# DERIVED CONCENTRATION GUIDELINE LEVEL REPORT

## GSA PROPERTY
## WATERTOWN, MASSACHUSETTS

**CONTRACT NO. DACA33-97-C-0023**

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**JANUARY 2001**

**VOLUME 1 OF 2**

# DERIVED CONCENTRATION GUIDELINE LEVEL REPORT
# WATERTOWN GSA SITE
# WATERTOWN, MASSACHUSETTS

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# Executive Summary

This report presents Derived Concentration Guidance Levels (DCGLs) for the GSA Watertown Site (RTN 3-02722). A DCGL is a site-specific concentration determined to be protective of the health of individuals that might be exposed in the future to the residual radioactivity that might be left in place on the site. The DCGLs have been calculated to meet requirements set by the Nuclear Regulatory Commission (NRC) the Massachusetts Department of Public Health (MADPH), and the Massachusetts Department of Environmental Protection (MADEP).

The Site consists of the 11.91 acre GSA Property as well as a portion of the adjoining, Massachusetts Metropolitan District Commission (MAMDC) Property 20. The Site was formerly part of the Watertown Arsenal. Past use of the Watertown GSA property by the U.S. Army involved the use of hazardous and potentially hazardous materials, most notably the oxidation, stabilization, and off-site disposal of depleted uranium scrap. The current objective is to excess this property in accordance with federal property transfer requirements and regulations.

Previous site characterization activities indicate the presence of detectable quantities of hazardous materials residues, including depleted uranium, polycyclic aromatic hydrocarbons (PAH), and heavy metals. Accordingly, the site has been listed under the Massachusetts Contingency Plan (MCP) as a Tier 1A site and is subject to the MCP criteria achieving a response action outcome. In addition, the NRC and MADPH also regulate the residual radioactivity on the site resulting from former operations involving depleted uranium.

To excess this property, the risks to human health associated with potential exposure to hazardous materials originating at the site must be evaluated and demonstrated to be within acceptable limits. To comply with the MCP, the response actions conducted at this site shall ensure a level of control of each identified substance such that no substance of concern shall present a substantial hazard or significant risk of harm to health, safety, public welfare, or the environment during any foreseeable period of time. To comply with NRC and MADPH criteria for site release, the residual radioactivity at the site must not contribute an annual radiation dose in excess of the NRC and MADPH criteria.

The evaluation of potential risks posed by substances present at the Site is being carried out on two parallel tracks. Chemical contamination at the Site has been evaluated by a series of investigations. A Supplemental Phase II Comprehensive Site Assessment (CSA) has been prepared based on the results of Harding ESE's chemical investigations. The Phase II CSA also evaluates the human health and ecological risks associated with potential exposures to chemical substances at the site. The Phase II CSA will be issued in early February 2001. Radiological contamination at the Site is being addressed following MARSSIM guidance through the submission of a Historical Site Assessment (Harding ESE, 2000) and the preparation of the DCGLs presented in this document.

The NRC, MADPH, and MADEP must approve any DCGL that is proposed. NRC and MADPH have dose-based criteria for release; the more conservative of the two criteria is the MADPH radiation dose limit of 10 mrem/year for unrestricted use. The MCP, administered by MADEP, requires that the excess lifetime cancer risk (ELCR) associated with radiation present at the Site be less than $1 \times 10^{-5}$, or one in 100,000. The DCGLs presented in this report are based on conservative assumptions and provide limits which are consistent with those required by the three regulatory agencies.

In the future, the site is anticipated to be used initially as a passive recreational or park area, followed by possible re-development into a sports facility with an ice rink, pool, and playing fields. Future residential use is considered to be prohibitively unlikely, and thus DCGLs are not derived to be protective of the residential use scenario. While the radiological considerations on the site do not require that a residential scenario be precluded, non-radiological considerations may require that a future residential use be prohibited by deed restriction.

