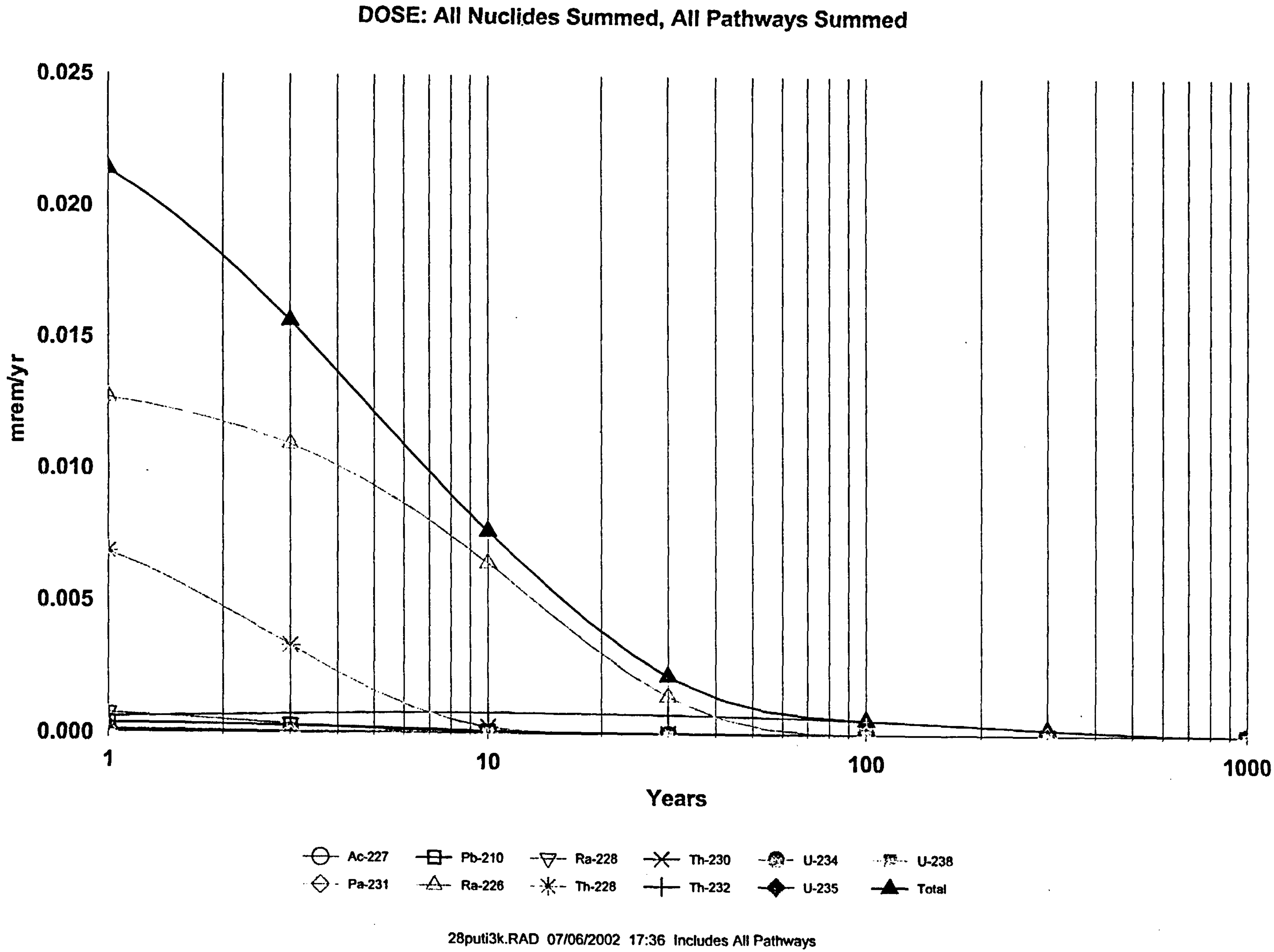
Radio-Nuclide	Ground mrem/yr	Ground fract.	Inhalation mrem/yr	Inhalation fract.	Radon mrem/yr	Radon fract.	Plant mrem/yr	Plant fract.	Meat mrem/yr	Meat fract.	Milk mrem/yr	Milk fract.	Soil mrem/yr	Soil fract.
Ac-227	1.247E-04	0.0045	9.248E-06	0.0003	0.000E+00	0.0000	0.000E+00	0.0000	0.000E+00	0.0000	0.000E+00	0.0000	3.147E-05	0.0011
Pa-231	1.250E-05	0.0005	1.628E-06	0.0001	0.000E+00	0.0000	0.000E+00	0.0000	0.000E+00	0.0000	0.000E+00	0.0000	1.967E-05	0.0007
Pb-210	3.522E-05	0.0013	7.769E-07	0.0000	0.000E+00	0.0000	0.000E+00	0.0000	0.000E+00	0.0000	0.000E+00	0.0000	3.761E-04	0.0137
Ra-226	1.358E-02	0.4946	3.096E-07	0.0000	0.000E+00	0.0000	0.000E+00	0.0000	0.000E+00	0.0000	0.000E+00	0.0000	7.693E-05	0.0028
Ra-228	2.681E-03	0.0977	7.878E-07	0.0000	0.000E+00	0.0000	0.000E+00	0.0000	0.000E+00	0.0000	0.000E+00	0.0000	2.269E-05	0.0008
Th-228	9.808E-03	0.3572	1.038E-05	0.0004	0.000E+00	0.0000	0.000E+00	0.0000	0.000E+00	0.0000	0.000E+00	0.0000	3.755E-05	0.0014
Th-230	8.378E-06	0.0003	1.145E-05	0.0004	0.000E+00	0.0000	0.000E+00	0.0000	0.000E+00	0.0000	0.000E+00	0.0000	2.976E-05	0.0011
Th-232	2.227E-04	0.0081	5.884E-05	0.0021	0.000E+00	0.0000	0.000E+00	0.0000	0.000E+00	0.0000	0.000E+00	0.0000	1.532E-04	0.0056
U-234	2.209E-06	0.0001	1.973E-06	0.0001	0.000E+00	0.0000	0.000E+00	0.0000	0.000E+00	0.0000	0.000E+00	0.0000	6.537E-06	0.0002
U-235	2.540E-05	0.0009	8.368E-08	0.0000	0.000E+00	0.0000	0.000E+00	0.0000	0.000E+00	0.0000	0.000E+00	0.0000	2.807E-07	0.0000
U-238	9.854E-05	0.0036	1.764E-06	0.0001	0.000E+00	0.0000	0.000E+00	0.0000	0.000E+00	0.0000	0.000E+00	0.0000	6.213E-06	0.0002
Total	2.660E-02	0.9688	9.724E-05	0.0035	0.000E+00	0.0000	0.000E+00	0.0000	0.000E+00	0.0000	0.000E+00	0.0000	7.604E-04	0.0277

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

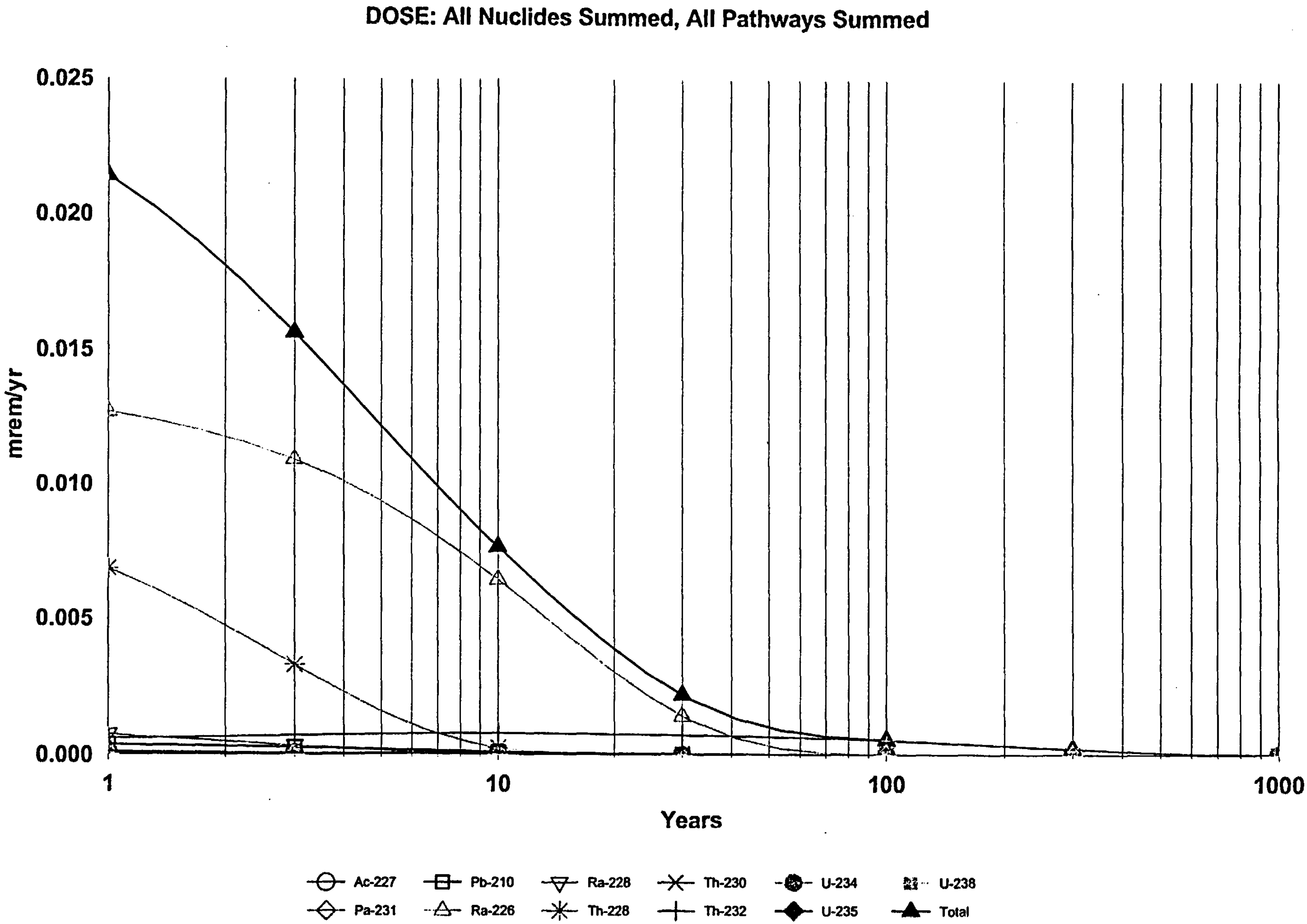
Water Dependent Pathways

Radio-Nuclide	Water mrem/yr	Water fract.	Fish mrem/yr	Fish fract.	Radon mrem/yr	Radon fract.	Plant mrem/yr	Plant fract.	Meat mrem/yr	Meat fract.	Milk mrem/yr	Milk fract.	All Pathways* mrem/yr	All Pathways* fract.
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	1.654E-04	0.0060
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	3.380E-05	0.0012
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	4.121E-04	0.0150
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	1.366E-02	0.4974
Ra-228	0.000E+00	0.0000	0.000E+00	0.0000	0.000E+00	0.0000	0.000E+00	0.0000	0.000E+00	0.0000	0.000E+00	0.0000	2.705E-03	0.0985
Th-228	0.000E+00	0.0000	0.000E+00	0.0000	0.000E+00	0.0000	0.000E+00	0.0000	0.000E+00	0.0000	0.000E+00	0.0000	9.856E-03	0.3590
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	4.959E-05	0.0018
Th-232	0.000E+00	0.0000	0.000E+00	0.0000	0.000E+00	0.0000	0.000E+00	0.0000	0.000E+00	0.0000	0.000E+00	0.0000	4.347E-04	0.0158
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	1.072E-05	0.0004
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	2.577E-05	0.0009
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	1.065E-04	0.0039
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	2.746E-02	1.0000

*Sum of all water independent and dependent pathways.

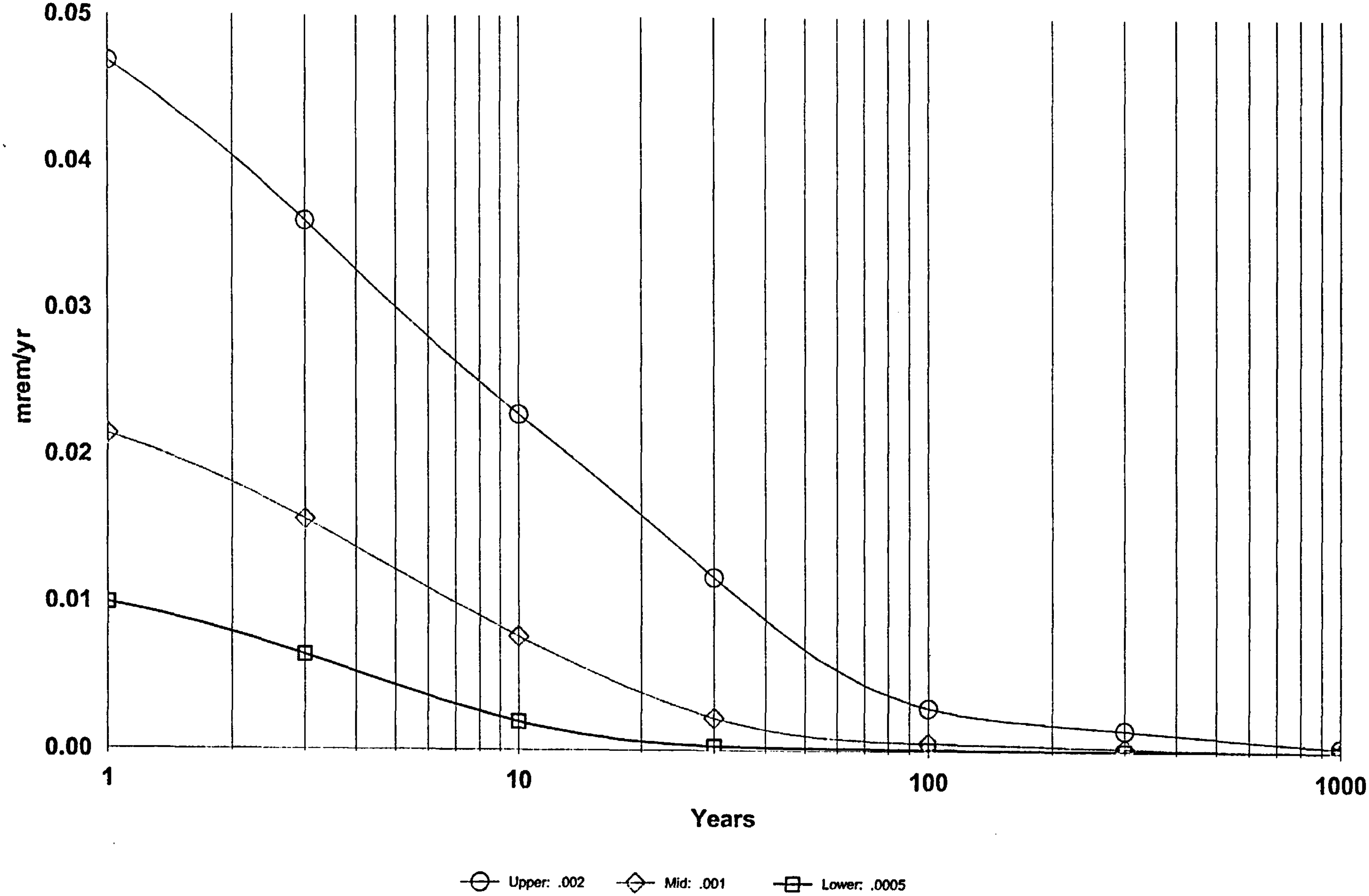


DOSE: All Nuclides Summed, All Pathways Summed
0.025
0.020
0.015
0.010
0.005
0.000
mrem/yr
1
10
100
1000
Years
Ac-227
Pb-210
Ra-228
Th-230
U-234
U-238
Pa-231
Ra-226
Th-228
Th-232
U-235
Total
28puti3k.RAD 07/06/2002 17:36 Includes All Pathways