DCGLs were calculated for four different potential exposure scenarios considered to be reasonably possible:

- a recreational visitor using the Site year-round,
- a recreational gardener gardening at the Site and consuming produce grown at the Site,
- a construction worker participating in a significant re-development project at the Site, and
- a site recreational facility worker spending the entire year performing both indoor and outdoor tasks at the Site.

The DCGL for the GSA site has been calculated using the RESRAD 6.0 modeling code. Each of the scenarios modeled is credible and foreseeable and each results in a concentration corresponding to the either the 10 mrem/y dose limit or the ELCR limit on the order of $1 \times 10^{-5}$. Considering the potential future land-use scenarios, the limiting scenario (the one that results in the smallest concentration yielding 10 mrem/y or ELCR on the order of $1 \times 10^{-5}$) is the Occupational Worker scenario. Based on this scenario, the proposed DCGL for the GSA site is 340 pCi/g total uranium.

However, conservatism has been built into the modeling by conscientiously selecting exposure factor values that err on the side of safety when confronted with uncertainty in the selection of input parameters. The uncertainty analysis shows that the deterministic point estimates used to derive the DCGL are very conservative. In fact, the analysis indicates that at the candidate DCGL the most likely annual dose to a member of the critical exposure group (the Occupational Worker) is more than 8 times lower than the MADPH limit, over 20 times lower than the permissible and safe public dose standard specified by the NRC, and 2.3 times less than the cancer risk limit promulgated by the MADEP. In effect, this means that the maximum permissible concentration in soil as calculated with deterministic method is 2.3 times more conservative than the probabilistic method. Having evaluated these uncertainties in a quantitative way, it would be conceivable and defensible to adjust the maximum permissible concentration up by the same factor of 2.3. This degree of conservatism in the proposed DCGL accommodates the remote possibility that uranium tailings might have been deposited in a small area at the north end of the site.

The DCGL proposed has been derived using appropriate techniques in accordance with governing guidance, standards, and regulations in concert with the input of a panel of experts and stakeholders assembled into a steering group and representing the interests of the stakeholders, the CENAE, the U.S. Army, and State and federal regulators. The recommended DCGL value for the Watertown GSA site is 340 pCi/g total uranium. It is recommended that this value be approved and adopted as the site-specific permissible concentration.

# 1.0 Introduction

## 1.1 Watertown GSA Site Transition

The General Services Administration (GSA) of the federal government currently owns the 11.9-acre parcel of land located in Watertown, Massachusetts and known as the "Watertown GSA site". The site was once owned by the Commonwealth of Massachusetts and was withdrawn by the federal government in 1920 for use by the U.S. Army, when the nearby Watertown Arsenal was in need of additional space. The Watertown GSA site is located at 670 Arsenal Street in Watertown, and is bounded by Arsenal Street to the south, Greenough Boulevard to the east, Grove Street to the north, and properties abutting Coolidge Avenue to the west. The property was used for the support of various Arsenal operations. In 1967, the Army, having discontinued operations at the Arsenal and having no further need for the property, transferred the 11.9-acre parcel to the GSA (hence, the name Watertown GSA Site). The GSA has made several uses of the property since taking title but has also now determined that the property is excess to the needs of the federal government.

The current objective is to dispose of this property in accordance with federal property disposal requirements and regulations.

As a condition of the federal land withdrawal, a "reverter clause" was established. The reverter clause specifies that in the event that the land is no longer required for use by the federal government, that title rights to the property would be reverted to the original owner, the Commonwealth of Massachusetts. The reverter clause specifically designates the Commonwealth's Metropolitan District Commission (MAMDC) as the title recipient.