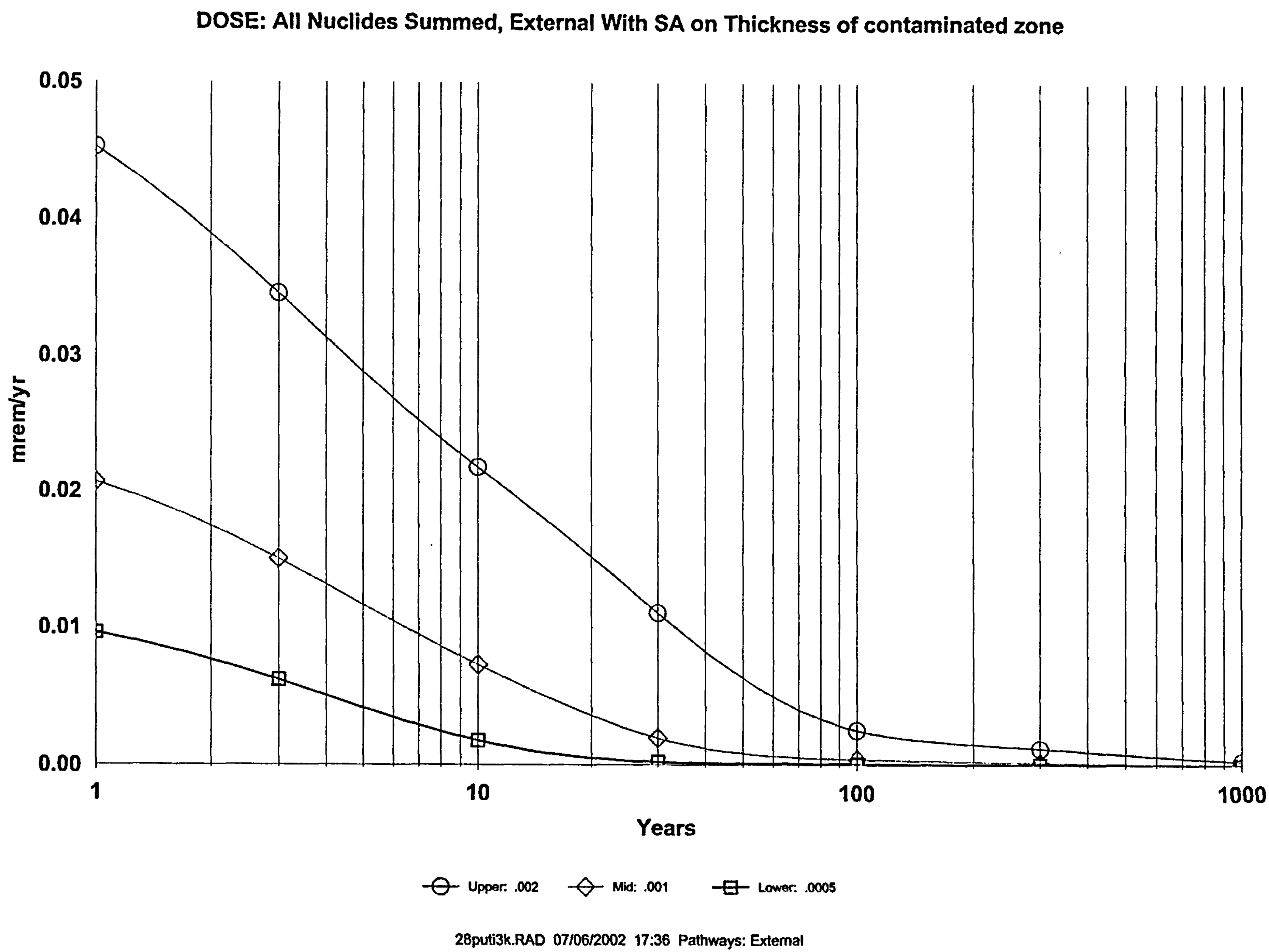


28puti3k.RAD 07/06/2002 17:36 Includes All Pathways

DOSE: All Nuclides Summed, All Pathways Summed With SA on Thickness of contaminated zone



28puti3k.RAD 07/06/2002 17:36 Includes All Pathways



DOSE: All Nuclides Summed, External With SA on Thickness of contaminated zone
0.05
0.04
0.03
0.02
0.01
0.00
mrem/yr
1
10
100
1000
Years
Upper: .002
Mid: .001
Lower: .0005
28puti3k.RAD 07/06/2002 17:36 Pathways: External

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

Nuclide (i)	t= 0.000E+00	1.000E+00	3.000E+00	1.000E+01	3.000E+01	1.000E+02	3.000E+02	1.000E+03
Ac-227	7.862E+03	1.121E+04	2.281E+04	2.737E+05	3.316E+08	*7.230E+13	*7.230E+13	*7.230E+13
Pa-231	3.592E+04	6.171E+04	1.667E+05	2.854E+06	3.608E+09	*4.722E+10	*4.722E+10	*4.722E+10
Pb-210	6.116E+04	7.053E+04	9.380E+04	2.544E+05	4.404E+06	9.497E+10	*7.631E+13	*7.631E+13
Ra-226	2.126E+03	2.291E+03	2.662E+03	4.506E+03	2.044E+04	4.142E+06	*9.882E+11	*9.882E+11
Ra-228	1.071E+04	3.977E+04	8.685E+04	1.132E+06	1.735E+09	*2.726E+14	*2.726E+14	*2.726E+14
Th-228	2.948E+03	4.255E+03	8.860E+03	1.155E+05	1.770E+08	*8.192E+14	*8.192E+14	*8.192E+14
Th-230	5.319E+05	5.029E+05	4.648E+05	4.319E+05	6.587E+05	1.121E+07	*2.018E+10	*2.018E+10
Th-232	6.291E+04	4.745E+04	4.000E+04	3.616E+04	3.911E+04	5.338E+04	*1.096E+05	*1.096E+05
U-234	2.428E+06	2.008E+07	1.357E+09	*6.245E+09	*6.245E+09	*6.245E+09	*6.245E+09	*6.245E+09
U-235	5.305E+04	4.388E+05	*2.160E+06	*2.160E+06	*2.160E+06	*2.160E+06	*2.160E+06	*2.160E+06
U-238	2.743E+05	*3.360E+05	*3.360E+05	*3.360E+05	*3.360E+05	*3.360E+05	*3.360E+05	*3.360E+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	4.550E-02	0.000E+00	3.180E-03	7.862E+03	3.180E-03	7.862E+03
Pa-231	4.550E-02	0.000E+00	6.959E-04	3.592E+04	6.959E-04	3.592E+04
Pb-210	1.000E+00	0.000E+00	4.088E-04	6.116E+04	4.088E-04	6.116E+04
Ra-226	1.000E+00	0.000E+00	1.176E-02	2.126E+03	1.176E-02	2.126E+03
Ra-228	1.000E+00	0.000E+00	2.333E-03	1.071E+04	2.333E-03	1.071E+04
Th-228	1.000E+00	0.000E+00	8.479E-03	2.948E+03	8.479E-03	2.948E+03
Th-230	1.000E+00	8.81 ± 0.02	5.802E-05	4.309E+05	4.700E-05	5.319E+05
Th-232	1.000E+00	9.61 ± 0.02	6.914E-04	3.616E+04	3.974E-04	6.291E+04
U-234	1.000E+00	0.000E+00	1.030E-05	2.428E+06	1.030E-05	2.428E+06
U-235	4.550E-02	0.000E+00	4.712E-04	5.305E+04	4.712E-04	5.305E+04
U-238	1.000E+00	0.000E+00	9.113E-05	2.743E+05	9.113E-05	2.743E+05

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

Water Independent Pathways (Inhalation excludes radon)

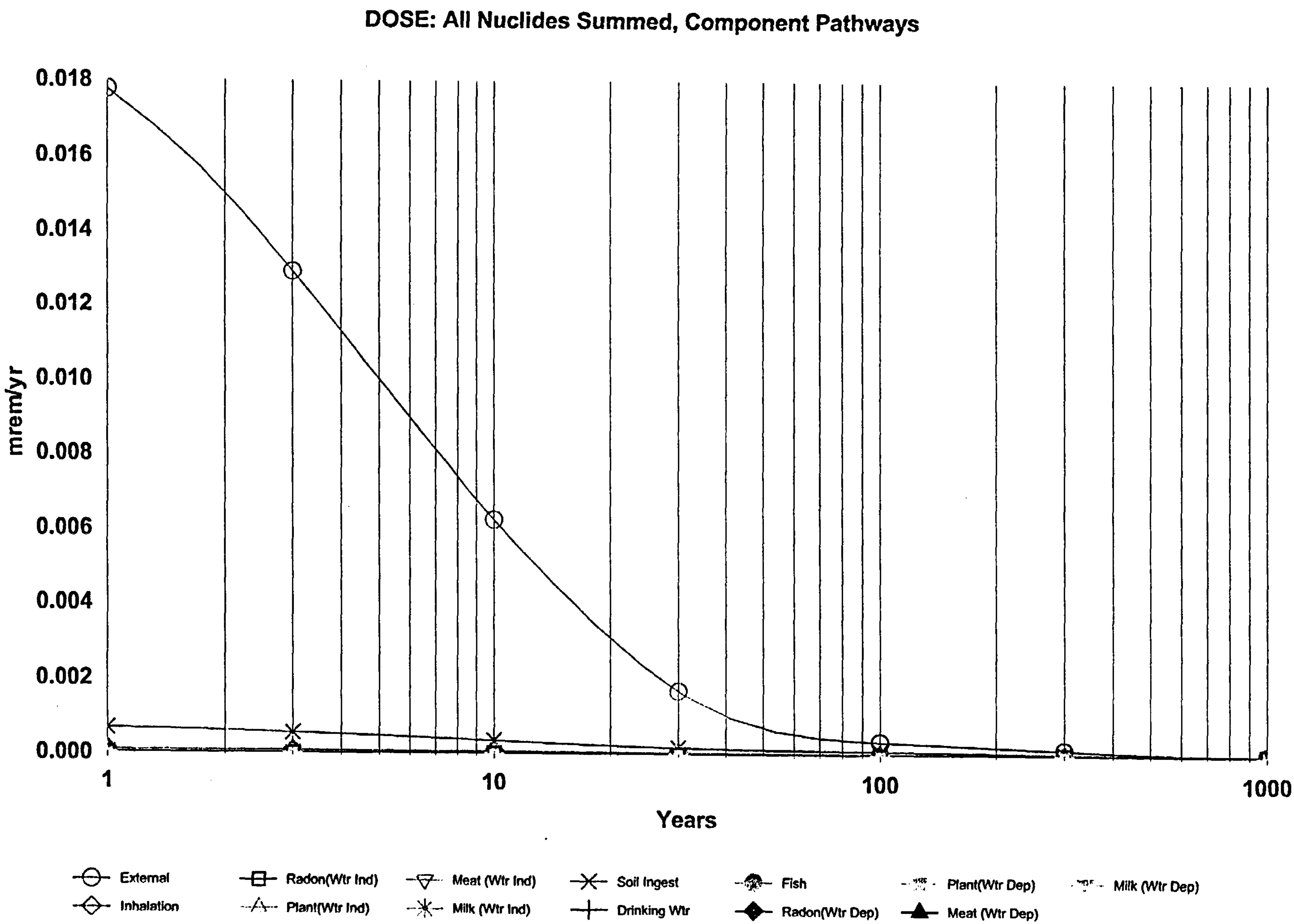
Radio-	Ground		Inhalation		Radon		Plant		Meat		Milk		Soil	
Nuclide	mrem/yr	fract.	mrem/yr	fract.	mrem/yr	fract.	mrem/yr	fract.	mrem/yr	fract.	mrem/yr	fract.	mrem/yr	fract.
Ac-227	1.050E-04	0.0044	8.222E-06	0.0003	0.000E+00	0.0000	0.000E+00	0.0000	0.000E+00	0.0000	0.000E+00	0.0000	3.147E-05	0.0013
Pa-231	1.055E-05	0.0004	1.448E-06	0.0001	0.000E+00	0.0000	0.000E+00	0.0000	0.000E+00	0.0000	0.000E+00	0.0000	1.967E-05	0.0008
Pb-210	3.194E-05	0.0013	6.907E-07	0.0000	0.000E+00	0.0000	0.000E+00	0.0000	0.000E+00	0.0000	0.000E+00	0.0000	3.761E-04	0.0159
Ra-226	1.168E-02	0.4924	2.753E-07	0.0000	0.000E+00	0.0000	0.000E+00	0.0000	0.000E+00	0.0000	0.000E+00	0.0000	7.693E-05	0.0032
Ra-228	2.310E-03	0.0974	7.004E-07	0.0000	0.000E+00	0.0000	0.000E+00	0.0000	0.000E+00	0.0000	0.000E+00	0.0000	2.269E-05	0.0010
Th-228	8.432E-03	0.3554	9.226E-06	0.0004	0.000E+00	0.0000	0.000E+00	0.0000	0.000E+00	0.0000	0.000E+00	0.0000	3.755E-05	0.0016
Th-230	7.060E-06	0.0003	1.018E-05	0.0004	0.000E+00	0.0000	0.000E+00	0.0000	0.000E+00	0.0000	0.000E+00	0.0000	2.976E-05	0.0013
Th-232	1.919E-04	0.0081	5.231E-05	0.0022	0.000E+00	0.0000	0.000E+00	0.0000	0.000E+00	0.0000	0.000E+00	0.0000	1.532E-04	0.0065
U-234	2.006E-06	0.0001	1.754E-06	0.0001	0.000E+00	0.0000	0.000E+00	0.0000	0.000E+00	0.0000	0.000E+00	0.0000	6.537E-06	0.0003
U-235	2.109E-05	0.0009	7.439E-08	0.0000	0.000E+00	0.0000	0.000E+00	0.0000	0.000E+00	0.0000	0.000E+00	0.0000	2.807E-07	0.0000
U-238	8.335E-05	0.0035	1.568E-06	0.0001	0.000E+00	0.0000	0.000E+00	0.0000	0.000E+00	0.0000	0.000E+00	0.0000	6.213E-06	0.0003
Total	2.288E-02	0.9643	8.645E-05	0.0036	0.000E+00	0.0000	0.000E+00	0.0000	0.000E+00	0.0000	0.000E+00	0.0000	7.604E-04	0.0321