### 1.1.1 Property Disposition Options

Past use of the Watertown GSA property by the U.S. Army involved the use of hazardous and potentially hazardous materials, most notably the oxidation, stabilization, and off-site disposal of depleted uranium scrap. Previous site characterization activities indicate the presence of detectable quantities of hazardous materials residues, including depleted uranium, polycyclic aromatic hydrocarbons (PAH), and heavy metals (Harding ESE 2000). Accordingly, the site has been listed under the Massachusetts Contingency Plan (MCP) as a Tier 1A site and is subject to the MCP criteria for de-listing and release. In addition, the U.S. Nuclear Regulatory Commission (NRC) and the Massachusetts Department of Public Health (MADPH) also regulate the residual radioactivity on the site resulting from former operations involving depleted uranium.

To dispose of this property, the potential human health impacts associated with exposure to hazardous materials originating at the site must be evaluated and demonstrated to be within acceptable limits. To comply with the MCP, the response actions conducted at this site shall ensure a level of control of each identified substance such that no substance of concern shall present a substantial hazard or significant risk of harm to health, safety, public welfare, or the environment during any foreseeable period of time.

The evaluation of potential risks posed by substances present at the Site is being carried out on two parallel tracks. Chemical contamination at the Site has been evaluated by a series of investigations. A Supplemental Phase II Comprehensive Site Assessment (Harding ESE, 2001) has been prepared based on the results of Harding ESE's chemical investigations. The Phase II also evaluates ecological risks posed by the site. Radiological contamination at the Site is being addressed following MARSSIM guidance through the submission of a Historical Site Assessment (Harding ESE, 2000) and the preparation of the DCGLs presented in this document.

The goal of reverting ownership of the site requires a response action to evaluate and, if warranted, address the residual radioactivity that might be present on the site. Data collected to date have identified locations on the site that have measurable concentrations of residual radioactivity in soil in excess of the naturally occurring background radioactivity levels in the surrounding area. The presence of residual radioactivity in excess of background concentrations precludes releasing the site from radiological controls without first addressing the site-specific potential public health hazards associated with current and future land use scenarios. There are essentially two options available to address the disposition of the Watertown GSA property.

- ***Remove all residual radioactivity exceeding the generic (or screening level) radioactivity in soil concentration guidelines***. This option, while direct, is estimated to be very costly to accomplish and would likely result in destruction of wetlands and wildlife habitat. Another disadvantage that should not be underestimated is the unnecessary generation of a substantial volume of excavated soil that would unnecessarily have to be treated and disposed of as radioactive waste.

- ***Derive and apply site-specific soil concentration guidelines based on the health hazard (dose) posed by any residual radioactivity present on the site.*** This option requires the evaluation of the potential for producing a radiation dose to individuals that might be exposed in the future to the residual radioactivity that might be left in place on the site. A property specific concentration guideline would be established, corresponding to an acceptable and safe level of public exposure in lieu of applying the generic (or default) guidelines. The NRC, MADPH, and MADEP must approve any site-specific concentration guideline proposed. Assuming that the actual residual radioactivity concentration present on the site is below the approved site-specific guideline(s), this option has the obvious advantages of avoiding significant soil excavation and the accompanying environmental damage, minimizing the amount of radioactive waste requiring special disposal, and potentially saving taxpayer costs compared with the preceding option.

The latter option is the chosen path for the GSA site.

## 1.2 Dose-Based Release Standards Site Steering Group

To facilitate the process of deriving a dose-based soil concentration guideline for the Watertown GSA site, the U.S. Army Corps of Engineers – New England District (CENAE) has commissioned the formation of a steering group comprised of technically competent individuals representing CENAE, the site regulators, and identified stakeholders. The steering group has representatives from:

- CENAE
- Army Research Laboratory (ARL)
- US Army Corps of Engineers, Baltimore District
- Nuclear Regulatory Commission:
  - Region I
  - Headquarters
- GSA
- Commonwealth of Massachusetts:
  - Department of Public Health (MADPH)
  - Department of Environmental Protection (MADEP)
  - Metropolitan District Commission (MAMDC)
- Town of Watertown, Massachusetts

The steering group is charged with representing the interests of CENAE, the regulating agencies, and identified stakeholders in the process to derive a dose-based soil concentration guideline value specific to the Watertown GSA site property. The steering group members are public health professionals and health physicists who are well versed in the details necessary to derive a site-specific concentration guideline or responsible individuals appointed to represent the interests of their constituency. While the NRC retains the federal regulatory authority and responsibility to approve the criteria for the radiological release of the property, it is clear that CENAE, the U.S. Army, and the NRC desire the cooperative input from the identified stakeholders and state regulators so that the decision is acceptable not only to NRC but also to the Commonwealth of Massachusetts and the impacted community. Federal members are charged with ensuring that federal expenditures are responsible and commensurate with the hazards presented, and that the site will be safe.

The steering group has met three times through this point in the process. The first meeting, held on August 8, 2000, discussed the process and regulatory framework for developing a site-specific derived concentration guidance level (DCGL), and established consensus for the maximum permissible annual public dose upon which the DCGL would be based. The working group also discussed the various exposure scenarios that would need to be investigated in the derivation process (CENAE 2000a).

A pair of meetings were held on October 31 and November 1, 2000. The October 31, 2000 meeting convened in Boston, Massachusetts specifically to address the comments of the MADEP and MADPH. An additional meeting convened on November 1, 2000 in Washington D.C. to address NRC comments. These meetings focused on finalizing the suite of proposed exposure scenarios, the design of the conceptual site models to be analyzed by the computer code, and the appropriateness and acceptability of values selected for key parameters to modeling calculations (CENAE 2000b). These two meetings also established the intent to derive a DCGL that meets NRC and MADPH annual dose limits, as well as MADEP Excess Lifetime Cancer Risk (ELCR) limits.

These steering group discussions are considered key to the process and the overall acceptance of the derived concentration guideline value(s).

## 1.3 Regulatory Framework for Development of the DCGL

Three regulatory agencies will oversee the development of the appropriate DCGLs and comprehensive response actions for the Site. The NRC has the regulatory licensing authority and responsibility to determine that the radiological criteria for release of this federally owned and operated site from NRC licensing have been achieved.

In addition, because the site has been identified and listed as a Tier 1A site under the MCP due to constituents other than radioactive materials, MADEP also has regulatory authority and responsibility to determine that the site meets the Massachusetts Contingency Plan (MCP) criteria to delist.

While the MADPH does not explicitly have regulatory authority or responsibility at the Watertown GSA site, state regulations comparable to those promulgated and enforced by the NRC and under the charge of the MADPH are in place within the Commonwealth of Massachusetts (105CMR 120, Massachusetts Regulations for the Control of Radiation).

Site-specific cleanup levels will be developed in cooperation with the Commonwealth of Massachusetts and in consideration of the current prevailing relevant standards and regulations.

Thus, there are essentially two separate regulatory frameworks, aimed at the same fundamental objective, which must be satisfied by the derivation of the site DCGL.

### 1.3.1 Nuclear Regulatory Commission Regulations

The regulatory criteria for license termination and release of real property with residual radioactive material under NRC jurisdiction are contained in the U.S. Code of Federal Regulations, Title 10, "Energy," Parts 20, 30, 40, 50, 51, 70, and 72, *Radiological Criteria for License Termination*.

The applicable NRC regulation is a performance-based standard that requires the responsible party (licensee) to demonstrate to a satisfactory degree that a member of the public potentially exposed to residual radioactivity at the site will not receive an annual dose in excess of 25 mrem in any one year, having considered all credible sources and pathways for exposure.

Although the Watertown GSA site is currently unlicensed, the license termination regulations will be applied.

### 1.3.2 State of Massachusetts Regulations

As an NRC agreement state, the Commonwealth of Massachusetts publishes regulations governing the licensure, control, and use of radioactive materials within the State. The MADPH administers the State's regulation, which includes a provision with the criteria for license termination and release of a site. The MADPH administered regulation is parallel to the NRC regulation. MADPH differs from the NRC in the annual dose criterion for unrestricted release: 10 mrem/y instead of 25 mrem/y.