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

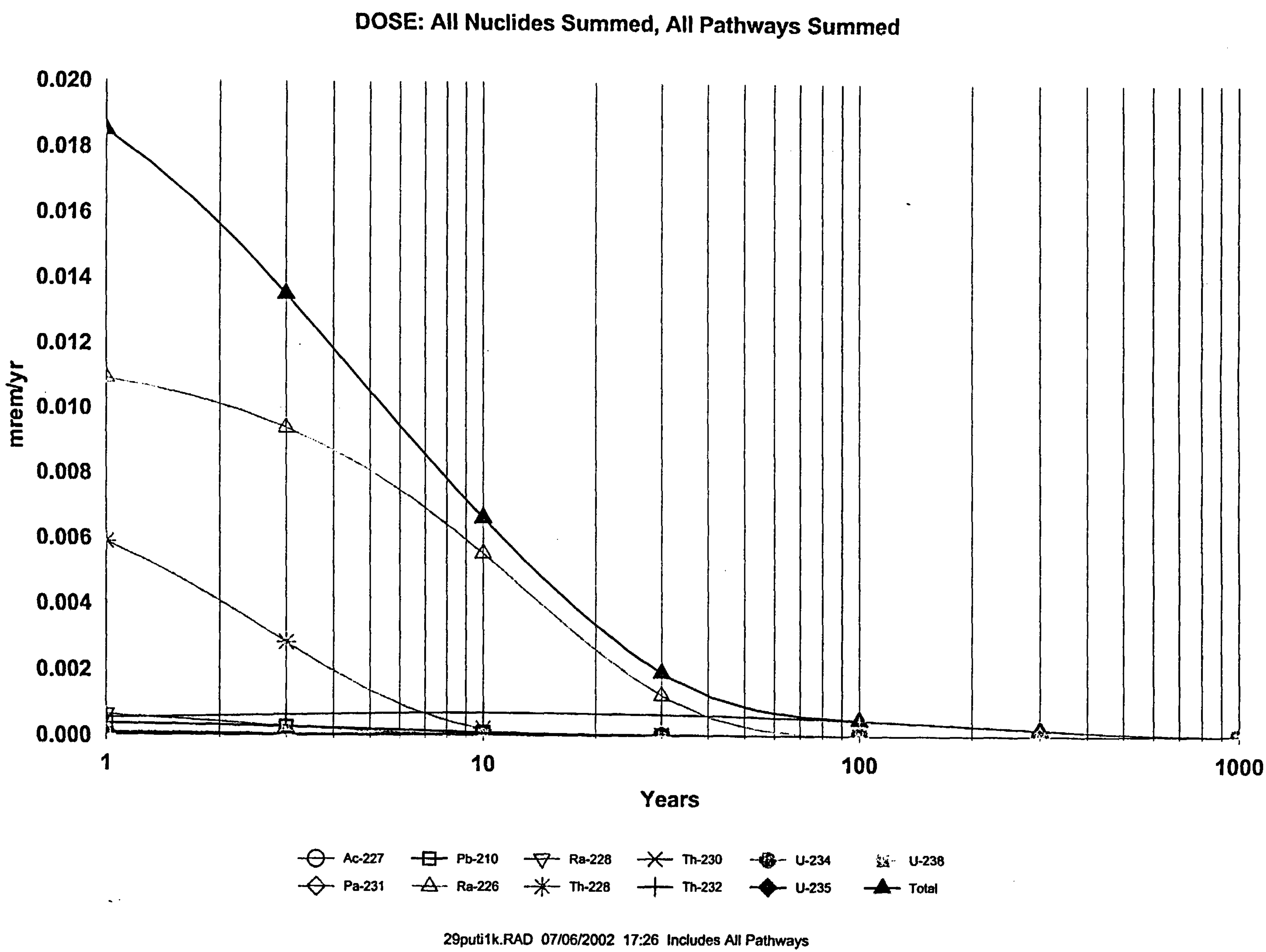
Water Dependent Pathways

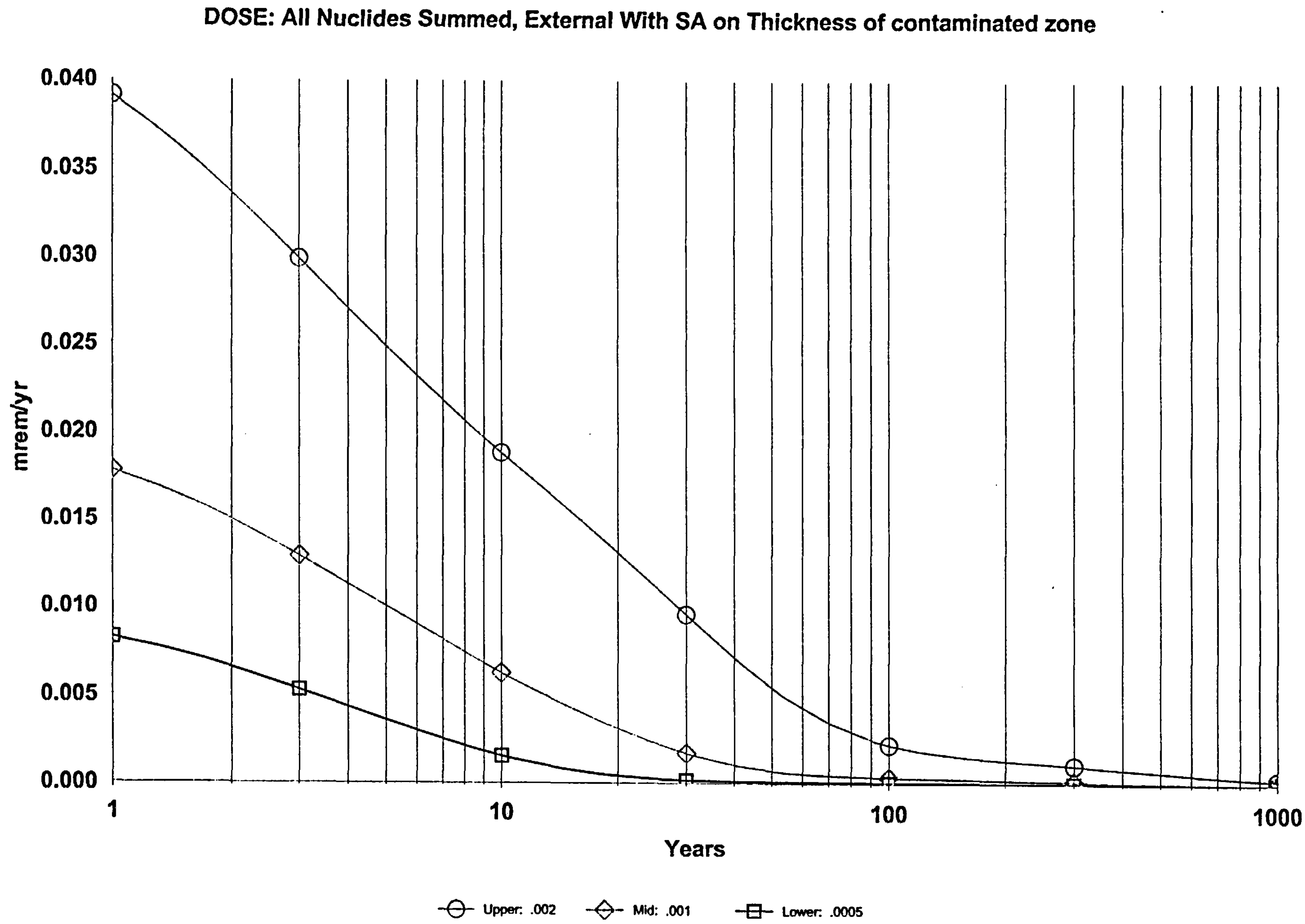
Radio-	Water		Fish		Radon		Plant		Meat		Milk		All Pathways*	
Nuclide	mrem/yr	fract.	mrem/yr	fract.	mrem/yr	fract.	mrem/yr	fract.	mrem/yr	fract.	mrem/yr	fract.	mrem/yr	fract.
Ac-227	0.000E+00	0.0000	0.000E+00	0.0000	0.000E+00	0.0000	0.000E+00	0.0000	0.000E+00	0.0000	0.000E+00	0.0000	1.447E-04	0.0061
Pa-231	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	3.166E-05	0.0013
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	4.088E-04	0.0172
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	1.176E-02	0.4957
Ra-228	0.000E+00	0.0000	0.000E+00	0.0000	0.000E+00	0.0000	0.000E+00	0.0000	0.000E+00	0.0000	0.000E+00	0.0000	2.333E-03	0.0984
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	8.479E-03	0.3574
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	4.700E-05	0.0020
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	3.974E-04	0.0168
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	1.030E-05	0.0004
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	2.144E-05	0.0009
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	9.113E-05	0.0038
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	2.372E-02	1.0000

*Sum of all water independent and dependent pathways.

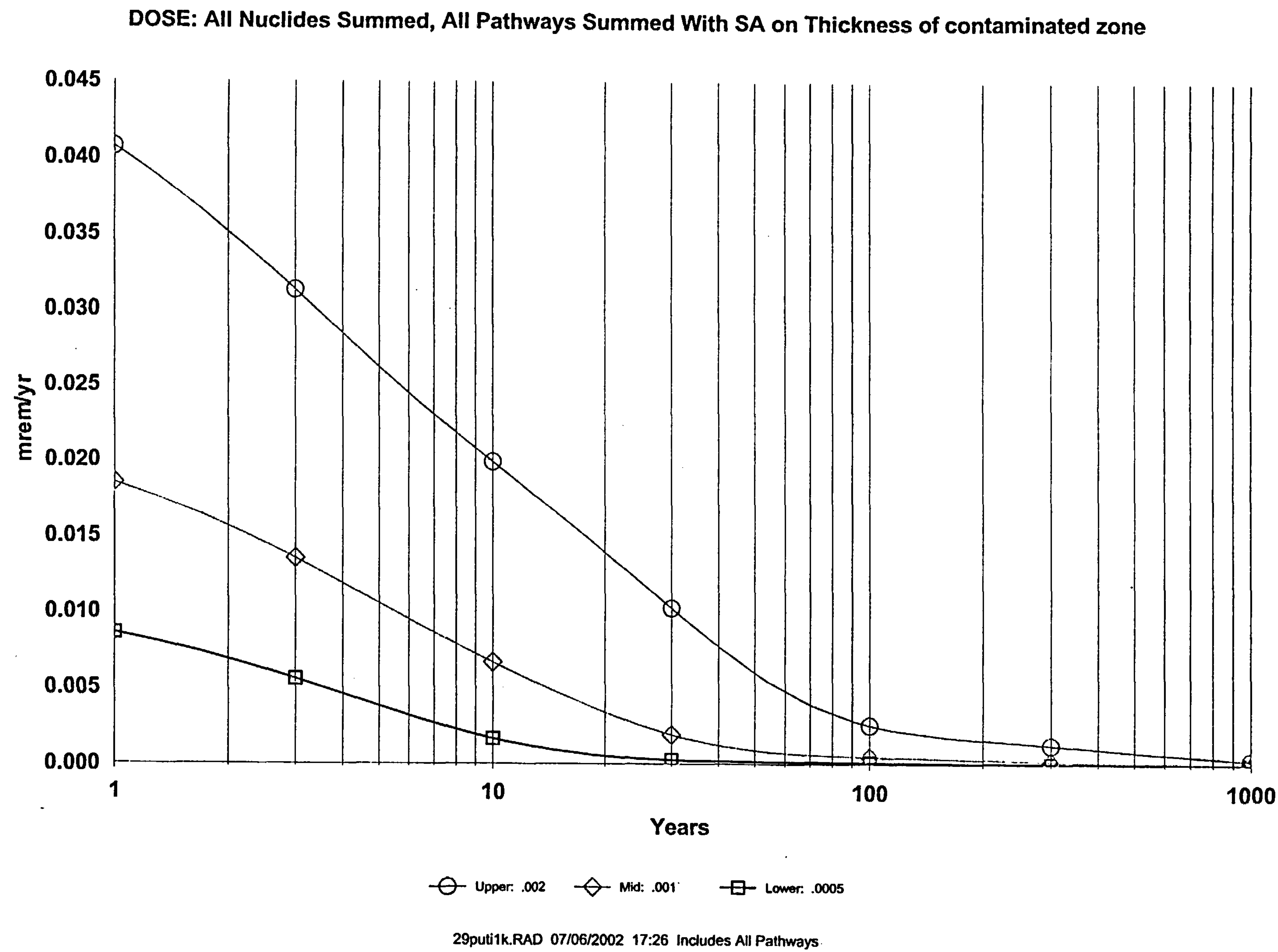


29puti1k.RAD 07/06/2002 17:26


DOSE: All Nuclides Summed, All Pathways Summed
mrem/yr
0.020
0.018
0.016
0.014
0.012
0.010
0.008
0.006
0.004
0.002
0.000
1
10
100
1000
Years
Ac-227
Pb-210
Ra-228
Th-230
U-234
U-238
Pa-231
Ra-226
Th-228
Th-232
U-235
Total
29puti1k.RAD 07/06/2002 17:26 Includes All Pathways



29putl1k.RAD 07/06/2002 17:26 Pathways: External


DOSE: All Nuclides Summed, All Pathways Summed With SA on Thickness of contaminated zone
0.045
0.040
0.035
0.030
0.025
0.020
0.015
0.010
0.005
0.000
mrem/yr
1
10
100
1000
Years
Upper: .002
Mid: .001
Lower: .0005
29puti1k.RAD 07/06/2002 17:26 Includes All Pathways

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

Nuclide (i)	t= 0.000E+00	1.000E+00	3.000E+00	1.000E+01	3.000E+01	1.000E+02	3.000E+02	1.000E+03
Ac-227	3.758E+04	5.359E+04	1.090E+05	1.308E+06	1.585E+09	*7.230E+13	*7.230E+13	*7.230E+13
Pa-231	3.074E+05	4.728E+05	1.062E+06	1.409E+07	1.724E+10	*4.722E+10	*4.722E+10	*4.722E+10
Pb-210	2.078E+06	2.397E+06	3.188E+06	8.646E+06	1.496E+08	3.227E+12	*7.631E+13	*7.631E+13
Ra-226	8.581E+03	9.257E+03	1.077E+04	1.831E+04	8.352E+04	1.696E+07	*9.882E+11	*9.882E+11
Ra-228	4.327E+04	1.607E+05	3.510E+05	4.574E+06	7.014E+09	*2.726E+14	*2.726E+14	*2.726E+14
Th-228	1.192E+04	1.719E+04	3.581E+04	4.666E+05	7.154E+08	*8.192E+14	*8.192E+14	*8.192E+14
Th-230	2.982E+06	2.717E+06	2.386E+06	2.042E+06	2.934E+06	4.868E+07	*2.018E+10	*2.018E+10
Th-232	*1.096E+05	*1.096E+05	*1.096E+05	*1.096E+05	*1.096E+05	*1.096E+05	*1.096E+05	*1.096E+05
U-234	1.265E+07	1.047E+08	*6.245E+09	*6.245E+09	*6.245E+09	*6.245E+09	*6.245E+09	*6.245E+09
U-235	2.254E+05	1.864E+06	*2.160E+06	*2.160E+06	*2.160E+06	*2.160E+06	*2.160E+06	*2.160E+06
U-238	*3.360E+05	*3.360E+05	*3.360E+05	*3.360E+05	*3.360E+05	*3.360E+05	*3.360E+05	*3.360E+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	4.550E-02	0.000E+00	6.653E-04	3.758E+04	6.653E-04	3.758E+04
Pa-231	4.550E-02	0.000E+00	8.132E-05	3.074E+05	8.132E-05	3.074E+05
Pb-210	1.000E+00	0.000E+00	1.203E-05	2.078E+06	1.203E-05	2.078E+06
Ra-226	1.000E+00	0.000E+00	2.913E-03	8.581E+03	2.913E-03	8.581E+03
Ra-228	1.000E+00	0.000E+00	5.778E-04	4.327E+04	5.778E-04	4.327E+04
Th-228	1.000E+00	0.000E+00	2.098E-03	1.192E+04	2.098E-03	1.192E+04
Th-230	1.000E+00	10.82 ± 0.02	1.226E-05	2.040E+06	8.385E-06	2.982E+06
Th-232	1.000E+00	9.88 ± 0.02	1.550E-04	*1.096E+05	8.151E-05	*1.096E+05
U-234	1.000E+00	0.000E+00	1.976E-06	1.265E+07	1.976E-06	1.265E+07
U-235	4.550E-02	0.000E+00	1.109E-04	2.254E+05	1.109E-04	2.254E+05
U-238	1.000E+00	0.000E+00	2.107E-05	*3.360E+05	2.107E-05	*3.360E+05

*At specific activity limit

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

Water Independent Pathways (Inhalation excludes radon)

Radio-Nuclide	Ground		Inhalation		Radon		Plant		Meat		Milk		Soil	
	mrem/yr	fract.	mrem/yr	fract.	mrem/yr	fract.	mrem/yr	fract.	mrem/yr	fract.	mrem/yr	fract.	mrem/yr	fract.
Ac-227	2.499E-05	0.0043	4.970E-06	0.0009	0.000E+00	0.0000	0.000E+00	0.0000	0.000E+00	0.0000	0.000E+00	0.0000	3.147E-07	0.0001
Pa-231	2.628E-06	0.0005	8.750E-07	0.0002	0.000E+00	0.0000	0.000E+00	0.0000	0.000E+00	0.0000	0.000E+00	0.0000	1.967E-07	0.0000
Pb-210	7.850E-06	0.0014	4.175E-07	0.0001	0.000E+00	0.0000	0.000E+00	0.0000	0.000E+00	0.0000	0.000E+00	0.0000	3.761E-06	0.0007
Ra-226	2.912E-03	0.5062	1.664E-07	0.0000	0.000E+00	0.0000	0.000E+00	0.0000	0.000E+00	0.0000	0.000E+00	0.0000	7.693E-07	0.0001
Ra-228	5.771E-04	0.1003	4.234E-07	0.0001	0.000E+00	0.0000	0.000E+00	0.0000	0.000E+00	0.0000	0.000E+00	0.0000	2.269E-07	0.0000
Th-228	2.092E-03	0.3637	5.577E-06	0.0010	0.000E+00	0.0000	0.000E+00	0.0000	0.000E+00	0.0000	0.000E+00	0.0000	3.755E-07	0.0001
Th-230	1.933E-06	0.0003	6.154E-06	0.0011	0.000E+00	0.0000	0.000E+00	0.0000	0.000E+00	0.0000	0.000E+00	0.0000	2.976E-07	0.0001
Th-232	4.836E-05	0.0084	3.162E-05	0.0055	0.000E+00	0.0000	0.000E+00	0.0000	0.000E+00	0.0000	0.000E+00	0.0000	1.532E-06	0.0003
U-234	8.498E-07	0.0001	1.061E-06	0.0002	0.000E+00	0.0000	0.000E+00	0.0000	0.000E+00	0.0000	0.000E+00	0.0000	6.537E-08	0.0000
U-235	4.999E-06	0.0009	4.497E-08	0.0000	0.000E+00	0.0000	0.000E+00	0.0000	0.000E+00	0.0000	0.000E+00	0.0000	2.807E-09	0.0000
U-238	2.006E-05	0.0035	9.481E-07	0.0002	0.000E+00	0.0000	0.000E+00	0.0000	0.000E+00	0.0000	0.000E+00	0.0000	6.213E-08	0.0000
Total	5.693E-03	0.9896	5.226E-05	0.0091	0.000E+00	0.0000	0.000E+00	0.0000	0.000E+00	0.0000	0.000E+00	0.0000	7.604E-06	0.0013

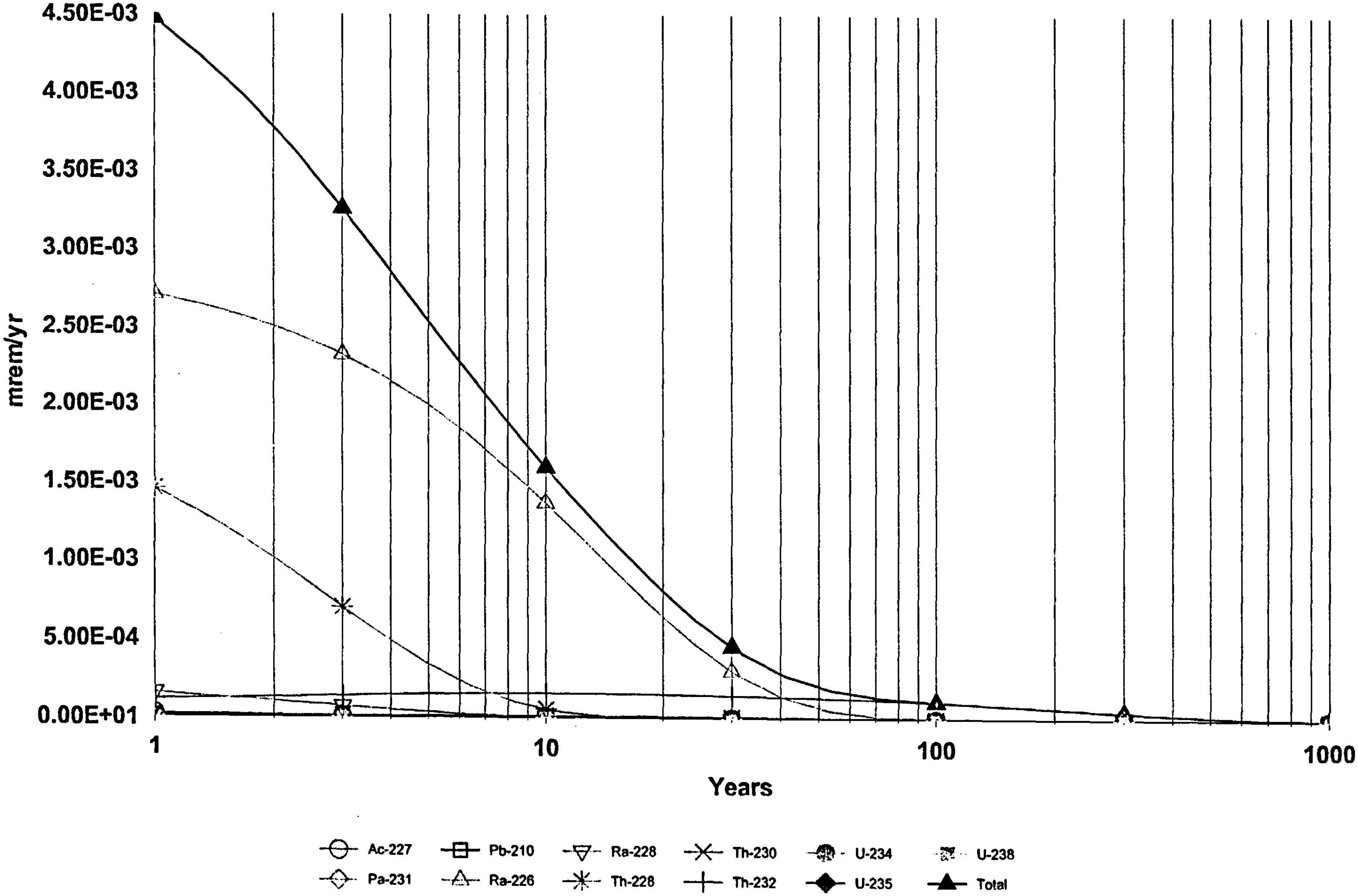
Total Dose Contributions TDOSE(i,p,t) for Individual Radionuclides (i) and Pathways (p)
As mrem/yr and Fraction of Total Dose At t = 0.000E+00 years

Water Dependent Pathways

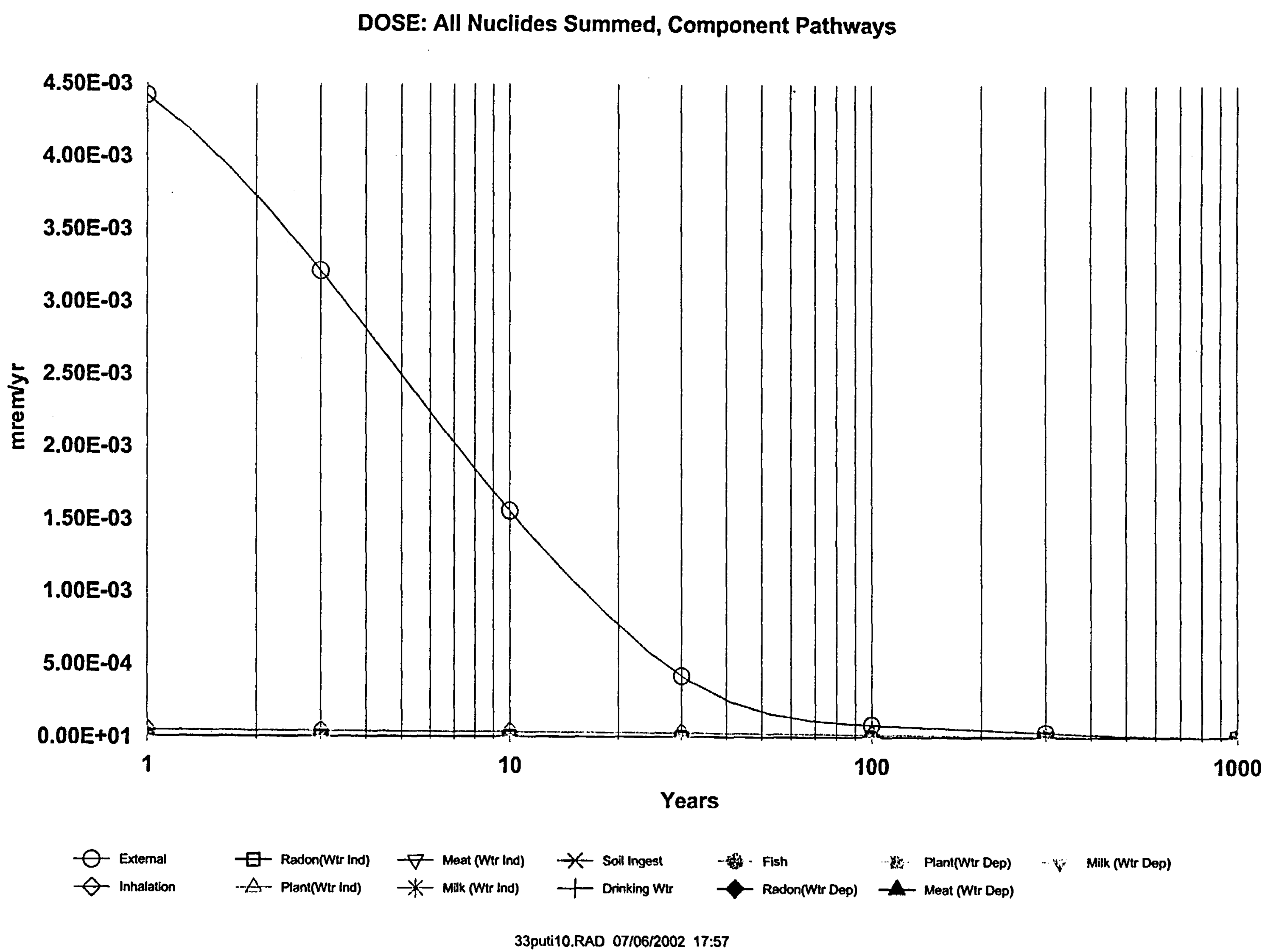
Radio-Nuclide	Water		Fish		Radon		Plant		Meat		Milk		All Pathways*	
	mrem/yr	fract.	mrem/yr	fract.	mrem/yr	fract.	mrem/yr	fract.	mrem/yr	fract.	mrem/yr	fract.	mrem/yr	fract.
Ac-227	0.000E+00	0.0000	0.000E+00	0.0000	0.000E+00	0.0000	0.000E+00	0.0000	0.000E+00	0.0000	0.000E+00	0.0000	3.027E-05	0.0053
Pa-231	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	3.700E-06	0.0006
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	1.203E-05	0.0021
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	2.913E-03	0.5064
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	5.778E-04	0.1004
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	2.098E-03	0.3647
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	8.385E-06	0.0015
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	8.151E-05	0.0142
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	1.976E-06	0.0003
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	5.047E-06	0.0009
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	2.107E-05	0.0037
Total	0.000E+00	0.0000	0.000E+00	0.0000	0.000E+00	0.0000	0.000E+00	0.0000	0.000E+00	0.0000	0.000E+00	0.0000	5.753E-03	1.0000

*Sum of all water independent and dependent pathways.

DOSE: All Nuclides Summed, All Pathways Summed



33puti10.RAD 07/06/2002 17:57 Includes All Pathways


DOSE: All Nuclides Summed, Component Pathways
4.50E-03
4.00E-03
3.50E-03
3.00E-03
2.50E-03
2.00E-03
1.50E-03
1.00E-03
5.00E-04
0.00E+01
mrem/yr
1
10
100
1000
Years
External
Inhalation
Radon(Wtr Ind)
Plant(Wtr Ind)
Meat (Wtr Ind)
Milk (Wtr Ind)
Soil Ingest
Drinking Wtr
Fish
Radon(Wtr Dep)
Plant(Wtr Dep)
Meat (Wtr Dep)
Milk (Wtr Dep)
33puti10.RAD 07/06/2002 17:57

**Sensitivity to Contaminated Zone Density –
Basis for Figure 5-3 at T=0**

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

Water Independent Pathways (Inhalation excludes radon)

Radio-Nuclide	Ground		Inhalation		Radon		Plant		Meat		Milk		Soil	
	mrem/yr	fract.	mrem/yr	fract.	mrem/yr	fract.	mrem/yr	fract.	mrem/yr	fract.	mrem/yr	fract.	mrem/yr	fract.
Ac-227	1.960E-02	0.0049	5.527E-03	0.0014	0.000E+00	0.0000	0.000E+00	0.0000	0.000E+00	0.0000	0.000E+00	0.0000	1.656E-02	0.0041
Pa-231	2.212E-03	0.0006	1.158E-03	0.0003	0.000E+00	0.0000	0.000E+00	0.0000	0.000E+00	0.0000	0.000E+00	0.0000	1.231E-02	0.0031
Pb-210	1.357E-03	0.0003	4.195E-04	0.0001	0.000E+00	0.0000	0.000E+00	0.0000	0.000E+00	0.0000	0.000E+00	0.0000	1.788E-01	0.0447
Ra-226	2.425E+00	0.6066	1.645E-04	0.0000	0.000E+00	0.0000	0.000E+00	0.0000	0.000E+00	0.0000	0.000E+00	0.0000	3.601E-02	0.0090
Ra-228	5.202E-01	0.1301	3.557E-04	0.0001	0.000E+00	0.0000	0.000E+00	0.0000	0.000E+00	0.0000	0.000E+00	0.0000	1.233E-02	0.0031
Th-228	6.183E-01	0.1547	1.772E-03	0.0004	0.000E+00	0.0000	0.000E+00	0.0000	0.000E+00	0.0000	0.000E+00	0.0000	5.644E-03	0.0014
Th-230	7.926E-04	0.0002	5.987E-03	0.0015	0.000E+00	0.0000	0.000E+00	0.0000	0.000E+00	0.0000	0.000E+00	0.0000	1.370E-02	0.0034
Th-232	2.979E-02	0.0075	1.006E-02	0.0025	0.000E+00	0.0000	0.000E+00	0.0000	0.000E+00	0.0000	0.000E+00	0.0000	2.347E-02	0.0059
U-234	8.956E-05	0.0000	2.423E-03	0.0006	0.000E+00	0.0000	0.000E+00	0.0000	0.000E+00	0.0000	0.000E+00	0.0000	7.066E-03	0.0018
U-235	7.537E-03	0.0019	1.027E-04	0.0000	0.000E+00	0.0000	0.000E+00	0.0000	0.000E+00	0.0000	0.000E+00	0.0000	3.034E-04	0.0001
U-238	2.970E-02	0.0074	2.166E-03	0.0005	0.000E+00	0.0000	0.000E+00	0.0000	0.000E+00	0.0000	0.000E+00	0.0000	6.716E-03	0.0017
Total	3.654E+00	0.9142	3.013E-02	0.0075	0.000E+00	0.0000	0.000E+00	0.0000	0.000E+00	0.0000	0.000E+00	0.0000	3.129E-01	0.0783

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

Water Dependent Pathways

Radio-Nuclide	Water		Fish		Radon		Plant		Meat		Milk		All Pathways*	
	mrem/yr	fract.	mrem/yr	fract.	mrem/yr	fract.	mrem/yr	fract.	mrem/yr	fract.	mrem/yr	fract.	mrem/yr	fract.
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	4.168E-02	0.0104
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	1.568E-02	0.0039
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	1.806E-01	0.0452
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	2.461E+00	0.6157
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	5.328E-01	0.1333
Th-228	0.000E+00	0.0000	0.000E+00	0.0000	0.000E+00	0.0000	0.000E+00	0.0000	0.000E+00	0.0000	0.000E+00	0.0000	6.257E-01	0.1565
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	2.048E-02	0.0051
Th-232	0.000E+00	0.0000	0.000E+00	0.0000	0.000E+00	0.0000	0.000E+00	0.0000	0.000E+00	0.0000	0.000E+00	0.0000	6.331E-02	0.0158
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	9.578E-03	0.0024
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	7.943E-03	0.0020
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	3.858E-02	0.0097
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	3.998E+00	1.0000

*Sum of all water independent and dependent pathways.