The MADEP administers the MCP regulations. Because the GSA site has been classified as a Tier 1A site under the MCP, MADEP has determined that response actions for radionuclides are also governed by the MCP[1] (MADEP, 2000). The regulatory framework for releasing a site under the MCP criteria is fundamentally consistent with the NRC and MADPH regulatory framework. The principle conceptual difference is found in the basic measure of potential significant risk to human health. The MCP measures detriment on the basis of ELCR for mortality. The acceptable ELCR under the MCP is on the order of $1 \times 10^{-5}$, or one in 100,000.

### 1.3.3 Approach to Deriving a Specific Property Guideline

Figure 1–1 below summarizes the overall approach used to establish the site-specific DCGL and determine whether the GSA site meets the release criteria. For the GSA site, the first step to obtaining approval of a dose/risk-based limit is to establish the acceptable dose and risk limits.

The NRC post decommissioning dose limit is constrained by the maximum allowable annual dose from all sources (in excess of background radiation contributions) of 100 mrem/y. Since it is possible that public exposure may occur not only at a regulated Site, but also from other contributors, only a fraction of the maximum allowable dose is typically allotted to any single site. A number of federal regulations and agencies as well as nationally and internationally recognized bodies recommending safe levels for public exposure (ICRP 1990, NCRP 1993) specify the total radiation dose contribution of 100 mrem/y. Within the jurisdiction of the NRC, the fraction allotted to a single site is specified in regulation. The MADPH also has specified an allowable fraction to be allotted to the GSA site. A third limit, human health risk as measured by ELCR resulting from human exposure to radionuclides, is also required for this site. The GSA site compliance limits for unrestricted release and reuse are:

[1] The GSA site was listed as a Tier 1A site under the provisions of the MCP based on constituents other than radionuclides. Nonetheless, the MADEP has determined that the human health risk criteria of the MCP apply also to the radionuclides on the site. In a letter iterating the State's position (MADEP, 2000), MADEP determined that excess lifetime cancer risk from radionuclides (excluding background) should be considered but independently from the risk associated with other (non-radioactive) contaminants of concern present on the site.

- 25 mrem/y—NRC
- 10 mrem/y—MADPH
- ELCR on the order of 1 x 10-5—MADEP

With these dose and risk limits in hand, computer modeling codes are used to ***derive*** a concentration-based ***site-specific guideline*** that is protective of each of the dose/risk limits established. A concentration-based guideline is critical since future potential dose or projected ELCR are measures of predicted future significant risk to human health, which cannot physically be measured. On the other hand, a media specific concentration derived from the expected future human exposure scenarios can physically be measured. That derived concentration is then submitted for regulator approval. The approved concentration level is identified as the derived concentration guideline level (DCGL).

The process to derive the DCGL involves the bulk of the subjectivity associated with the overall site release decision process. Addressing the DCGL first puts the approval process at the beginning rather than at the end of the project. With an approved DCGL, the remainder of the process is expected to move forward in a rather methodical fashion, using standard Data Quality Objective (DQO) methods and the *Multi-Agency Radiation Survey and Site Investigation Manual* (MARSSIM) sampling strategy to develop a sampling and analysis plan (SAP). Retrospective analysis of the data would already have an established and approved framework within which the data could be evaluated, and true cost-benefit analysis could be performed using known concentrations of residual radioactivity to perform as low as reasonably achievable (ALARA) analysis.