3U + 1 Th

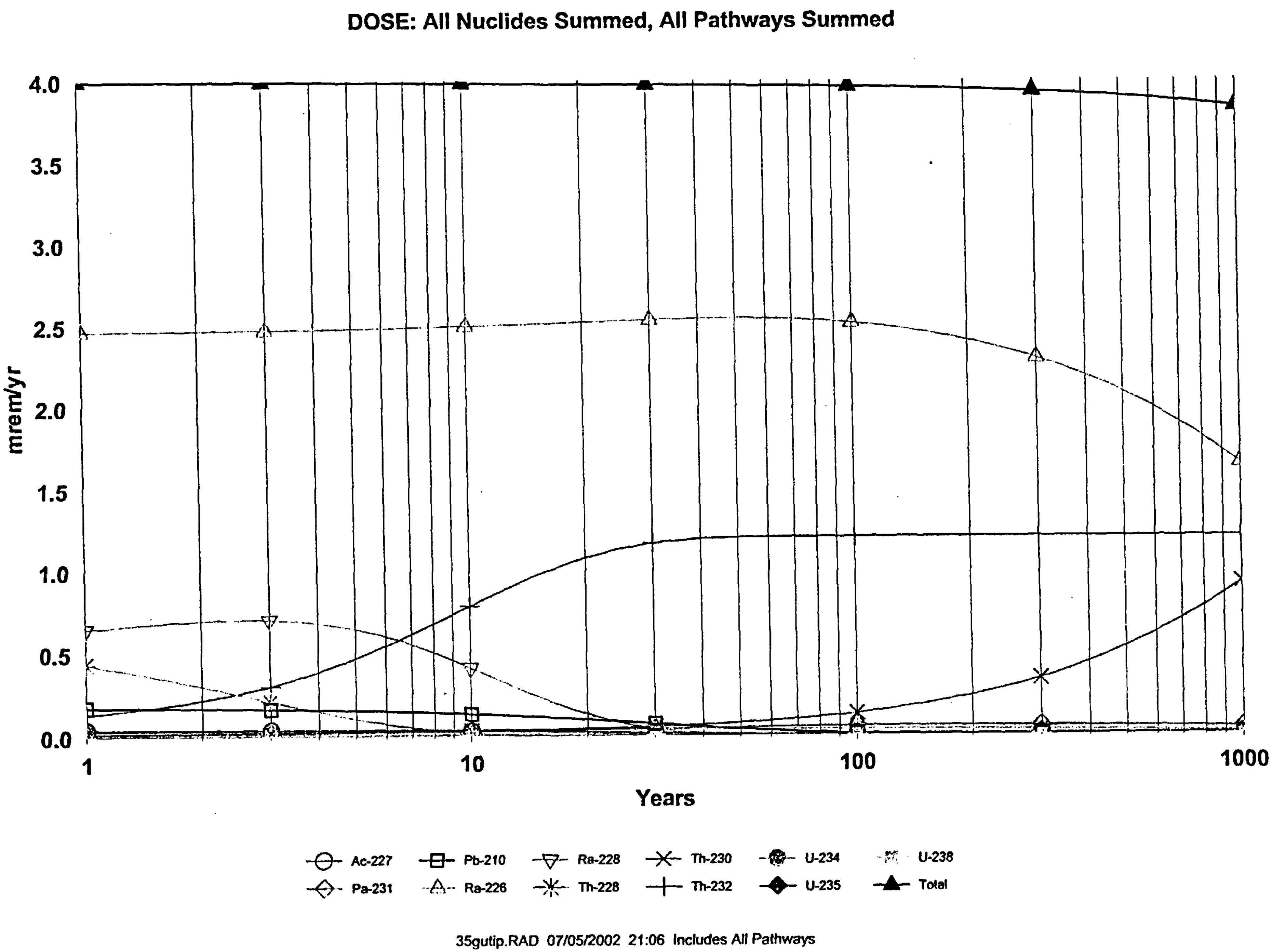
Single Radionuclide Soil Guidelines G(i,t) in pCi/g
Basic Radiation Dose Limit = 2.500E+01 mrem/yr

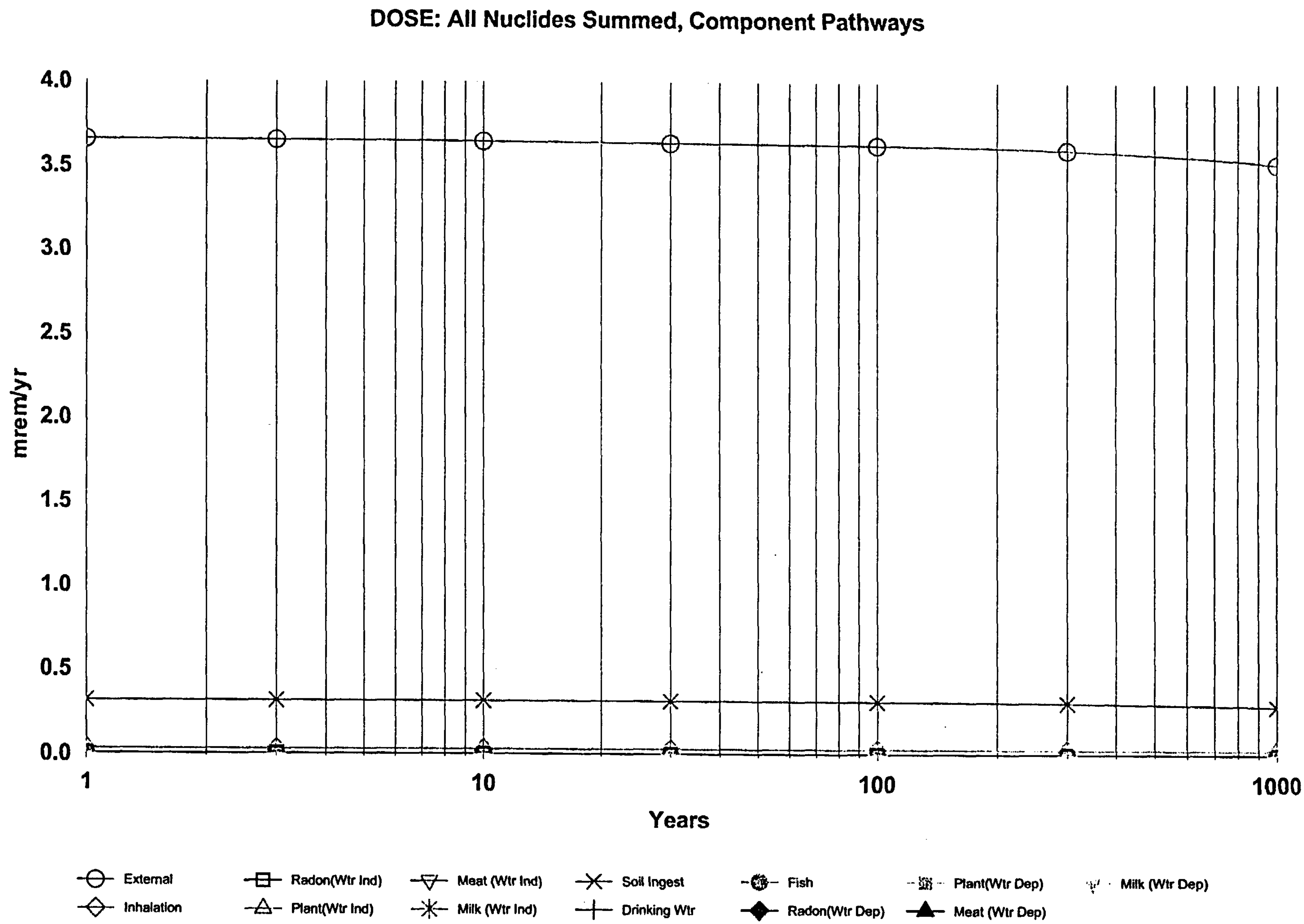
Nuclide (i)	t= 0.000E+00	1.000E+00	3.000E+00	1.000E+01	3.000E+01	1.000E+02	3.000E+02	1.000E+03
Ac-227	8.187E+01	8.453E+01	9.012E+01	1.127E+02	2.138E+02	2.008E+03	1.208E+06	*7.230E+13
Pa-231	2.176E+02	2.010E+02	1.754E+02	1.266E+02	8.337E+01	6.340E+01	6.619E+01	8.587E+01
Pb-210	4.153E+02	4.285E+02	4.560E+02	5.670E+02	1.057E+03	9.348E+03	4.736E+06	*7.631E+13
Ra-226	3.047E+01	3.042E+01	3.032E+01	3.003E+01	2.958E+01	2.983E+01	3.267E+01	4.543E+01
Ra-228	4.692E+01	3.848E+01	3.547E+01	6.110E+01	6.665E+02	3.516E+06	*2.726E+14	*2.726E+14
Th-228	3.995E+01	5.740E+01	1.185E+02	1.497E+03	2.100E+06	*8.192E+14	*8.192E+14	*8.192E+14
Th-230	3.663E+03	3.481E+03	3.167E+03	2.403E+03	1.415E+03	5.783E+02	2.228E+02	8.192E+01
Th-232	3.949E+02	1.846E+02	8.272E+01	3.186E+01	2.142E+01	2.077E+01	2.078E+01	2.081E+01
U-234	7.830E+03	7.838E+03	7.855E+03	7.912E+03	8.074E+03	8.640E+03	1.012E+04	1.145E+04
U-235	4.296E+02	4.300E+02	4.309E+02	4.339E+02	4.424E+02	4.716E+02	5.631E+02	1.015E+03
U-238	1.944E+03	1.946E+03	1.950E+03	1.965E+03	2.007E+03	2.161E+03	2.668E+03	5.586E+03

*At specific activity limit

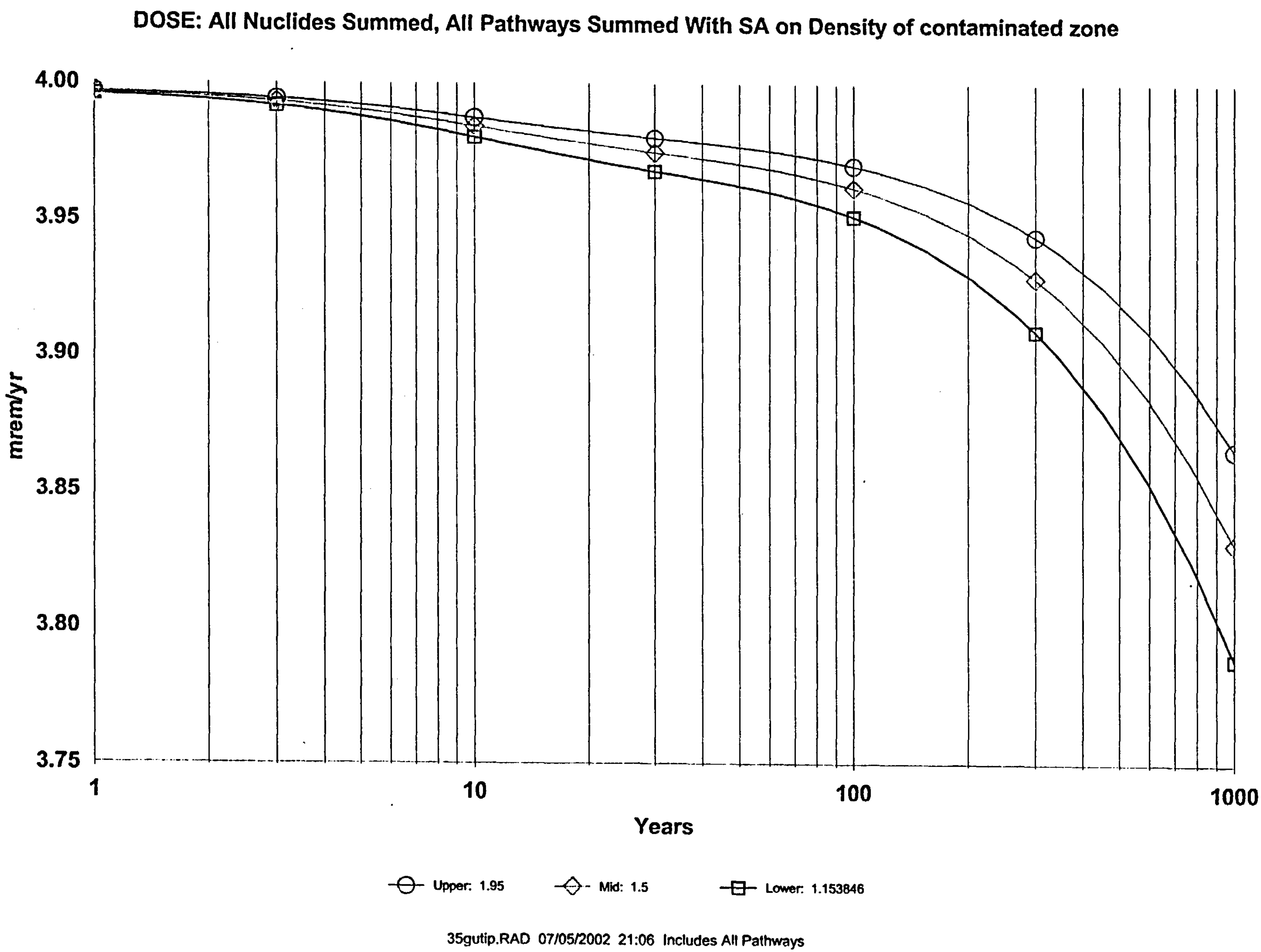
Summed Dose/Source Ratios DSR(i,t) in (mrem/yr)/(pCi/g)
and Single Radionuclide Soil Guidelines G(i,t) in pCi/g
at tmin = time of minimum single radionuclide soil guideline
and at tmax = time of maximum total dose = 0.000E+00 years

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	1.365E-01	0.000E+00	3.054E-01	8.187E+01	3.054E-01	8.187E+01
Pa-231	1.365E-01	130.8 ± 0.3	3.976E-01	6.288E+01	1.149E-01	2.176E+02
Pb-210	3.000E+00	0.000E+00	6.019E-02	4.153E+02	6.019E-02	4.153E+02
Ra-226	3.000E+00	49.65 ± 0.10	8.480E-01	2.948E+01	8.204E-01	3.047E+01
Ra-228	1.000E+00	2.659 ± 0.005	7.066E-01	3.538E+01	5.328E-01	4.692E+01
Th-228	1.000E+00	0.000E+00	6.257E-01	3.995E+01	6.257E-01	3.995E+01
Th-230	3.000E+00	1.000E+03	3.052E-01	8.192E+01	6.826E-03	3.663E+03
Th-232	1.000E+00	91.0 ± 0.2	1.204E+00	2.077E+01	6.331E-02	3.949E+02
U-234	3.000E+00	0.000E+00	3.193E-03	7.830E+03	3.193E-03	7.830E+03
U-235	1.365E-01	0.000E+00	5.819E-02	4.296E+02	5.819E-02	4.296E+02
U-238	3.000E+00	0.000E+00	1.286E-02	1.944E+03	1.286E-02	1.944E+03

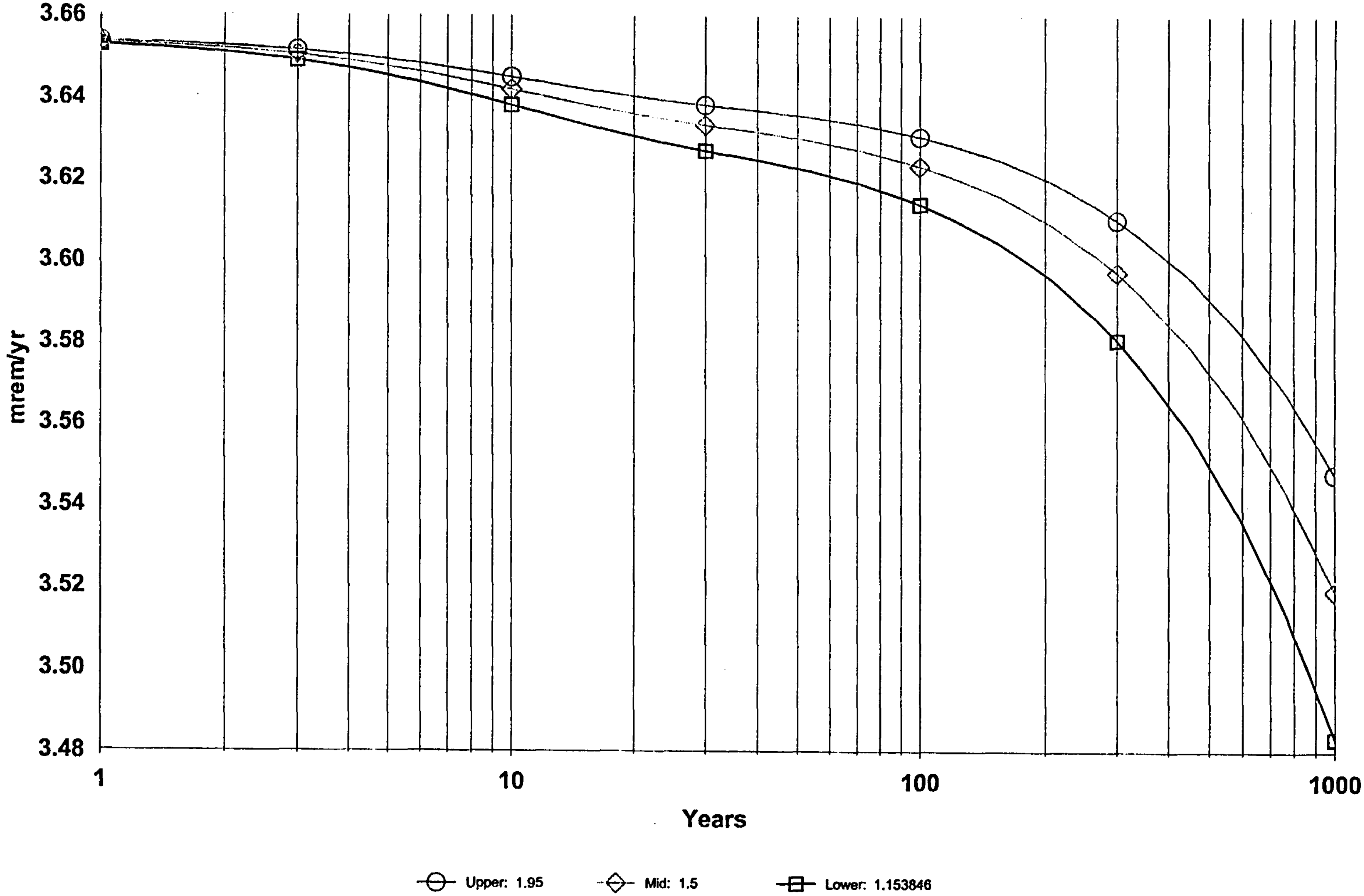

DOSE: All Nuclides Summed, All Pathways Summed
4.0
3.5
3.0
2.5
2.0
1.5
1.0
0.5
0.0
mrem/yr
1
10
100
1000
Years
Ac-227
Pb-210
Ra-228
Th-230
U-234
U-238
Pa-231
Ra-226
Th-228
Th-232
U-235
Total
35gutip.RAD 07/05/2002 21:06 Includes All Pathways



35gutip.RAD 07/05/2002 21:06


DOSE: All Nuclides Summed, All Pathways Summed With SA on Density of contaminated zone
4.00
3.95
3.90
3.85
3.80
3.75
mrem/yr
1
10
100
1000
Years
Upper: 1.95
Mid: 1.5
Lower: 1.153846
35gutip.RAD 07/05/2002 21:06 Includes All Pathways

DOSE: All Nuclides Summed, External With SA on Density of contaminated zone



35gutip.RAD 07/05/2002 21:06 Pathways: External

Sensitivity to Pavement Direct Gamma Radiation Pathway – Basis for Figure 5-3

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

Water Independent Pathways (Inhalation excludes radon)

Radio-	Ground		Inhalation		Radon		Plant		Meat		Milk		Soil	
Nuclide	mrem/yr	fract.	mrem/yr	fract.	mrem/yr	fract.	mrem/yr	fract.	mrem/yr	fract.	mrem/yr	fract.	mrem/yr	fract.
Ac-227	3.212E-03	0.0031	0.000E+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
Pa-231	3.686E-04	0.0004	0.000E+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
Pb-210	7.219E-05	0.0001	0.000E+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
Ra-226	6.738E-01	0.6557	0.000E+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
Ra-228	1.404E-01	0.1366	0.000E+00	0.0000	0.000E+00	0.0000	0.000E+00	0.0000	0.000E+00	0.0000	0.000E+00	0.0000	0.000E+00	0.0000
Th-228	1.941E-01	0.1889	0.000E+00	0.0000	0.000E+00	0.0000	0.000E+00	0.0000	0.000E+00	0.0000	0.000E+00	0.0000	0.000E+00	0.0000
Th-230	1.598E-04	0.0002	0.000E+00	0.0000	0.000E+00	0.0000	0.000E+00	0.0000	0.000E+00	0.0000	0.000E+00	0.0000	0.000E+00	0.0000
Th-232	7.930E-03	0.0077	0.000E+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
U-234	3.474E-06	0.0000	0.000E+00	0.0000	0.000E+00	0.0000	0.000E+00	0.0000	0.000E+00	0.0000	0.000E+00	0.0000	0.000E+00	0.0000
U-235	8.978E-04	0.0009	0.000E+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
U-238	6.666E-03	0.0065	0.000E+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
Total	1.028E+00	1.0000	0.000E+00	0.0000	0.000E+00	0.0000	0.000E+00	0.0000	0.000E+00	0.0000	0.000E+00	0.0000	0.000E+00	0.0000

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

Water Dependent Pathways

Radio-	Water		Fish		Radon		Plant		Meat		Milk		All Pathways*	
Nuclide	mrem/yr	fract.	mrem/yr	fract.	mrem/yr	fract.	mrem/yr	fract.	mrem/yr	fract.	mrem/yr	fract.	mrem/yr	fract.
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	3.212E-03	0.0031
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	3.686E-04	0.0004
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	7.219E-05	0.0001
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	6.738E-01	0.6557
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	1.404E-01	0.1366
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	1.941E-01	0.1889
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	1.598E-04	0.0002
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	7.930E-03	0.0077
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	3.474E-06	0.0000
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	8.978E-04	0.0009
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	6.666E-03	0.0065
Total	0.000E+00	0.0000	0.000E+00	0.0000	0.000E+00	0.0000	0.000E+00	0.0000	0.000E+00	0.0000	0.000E+00	0.0000	1.028E+00	1.0000

*Sum of all water independent and dependent pathways.

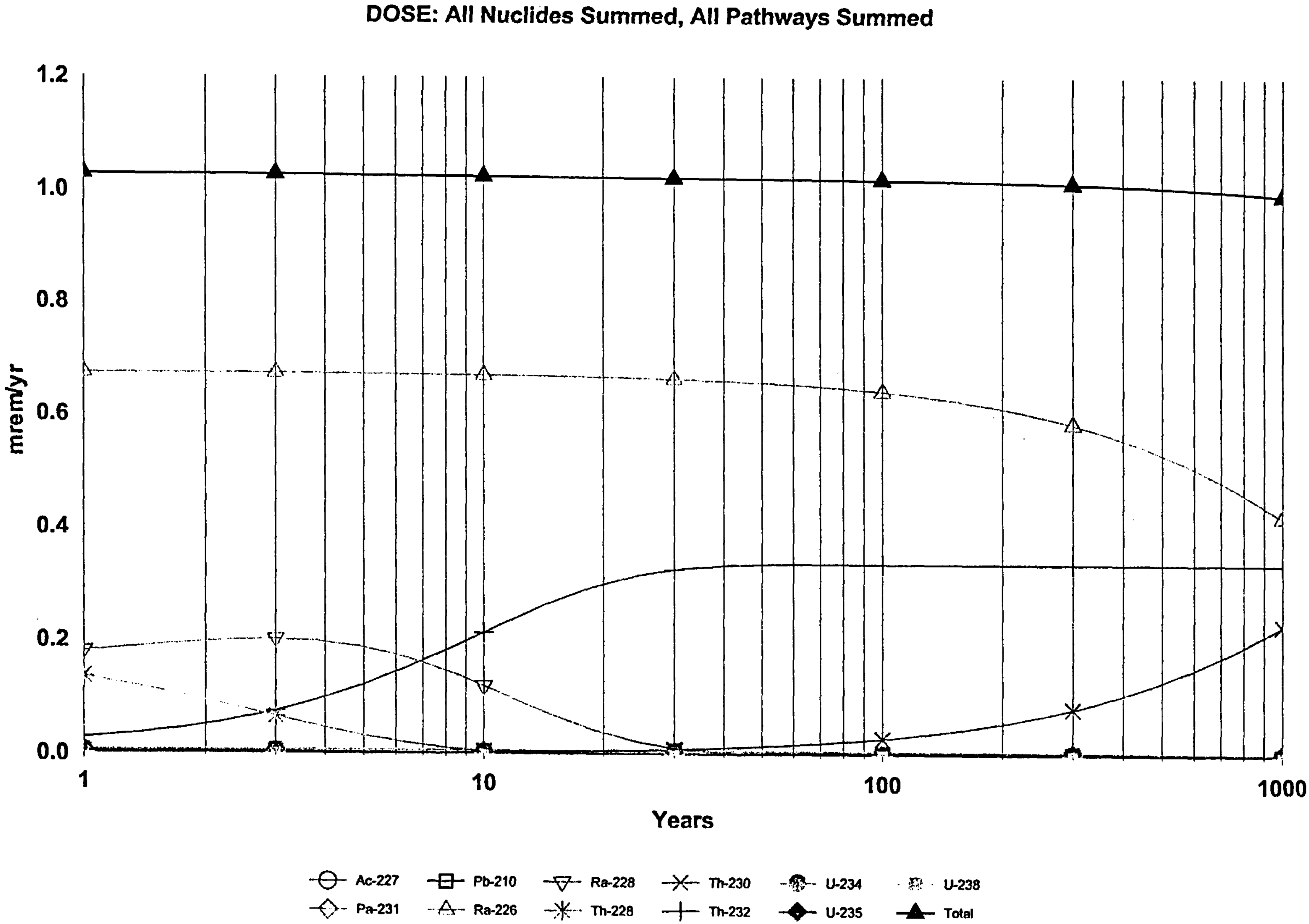
Single Radionuclide Soil Guidelines G(i,t) in pCi/g
Basic Radiation Dose Limit = 2.500E+01 mrem/yr

Nuclide (i)	t= 0.000E+00	1.000E+00	3.000E+00	1.000E+01	3.000E+01	1.000E+02	3.000E+02	1.000E+03
Ac-227	1.062E+03	1.097E+03	1.170E+03	1.463E+03	2.775E+03	2.606E+04	1.567E+07	*7.230E+13
Pa-231	9.258E+03	7.275E+03	5.166E+03	2.751E+03	1.469E+03	1.022E+03	1.059E+03	1.374E+03
Pb-210	1.039E+06	1.072E+06	1.141E+06	1.418E+06	2.644E+06	2.338E+07	1.185E+10	*7.631E+13
Ra-226	1.113E+02	1.114E+02	1.115E+02	1.118E+02	1.129E+02	1.167E+02	1.282E+02	1.783E+02
Ra-228	1.781E+02	1.393E+02	1.241E+02	2.090E+02	2.272E+03	1.199E+07	*2.726E+14	*2.726E+14
Th-228	1.288E+02	1.851E+02	3.820E+02	4.825E+03	6.769E+06	*8.192E+14	*8.192E+14	*8.192E+14
Th-230	4.692E+05	1.661E+05	7.248E+04	2.442E+04	8.474E+03	2.620E+03	9.210E+02	3.275E+02
Th-232	3.152E+03	9.100E+02	3.356E+02	1.166E+02	7.661E+01	7.416E+01	7.419E+01	7.431E+01
U-234	2.159E+07	2.159E+07	2.156E+07	2.094E+07	1.640E+07	4.766E+06	7.194E+05	9.375E+04
U-235	3.801E+03	3.805E+03	3.813E+03	3.841E+03	3.919E+03	4.197E+03	5.087E+03	9.766E+03
U-238	1.125E+04	1.126E+04	1.129E+04	1.137E+04	1.161E+04	1.250E+04	1.545E+04	3.235E+04

*At specific activity limit

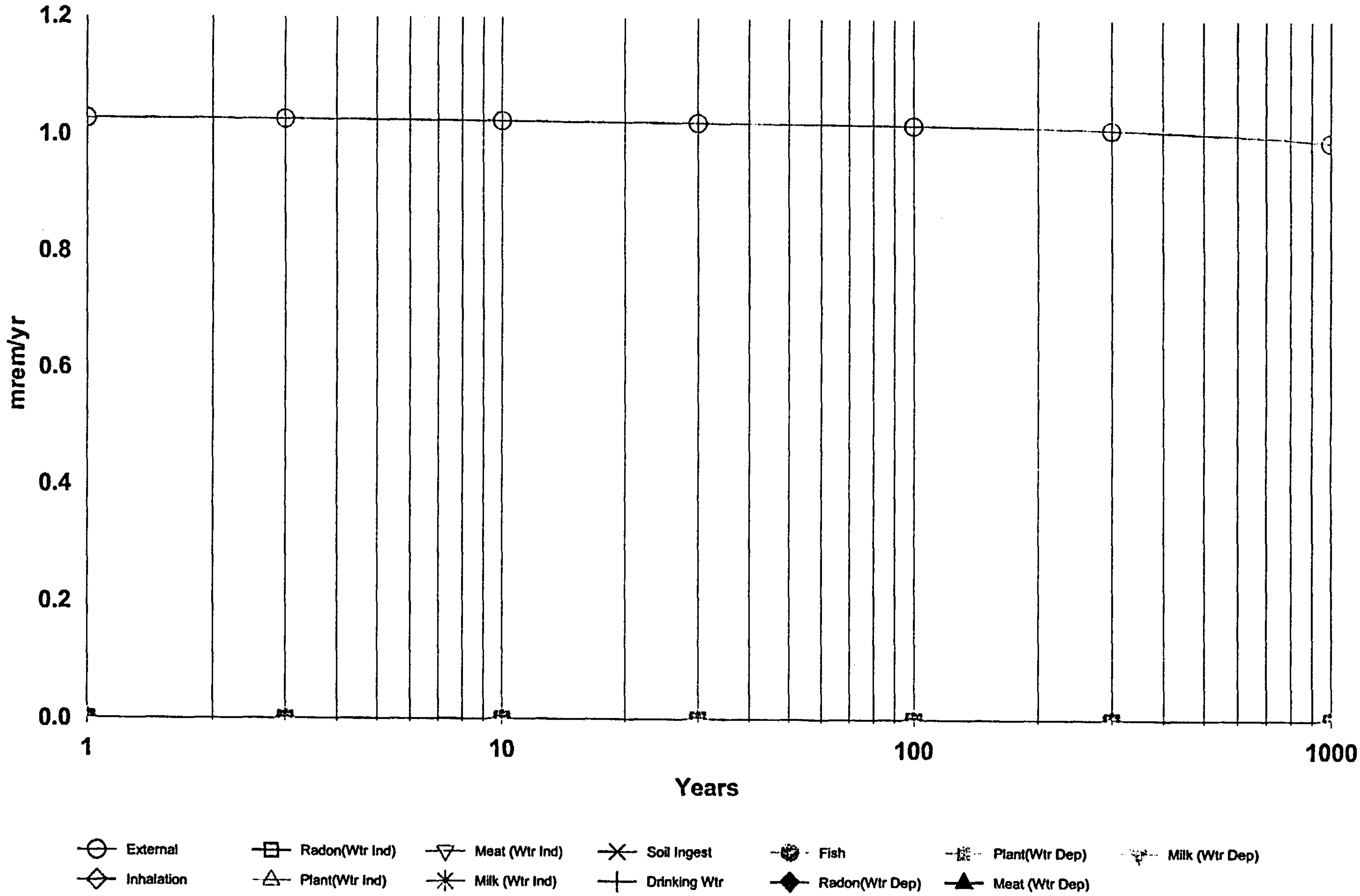
Summed Dose/Source Ratios DSR(i,t) in (mrem/yr)/(pCi/g)
and Single Radionuclide Soil Guidelines G(i,t) in pCi/g
at tmin = time of minimum single radionuclide soil guideline
and at tmax = time of maximum total dose = 0.000E+00 years