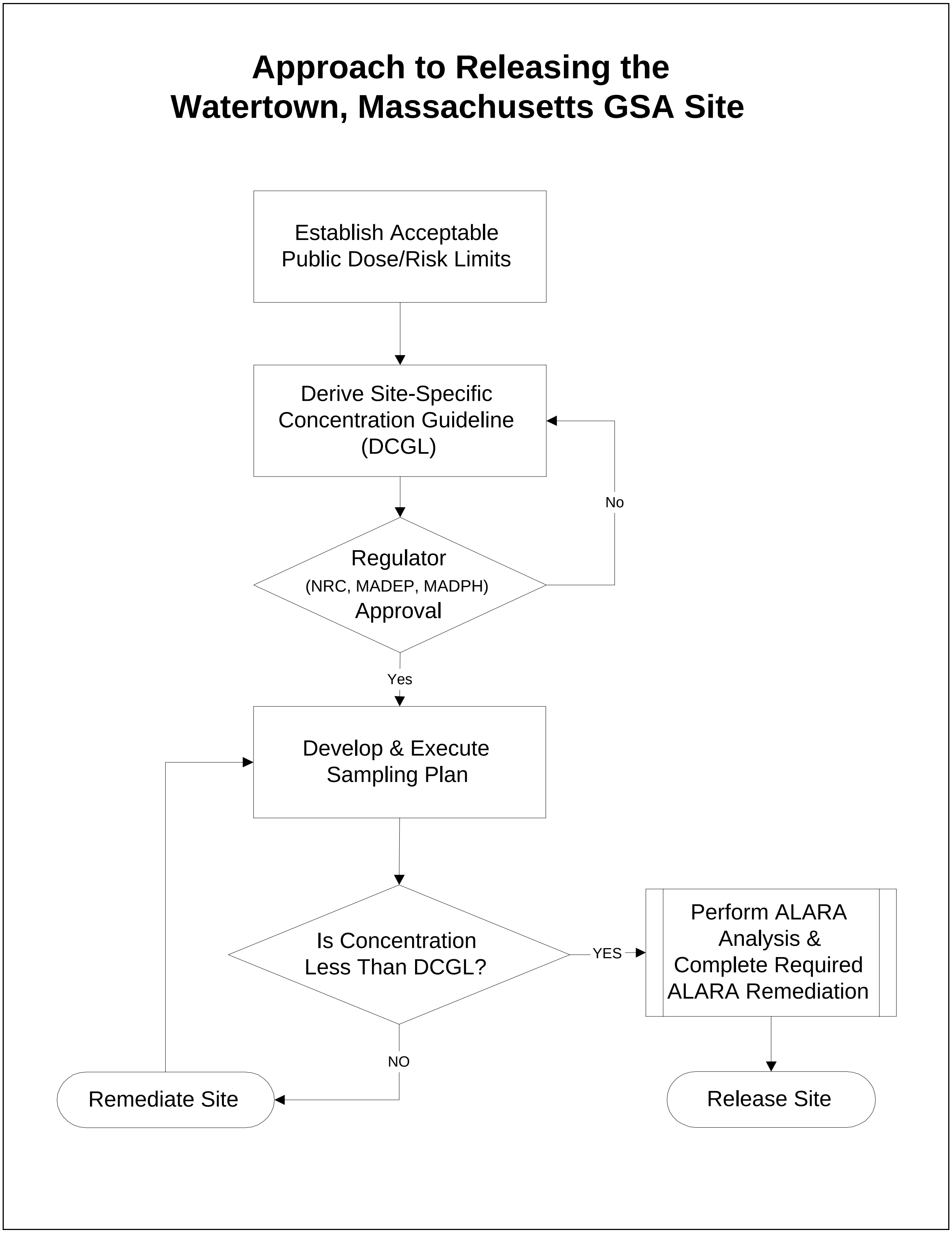


*Figure 1-1. Approach to Deriving a DCGL and Releasing the Watertown GSA Site*

## 1.4 Objective of the Derived Concentration Guideline Level

It is evident from the information available that the historical use of this property to store, chemically stabilize (burn), and package depleted uranium (DU) fragments for disposal has resulted in residual radioactivity in the soil. Earlier attempts to simply remove measurable DU traces at the site have demonstrated that the DU fragments are not readily removed or cleaned up. Relatively small, yet detectable concentrations of DU remain after two major remedial efforts, in which significant volumes of low activity soils were excavated and disposed of offsite. Residual radioactivity remaining on the site may expose future occupants or users of the site resulting in some potential for radiation dose. To demonstrate compliance with the public radiological dose and risk limits it is necessary to determine the residual radioactive concentration that can be left in place on this site without exceeding these limits. In essence, the DCGL standard is the on-site concentration below which the resulting radiological dose or ELCR to the public from future unrestricted use of the site would not exceed approved and allowable levels. The DCGL is the value upon which the subsequent sampling plan for the GSA site will be based. In addition to the requirement for conformance with accepted NRC, MADPH, and MADEP guidance, it is necessary to derive the allowable residual concentration value(s) before performing additional sampling at the site for the following reasons:

- If insufficient data were collected as a result of poor knowledge of the sampling objectives (i.e., the DCGL was unknown at the time of sampling), it is very likely that some of the data needed to make sound risk management decisions would be absent.

- Costs to mobilize to sample are significant. It is desirable to avoid the expense of remobilizing and resampling due to insufficient or poor quality data. In addition to added cost, schedule slip would likely occur if insufficient data necessitated multiple sampling events. Clearly defining the objective for data needs prior to mobilization will minimize sampling costs, meet data quality objectives, and likely lead to the most expedient release of the site.

- It is desirable to remediate only those sections or areas of the property that pose an unacceptable risk to human health. Thus, defining a condition of no significant risk to human health (i.e., DCGL), and developing a sampling program focused on evaluating DCGL occurrence and distribution will result in the most cost- and health-effective remediation, while minimizing the volume of radioactive waste requiring disposal and damage to wetlands and wildlife habitat.