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	1.365E-01	0.000E+00	2.353E-02	1.062E+03	2.353E-02	1.062E+03
Pa-231	1.365E-01	137.4 ± 0.3	2.478E-02	1.009E+03	2.700E-03	9.258E+03
Pb-210	3.000E+00	0.000E+00	2.406E-05	1.039E+06	2.406E-05	1.039E+06
Ra-226	3.000E+00	0.000E+00	2.246E-01	1.113E+02	2.246E-01	1.113E+02
Ra-228	1.000E+00	2.891 ± 0.006	2.014E-01	1.241E+02	1.404E-01	1.781E+02
Th-228	1.000E+00	0.000E+00	1.941E-01	1.288E+02	1.941E-01	1.288E+02
Th-230	3.000E+00	1.000E+03	7.634E-02	3.275E+02	5.328E-05	4.692E+05
Th-232	1.000E+00	90.5 ± 0.2	3.371E-01	7.416E+01	7.930E-03	3.152E+03
U-234	3.000E+00	1.000E+03	2.667E-04	9.375E+04	1.158E-06	2.159E+07
U-235	1.365E-01	0.000E+00	6.577E-03	3.801E+03	6.577E-03	3.801E+03
U-238	3.000E+00	0.000E+00	2.222E-03	1.125E+04	2.222E-03	1.125E+04



36gutip.RAD 07/05/2002 20:56 Includes All Pathways

DOSE: All Nuclides Summed, Component Pathways



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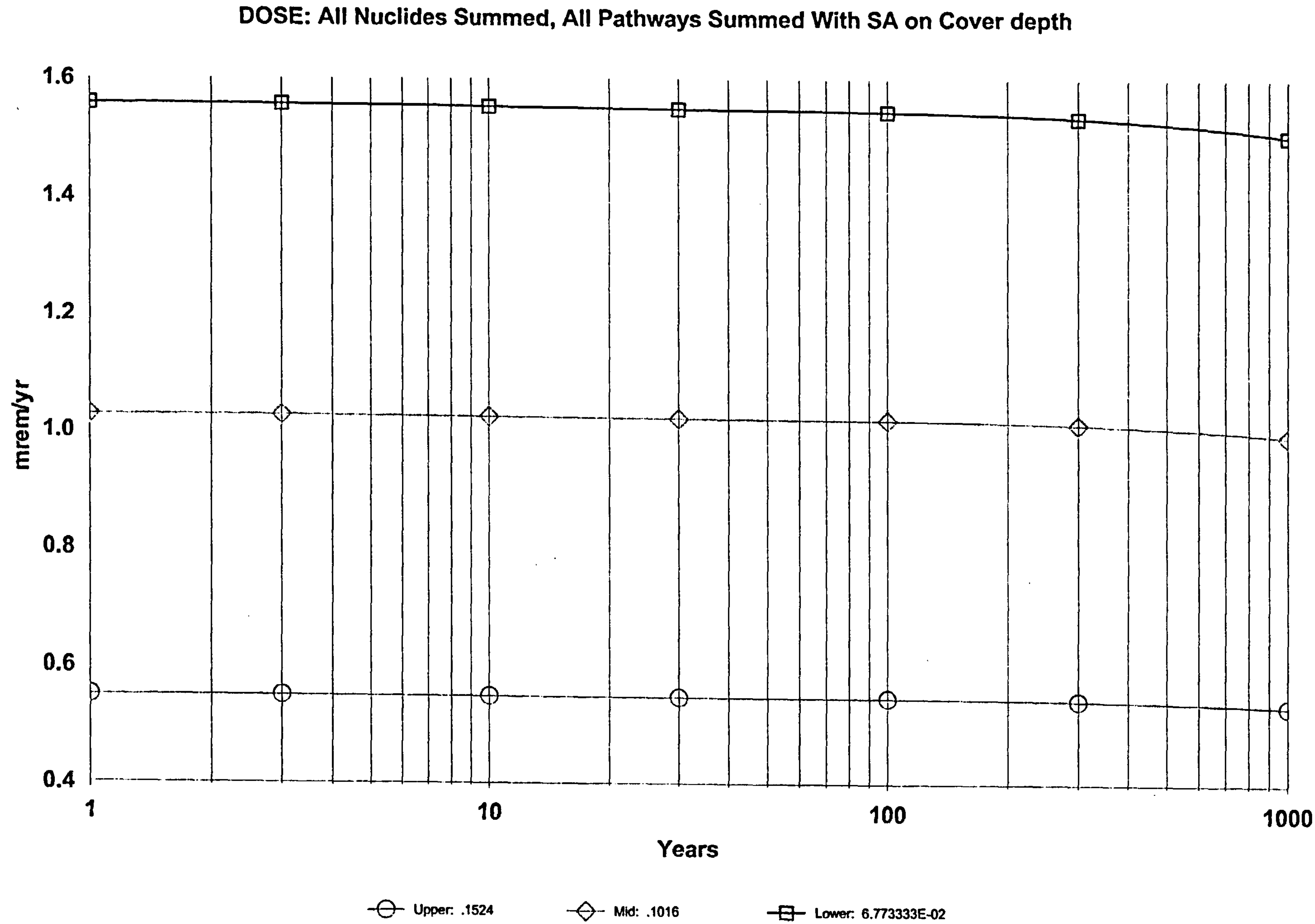

36gutip.RAD 07/05/2002 20:56 Includes All Pathways

APPENDIX E

LOWER LIMIT OF DETECTION

Mallinckrodt Inc.

C-T Phase II Decomissioning Plan
May 15, 2003

NRC Docket: 40-06563
NRC License: STB-401

E1. LOWER LIMIT OF DETECTION

The terminology adopted to reflect the measurement (detection) capability is the lower limit of detection (LLD) or the minimum detectable radioactivity (MDA); it refers to the intrinsic detection capability of the entire measurement process. The lower limit of detection is normally an *a priori*, *i.e.*, before the fact, estimate of the capability of a measurement system, although it might be estimated from background in conjunction with a measurement. The LLD, or MDA, is the smallest concentration of radioactive material in a sample that will yield a net count, above system blank, that will be detected with at least 95% probability with no greater than a 5% probability of falsely concluding that a blank observation represents a real signal. It is desirable to express the MDA as minimum detectable areal density (MDAD) or minimum detectable concentration (MDC) in units comparable to a regulatory limit with which a measurement may be compared.

E.1.1. STATIC MEASUREMENT

E.1.1.1. General

When a gross count is to be compared with a detection decision criterion, without subtracting background, the MDA equation is:

$$\text{MDA} = \frac{3 + 3.29 \cdot s_B}{K \cdot t}$$

where:
- s_B = standard deviation of background, or blank, count
- 3.29 = 2 x 1.645 = standard normal variate for decision errors, $\alpha = 0.05$ and $\beta = 0.05$
- K = factor converting from counts to units in which MDA is expressed
- t = counting time, assuming equal background, or blank, and sample counting times

The form of the equation for estimating MDA when background and sample count times are equal is

$$\text{MDA} = \frac{3 + 4.65 \cdot s_B}{K \cdot t}$$

Application of MDA estimation to 3 areal density measurement situations is illustrated hereafter.

E.1.1.2. Gross Counting.

When a gross count is to be compared simply with the detection decision criterion, the equation to estimate MDAD is:

$$\text{MDAD} = \frac{3 + 3.29\sqrt{B}}{E \cdot t_s \frac{A}{100}}$$

where:
- B = background, or blank, count (ct)
- E = detection sensitivity (dis/ct)
- t_s = sample count time (min) where $t_{background} = t_{sample}$

A = detection area[1] (cm^2)

E.1.1.3. Gross Minus Blank Counting.

In the event the radiation of interest is measured as the sample gross count minus the blank, or background, count, and the sample gross count time and the blank count time are equal, the equation to estimate minimum detectable areal density is:

$$MDAD = \frac{3 + 4.65\sqrt{B}}{E \cdot t_s \frac{A}{100}}$$

where t_s = sample count time (min) where $t_{background} = t_{sample}$

E.1.1.4. Unequal Blank and Sample Count Times.

In the event the radiation of interest is measured as the sample gross count minus the blank count, and the sample count time, t_s, and the blank count time, t_b, are unequal, the equation to estimate MDAD is:

$$MDAD = \frac{3 + 3.29\sqrt{B \cdot \frac{t_s}{t_b}\left(\frac{t_s + t_b}{t_b}\right)}}{E \cdot t_s \frac{A}{100}}$$

where: t_b = background, or blank, count (ct)

E.1.1.5. Ambient Gamma Radiation.

Ambient gamma radiation in a survey unit will be measured by the detector type , an AB-100 or equivalent, that is to be used to perform a final status survey in that unit. Its purpose will be to assess whether ambient gamma radiation might be elevated enough to warrant recalculation of the minimum detectable radioactivity estimate of the measurement capability.

E.1.1.6. *A priori* Lower Limit of Detection.

The lower limits of detection of instruments that may be used to perform final radiation status surveys are estimated in Tables 4-1 and 4-2 where background readings representative of the site are available. The lower limit of detection of each instrument type, for which a representative background reading is not now available, will be estimated by methodology herein before use in a final status survey.

E.1.2. SCANNING SENSITIVITY[2]

Surfaces are scanned to detect a small area of radioactive contamination. The minimum detectable areal density of radioactive contamination depends on both the instrumentation and the surveyor. The minimum detectable net count rate of a scanning instrument[3] is

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[1] A/100 = 1 when Lucas calibration is applied to Bicron AB-100, Ludlum 43-89, or equivalent detector

[2] MARSSIM, §6.7.2.

[3] Abelquist. E.W., *et.al.*, *Minimum Detectable Concentrations with Typical Radiation Survey Instruments for Various Contaminants and Field Conditions*, NUREG-1507, §6.1, Dec. 1997.

$$MDCR = d'\sqrt{b_i} \cdot \frac{60}{i} = s_i \frac{60}{i}$$

where: MDCR = minimum detectable net count rate (ct/min)

d' = 1.38 when false positive decision error, $\alpha = 0.60$, and correct decision fraction, $1\text{-}\beta = 0.95^{\{ref\,4\}}$

i = observation interval (sec) = $\sqrt{\text{det ector area}} \div \text{scan speed}$

s_i = minimum detectable number of net source counts in observation interval (ct)

b_i = background counts in observation interval (ct)

60 = conversion, 60 (sec/min)

The minimum detectable areal activity density by scanning is:

$$\text{Scan MDC} = \frac{MDCR}{\sqrt{p} \cdot E_c E_p}$$

where:

Scan MDC = minimum detectable areal activity density by scanning (dpm/100 cm^2)

p = surveyor efficiency, assumed[5] to be 0.5.

and where the scan spped is specified in section 4.2.

When an AB-100 detector is used for scanning, it is done in window open mode. Detection sensitivity is expressed per 100 cm^2 according to Lucas and Colyott.

Each composite areal U series and Th series radioactivity density on surface, AD_c, is thereby expressed in units comparable with the composite limit, $Limit_{composite}$, for a U series and Th series mixture.

With background readings from a reference area and or a reference material, similarly interpreted, the measurements are amenable to statistical comparison of populations of background + AD_c versus survey unit measurements to test compliance with criteria in C-T Phase II Decommissioning Plan, section 5.

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[4] Abelquist. E.W., et.al., Table 6.1 p. 6.23.

[5] Abelquist, E.W., *et.al.*, §6.7.1.

APPENDIX F

RADIONUCLIDE ANALYSIS IN SOIL BY IN-GROUND GAMMA SPECTROMETRY

Mallinckrodt Inc.

C-T Phase II Decomissioning Plan
May 15, 2003

NRC Docket: 40-06563
NRC License: STB-401

F1. RADIONUCLIDE ANALYSIS IN SOIL BY IN-GROUND GAMMA SPECTROMETRY

F 1.1. APPLICATION

This describes a gamma spectrometry method using a sodium iodide crystal detector coupled to a multi-channel analyzer to measure radioactivity attributable to uranium series and thorium series in soil surrounding the detector.

F 1.2. DESCRIPTION

The gamma spectrometer consists of a NaI(Tl) crystal detector, photomultiplier, preamplifier, multi-channel spectrum analyzer (MCA), and computer. All are sufficiently transportable for outdoor use. The detector may be connected with the MCA by a long cabling to allow lowering it into a hole augered into the ground. The MCA has provision for storing a small number of spectra independently of the computer. Spectra will be downloaded to a portable computer for interpretation. The analysis and archiving method enable data review in extensive detail.

F 1.3. CHARACTERISTICS

Gamma spectrometry with the detector in the ground is advantageous over soil removal sampling in that it samples a larger volume of soil than is convenient in removal sampling. Further, the method provides immediate feedback on the possible presence of radioactivity. Increase in counting rate is the first indicator of excess radioactivity. Analysis of the spectrum will then yield the nuclide mix, which, when considered with the release limits, may aid in a remediation decision.

It is notable that a core sample is not exactly the same material as that remaining in the ground surrounding the cavity from which it was taken. In-ground measurement "samples" a larger quantity of soil, perhaps more than 10 times more, than a core sample. That suppresses the variability inherent in exceedingly small samples.

F 1.4. MATHEMATICAL BASIS.

Calibration spectra will be recorded in such a way that deconvolution of any observed spectrum using the calibration spectra will yield the soil radionuclide concentration. The mathematical basis for this process is described below.

A calibration spectrum of each radionuclide family to be interpreted by measurement is acquired in a source environment simulating that of measurement in-ground. The same number of calibration observations, albeit differing in concentration, are acquired as the number of nuclide families which are to be determined.

After calibration spectra are derived, measurement is performed by lowering a scintillation detector into an augered hole in soil where a pulse height spectrum accumulated. The spectrum recorded is a composite of spectra, each presented by a key radionuclide and its short-lived progeny. After accumulation of a spectrum of unknowns, the analyzer software is operated in an iterative calculation wherein aliquots of standard spectra are added together until the spectrum shape of the added aliquots matches that of the unknown as judged by minimizing the square of the errors between the observed spectrum and the weighted sum of the standard spectra. Then, knowing the amount of each aliquot of calibration standard, the matching quantity and or concentration of each measured radionuclide in a composite spectrum may be reported. Mathematically this may be expressed as:

$$S(E) = A_U S_U(E) + A_{Th} S_{Th}(E) + A_{Ra} S_{Ra}(E) + A_K S_K(E) \qquad \text{eqtn F1}$$

where: $S_i(E)$ = spectra of 1024 channels having calibration factor (counts/sec per pCi/g) stored in each channel

A_i = radioactivity concentration of radionuclide *i* (pCi/gm)

so that, when the A_i are chosen by iteration, the counts in the unknown spectrum are predicted. The A_i may then be taken to represent the radioactivity concentration of each nuclide or nuclide family related to the standard spectra.

The goodness of fit to the measured spectrum is calculated at each iteration by summing the squares of the differences between the right side of equation F1 and the left side, *i.e.*, the original measured spectrum. This sum, called the weighted sum of squares (wss) is used as an index of improvement as the process proceeds. When, by statistical criteria, it becomes clear that the solution may not be improved, the process is terminated.

F 1.5. CALIBRATION

Energy pulse height calibration is performed by using the signal detected from a small cesium-137 button source to normalize the spectra to photon energy.

The objective of quantitative calibration is to produce standard spectra representative of uranium, thorium, radium, and potassium. Implicit in the method is a calibration which is traceable to the NIST or other recognized provider and a data reduction method which uses the calibrations to interpret the acquired spectra.

Standard sources of natural uranium, thorium-232 and daughters, radium-226 and daughters, and potassium-40 are planned to be fabricated by filling containers with silica sand which has been doped with a known quantity of liquid radionuclide standard material to simulate an in-ground source. The specific activities of the radionuclide standards are traceable to NIST and the spectrum shapes.

F 1.6. BACKGROUND

A drum of silica sand may be prepared as an environment for subtraction of ambient background from the standard source drums. This in-ground gamma spectrometry measurement method is expected to achieve detectability to a level below that found in uncontaminated cinder-fill soil.

Alternatively, for backgrounding spectra collected in field application, one may want to consider only the radioactivity in the detector and that due to cosmic rays. For this purpose, the detector may be operated in 4-inches of lead bricks. The spectrum accumulated would be subtracted from all field spectra.

F 1.7. LOWER LIMIT OF DETECTION

The lower limit of detection (LLD) of a gamma spectrometer used in-ground will be determined. The LLD of key radionuclides in soil is expected to be as low as is detectable by the same instrument configured with lead-shielded detector in a counting room setting. Reasons to expect comparably low LLD are that

- instrumentation used in the field is practically the same as used in a counting room.
- the quantity of gamma-emitting soil surrounding a detector in the ground is about 10 to 15 times more than a soil sample typically taken to a counting room.
- soil surrounding a detector in the ground is its own shield against background radiation
- the background radioactivity concentration in-ground or in a core sample from the same location should be the same.

ATTACHMENT 1

OCCUPATIONAL DOSE EVALUATION

Mallinckrodt Inc.

C-T Phase II Decomissioning Plan
May 15, 2003

NRC Docket: 40-06563
NRC License: STB-401

Occupational Dose Evaluation

Introduction

This attachment describes an estimate and evaluation of the occupational radiation dose to a worker participating in the C-T Phase II Decommissioning Project. The estimate of dose considers a hypothetical situation, likely a bounding scenario, which could occur during the decommissioning. The evaluation provides justification that the activities to be performed during the C-T Phase II Decommissioning Project will maintain occupational exposure to source material as low as reasonably achievable (ALARA).

Hypothetical Occupational Exposure Scenario

The scope of the C-T Phase II Decommissioning Plan includes only contaminated surface soils (pavement and slabs) and contaminated subsurface soils (cinder/fill) in Plant 5. The surface soils are of such physical makeup that they would not lend themselves to dispersion. Also, the contamination levels of the surface soils are not significant, in the context of worker exposure, to warrant further consideration. The dominant exposure scenario is the construction workers interaction with subsurface soils. Then the exposure pathways of concern are those associated with the chronic (occupational) exposure scenario of construction activities during the C-T Phase II Decommissioning Project; 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.

A construction worker may be exposed to subsurface soils during the entire period of excavation activities at Plant 5. This is a bounding scenario because it is believed to pose the maximum integral exposure to a worker. The occupational exposure scenario assumptions below are conservative and will result in a dose to the worker that is bounding.

Scenario Assumptions

The 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 – A soil concentration was estimated for each of the six key radionuclides. The estimate was derived as an average of the sample results for

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

which the sum-of-fractions value is greater than one. The input soil concentrations are:

U-238 - 27 pCi/g,

U-235 – 1 pCi/g,

U-234 – 27 pCi/g

Th-230 - 47 pCi/g,

Ra-226 - 228 pCi/g,

Th-232 - 12 pCi/g,

Ra-228 – 42 pCi/g, and

Th-228 - 17 pCi/g.

2. Basic Radiation Dose Limit – The radiation dose limit for a radiation worker is 5000 mrem/y. [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.

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.

[2] 10 CFR 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 1926.

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.

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 42000 ft^3. It is also estimated that about 1000 ft^3 of soil can be excavated per workday. Then the contaminated soil could be excavated in about 42 workdays. The outdoor time in the contaminated area is assumed comprised of 6 hours per workday, 5 days per workweek, for 12.5 workweeks, or 375 workhours. The fraction of time per year that the construction worker spends outside in the contaminated area is 375 work hours / 8766 total hours = 0.043.

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] As an account for the aggressive nature of excavation activities, the inadvertent soil ingestion rate will be assumed to increase to 73 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 C-T Phase II decommissioning Project is 11.

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 120 mrem per year.

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.

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

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

expended to reduce risk. Applying this criterion to the C-T Phase II Decommissioning Project, the expenditure that would be justifiable if all radiological dose to C-T decommissioning workers could be averted would be about:

Occupational Dose = 120 mrem per construction worker.
Collective dose = 0.120 rem/worker x 11 workers = 1.3 person-rem.
Justifiable expenditure = $2,000/person-rem x 1.3 person-rem = $2640.

The funds spent to avert dose for the C-T Phase II Decommissioning Project already far exceed $2640. Therefore, the project meets the definition of ALARA and should not require measures beyond good health practices to avert dose. Mallinckrodt has incorporated ALARA practices into its radiation protection program through the use of plans, procedures, training, safety work permits, and oversight. Therefore, the intent of the regulations has been met with respect to ALARA.

Conclusions

An occupational dose evaluation was performed for decommissioning work associated with the C-T Decommissioning Project. Modeling performed using the RESRAD computer code and site-specific information or estimates yielded an estimate of 120 mrem per year for a representative construction worker. Based upon an estimate of 11 workers on the project, the collective dose was estimated as 1.3 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 C-T Decommissioning Project. Additional measures such as a formal ALARA program, or ALARA Committee, are not warranted.

ATTACHMENT 2

ACCIDENT ANALYSIS

Mallinckrodt Inc.

C-T Phase II Decomissioning Plan
May 15, 2003

NRC Docket: 40-06563
NRC License: STB-401

Accident Analysis

Introduction

This attachment describes a credible accident, estimates the resulting quantity of radioactive material (as a contaminant in soils), which could potentially be released, and evaluates a dose to a worker due to the accident. Analysis of the accident considers a worst-case hypothetical situation, likely a bounding scenario, which could occur during the decommissioning process.

Hypothetical Accident Scenario

The scope of the C-T Phase II Decommissioning Plan includes only contaminated pavement and slabs and contaminated soils (cinder/fill) in Plant 5. The surfaces are of such physical makeup that they would not lend themselves to dispersion. The most readily dispersible contamination occurs in the subsurface soils. Dispersion by water is unlikely considering the soils will be excavated below grade. Intuitively, the exposure pathway of concern for an acute (accident) exposure scenario is identified as inhalation.

Contaminated subsurface soil spilling and generating a dust cloud, which might then be breathed by a worker on-site, is believed to pose the maximum integral exposure to a worker, and thus was chosen as the bounding scenario. The accident scenario assumptions below are conservative and will result in a calculated release and dose to the worker that is a bounding maximum

Scenario Assumptions

Notable assumptions in the accident scenario are:

1. Comparison of the Allowable Limit on Intake[1] for the six key radionuclides reveals Th-230 and Th-232 to be the most restrictive.
2. Spilled, contaminated soils are assumed to come from beneath Building 238. The subsurface soils in Plant 5 with maximal concentrations of radioactive material are surrounding and beneath Building 238. The most contaminated subsurface soil is characterized by the sample of bottom depth 9.5 feet at BH-15. This sample has the highest concentration of Th-230 and Th-232 with also the greatest combination of the other key radionuclides.
3. Short-lived transformation products are in secular equilibrium with their parents.
4. One cubic meter of soil is spilled; approximately one excavation bucket.
5. The spilled soil generates a puff of dust that is contained within a volume of 10000 cubic meters. (A work area 31.6 m long, 31.6 m wide, and 10 m high.)
6. The estimated instantaneous mass loading of dust in air is 1.3 g/m^3.[2]

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[1] 10 CFR 20, Appendix B, Table 1, Column 2.

[2] Yu, C., *et.al.*, Data Collection Handbook to Support Modeling the Impacts of Radioactive Material in Soil. ANL/EAIS/8. p. 111. April 1993.

7. There is no atmospheric dispersion.
8. The wind is blowing at an average speed of 4.3 meters per second.
9. A worker is at the scene of the accident and is exposed to the dust as it passes around him.
10. The worker's breathing rate is 1.2 m^3/h.

Calculations

The concentration of radioactive material in air due to the spilled soil is:

$$C_{U238} = 72\,\frac{\text{pCi}}{\text{g}} \times 1.3\,\frac{\text{g dust}}{\text{m}^3\text{ air}} \times \frac{1\,\mu\text{Ci}}{10^6\text{ pCi}} \times \frac{1\text{ m}^3}{10^6\text{ cm}^3} = 9.4x10^{-11}\,\frac{\mu\text{Ci}}{\text{cm}^3\text{ air}}$$

$$C_{Th230} = 262\,\frac{\text{pCi}}{\text{g}} \times 1.3\,\frac{\text{g dust}}{\text{m}^3\text{ air}} \times \frac{1\,\mu\text{Ci}}{10^6\text{ pCi}} \times \frac{1\text{ m}^3}{10^6\text{ cm}^3} = 3.4x10^{-10}\,\frac{\mu\text{Ci}}{\text{cm}^3\text{ air}}$$

$$C_{Ra226} = 745\,\frac{\text{pCi}}{\text{g}} \times 1.3\,\frac{\text{g dust}}{\text{m}^3\text{ air}} \times \frac{1\,\mu\text{Ci}}{10^6\text{ pCi}} \times \frac{1\text{ m}^3}{10^6\text{ cm}^3} = 9.7x10^{-10}\,\frac{\mu\text{Ci}}{\text{cm}^3\text{ air}}$$

$$C_{Th232} = 48\,\frac{\text{pCi}}{\text{g}} \times 1.3\,\frac{\text{g dust}}{\text{m}^3\text{ air}} \times \frac{1\,\mu\text{Ci}}{10^6\text{ pCi}} \times \frac{1\text{ m}^3}{10^6\text{ cm}^3} = 6.2x10^{-11}\,\frac{\mu\text{Ci}}{\text{cm}^3\text{ air}}$$

$$C_{Ra228} = 193\,\frac{\text{pCi}}{\text{g}} \times 1.3\,\frac{\text{g dust}}{\text{m}^3\text{ air}} \times \frac{1\,\mu\text{Ci}}{10^6\text{ pCi}} \times \frac{1\text{ m}^3}{10^6\text{ cm}^3} = 2.5x10^{-10}\,\frac{\mu\text{Ci}}{\text{cm}^3\text{ air}}$$

$$C_{Th228} = 61\,\frac{\text{pCi}}{\text{g}} \times 1.3\,\frac{\text{g dust}}{\text{m}^3\text{ air}} \times \frac{1\,\mu\text{Ci}}{10^6\text{ pCi}} \times \frac{1\text{ m}^3}{10^6\text{ cm}^3} = 7.9x10^{-11}\,\frac{\mu\text{Ci}}{\text{cm}^3\text{ air}}$$

The largest dimension of the plume at the breathing zone is diagonal of the work area or 45 m. Assuming that the wind blows such that the worker is exposed for the longest possible time, the time of exposure is then 45 m ÷4.3m/s, or 10 seconds.

Based on the above assumptions and calculations, the intake is:

$$I_{U238} = 9.4\,x10^{-11}\,\frac{\mu Ci}{cm^3\ air} \times 1.2\frac{m^3}{hour} \times \frac{10^6\ cm^3}{m^3} \times \frac{1\,hour}{3600s} \times 10s = 3.2x10^{-07}\,\mu Ci$$

$$I_{Th230} = 3.4\,x10^{-10}\,\frac{\mu Ci}{cm^3\ air} \times 1.2\frac{m^3}{hour} \times \frac{10^6\ cm^3}{m^3} \times \frac{1\,hour}{3600s} \times 10s = 1.2x10^{-06}\,\mu Ci$$

$$I_{Ra226} = 9.7\,x10^{-10}\,\frac{\mu Ci}{cm^3\ air} \times 1.2\frac{m^3}{hour} \times \frac{10^6\ cm^3}{m^3} \times \frac{1\,hour}{3600s} \times 10s = 3.4x10^{-06}\,\mu Ci$$

$$I_{Th232} = 6.2\,x10^{-11}\,\frac{\mu Ci}{cm^3\ air} \times 1.2\frac{m^3}{hour} \times \frac{10^6\ cm^3}{m^3} \times \frac{1\,hour}{3600s} \times 10s = 2.2x10^{-07}\,\mu Ci$$

$$I_{Ra228} = 2.5\,x10^{-10}\,\frac{\mu Ci}{cm^3\ air} \times 1.2\frac{m^3}{hour} \times \frac{10^6\ cm^3}{m^3} \times \frac{1\,hour}{3600s} \times 10s = 8.7x10^{-06}\,\mu Ci$$

$$I_{Th228} = 7.9\,x10^{-11}\,\frac{\mu Ci}{cm^3\ air} \times 1.2\frac{m^3}{hour} \times \frac{10^6\ cm^3}{m^3} \times \frac{1\,hour}{3600s} \times 10s = 2.7x10^{-07}\,\mu Ci$$

Comparison with the Allowable Limit on Intake (ALI)

The ALI is the quantity, in microcuries, of a radionuclide that can be taken into the body in one year by the reference man while still meeting the occupational dose limits. The following table lists the most restrictive lung solubility class ALIs from 10 CFR 20 for radionuclides in the U-238 and Th-232 series up to radon, and calculates the fractional ALI intake by the hypothetical worker exposed to the dust cloud from the spilled soil.

Nuclide	ALI[3] (μCi)	Intake (μCi)	Fraction of ALI
U-238	5 E-02	3.2 E-07	6.5 E-06
Th-234	2 E+02	3.2 E-07	1.6 E-09
Pa-234m	7 E+03	3.2 E-07	4.6 E-11
U-234	7 E-01	3.2 E-07	4.6 E-07
Th-230	6 E-03	1.2 E-06	2.0 E-04
Ra-226	6 E-01	3.4 E-06	5.6 E-06
Th-232	1 E-03	2.2 E-07	2.2 E-04
Ra-228	1 E+00	8.7 E-06	8.7 E-07
Ac-228	9 E+00	8.7 E-06	9.7 E-08
Th-228	1 E-02	2.7 E-07	2.7 E-05
Ra-224	2 E+00	2.7 E-07	1.4 E-07
		Sum of fractions:	4.5 E-04

Thus, the total fractional ALI attributable to the hypothetical accident is so small as to be considered negligible.

As the onsite intake of radioactive material from this accident scenario is insignificant, the offsite intake will also be insignificant. Therefore, no special evaluations were performed for offsite intake or dose.

Conclusions

An accident evaluation was performed to determine the significance of releases and dose to workers. The evaluation was performed for a spill of contaminated soil that released a cloud of dust. The assumptions utilized in the calculations were conservative and it is expected that the results are upper bounds of the actual quantities and doses. Even under these conservative assumptions, the total source term was very small, with a projected intake to the maximum exposed individual onsite of an extremely small fraction of the ALI. The intake, and hence dose, to an offsite individual would be even lower than for the onsite individual. Since the onsite intake calculated under this scenario was negligible, no offsite calculations were performed.

[3] 10 CFR 20, Appendix B, Table 1, Column 2.