- It is important to design a sampling plan to collect enough sample data that results provide risk managers with sufficient statistical information to be able to make sound decisions about the fate of the property.

Thus, the objective of deriving the DCGL before engaging in a complicated sampling process complies with the applicable regulatory guidance and offers the best opportunity to design an appropriate sampling plan and ultimately an appropriate remediation plan for the site, should one be needed.

## 1.5 Documentation in the Site Release Process

The process outlined in Figure 1-1 for releasing the Watertown GSA site from radiological controls will be documented in three separate, though interrelated, reports described below:

- *Development of the Derived Concentration Guideline Level* (this report) derives the DCGLs and explains how they were developed. The DCGLs serve as the starting point for the sampling process by establishing the relationship between soil concentrations of residual radioactivity, the acceptable annual public dose limits, and excess lifetime cancer risk limit. The ensuing work involves verifying that radionuclide concentrations in soil on the site exceed or do not exceed the DCGLs.

- The *Sampling and Analysis Plan* (SAP) develops the DQOs including decision rules. It defines the criteria for evaluating existing data and then prescribes the procedures for conducting any additional sampling and surveys that may be needed to obtain the data required to make a decision about the release of the site. Starting with the DCGLs, the SAP uses guidance from MARSSIM to determine the type, number, and spatial configuration of samples needed to determine with statistical verity, whether the DCGLs are, or are not, exceeded. The SAP also addresses the quality control issues such as minimum detection limits, control of measurement error, and provides detailed field and laboratory procedures.

- A *Sampling and Survey Report* will be prepared following completion of a statistical review of the existing site data and any additional data collected in support of the release decision. The report will include a compilation and analysis of the data, dose and risk estimates based on actual data collected from the site, and a determination of whether residual concentrations lower than the DCGLs have, or have not, been attained. The report will also contain an ALARA analysis, designation of remedial action objectives (as necessary), and recommendations for subsequent actions. Further actions could include releasing the site from radiological controls, additional investigation, or consideration of alternative remedial actions consistent with the release objective for the site.

End of current text

# 2.0 Site History & Description

## 2.1 Location and Setting

The Watertown GSA site (hereafter referred to as the Site) is located at 670 Arsenal Street in the eastern portion of the town of Watertown in Middlesex County, Massachusetts (See Figure 2–1). The Site is located on an elongated north-south trending tract of approximately 12 acres separated from the Charles River to the east by Greenough Boulevard. The Site is situated among wetland areas on three sides. The Site is part of the U.S. Army's former Watertown Arsenal, but located north of the former main Arsenal complex. The site contains the 11.91 acre GSA property parcel and a small portion (approximately 0.1 acres) of the MAMDC-owned parcel known as Property 20, which adjoins the GSA Property on the north. The Site is bounded on the north by Grove Street, on the south by Arsenal Street, on the east by Greenough Boulevard, and on the west by privately held properties facing Coolidge Avenue (Figure 2-2).

## 2.2 Site History

The pertinent site history begins with the acquisition of the property by the Federal government. In March of 1920, the Commonwealth of Massachusetts transferred the 11.91 acres that comprise the GSA property to the United States for the use of the Department of the Army with a quitclaim deed (ABB-ES, 1993). In the ensuing years, the Army developed the Watertown Arsenal Complex, primarily on the AMTL and FUDS properties, south of the Watertown GSA site. Historical documents indicate that the Site was filled, primarily during World War II. Filling activities had reached the northern edge of the GSA property by approximately 1948, and the adjoining Property 20 was leased to the Army in June of 1948 (CNSI, 1990) in order to allow filling activities to continue. Historical documents and aerial photographs indicate the buildings at the southern end of the Site were constructed following World War II, prior to 1952. The site was in use by the Army until June of 1967, when the Army transferred the property to GSA control[2].

Arsenal activities included the processing of depleted uranium for munitions. Most sources describe this use as having begun in the mid-1950s, although there is not complete agreement. The machining operations performed with DU at the Arsenal included grinding, milling, heat treating and melting, cutting, drilling, electrochemical plating, and polishing. The DU scrap was stored in barrels packed with cooling oil to prevent exposure to the air, since small particles of DU are pyrophoric. When filled, the barrels of scrap were transported from the main Arsenal property south of Arsenal Street to the GSA property where they were transferred to large steel bins. The 3½ feet wide by 6 feet long by 3½ feet deep bins were specially constructed of ½ inch steel

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[2] This Site history section is provided as a brief summary of the history and characterization of the Watertown GSA Site. Only those features directly applicable to the description of the site conceptual model and the derivation of the site-specific DCGL have been included. A detailed site history and compendium of past characterization efforts and results is contained in the report, *Historical Site Assessment, GSA Property, Watertown Massachusetts* (Harding ESE, 2000), prepared in October 2000.

plate designed to contain, incinerate, and dispose of the DU waste material (ABB-ES, 1993).

An area in the northern portion of the GSA Property was designated for the burning of the DU turnings and waste generated by machining operations at the Arsenal. The burn area was provided with a concrete pad and a locked wire fence enclosure. When enough scrap DU had accumulated in the bins, the scrap was ignited and allowed to burn, converting the DU metal to a more chemically stable oxide form and reducing the waste volume. When the burn container was full of depleted uranium oxide, a top was welded on the bin, and the whole container was then shipped offsite for disposal (PAL 1992).

Offsite disposal shipments of DU originating at the Arsenal are well documented and listed and provide no indication that DU waste materials were systematically disposed of on-site.

In 1968, the Site began to be used by GSA, other agencies, and private organizations following transfer of the site from the Army. By 1981, the GSA; the U.S. Customs Service; the Bureau of Alcohol, Tobacco, and Firearms (ATF); the Internal Revenue Service (IRS); and the Drug Enforcement Administration (DEA) were all using the Site. Buildings on the site were being used for storage, equipment maintenance, and a pistol firing range. An outdoor fenced area (the clinker area) was being used for storage of excess federal vehicles pending disposal at auctions, some of which were conducted at the property. In addition, the Federal Bureau of Investigation (FBI) used the Site as a Motor Pool, changing oil, repairing radios, and performing other related work. The DEA stored vehicles in one of the buildings, and the GSA and IRS stored miscellaneous materials such as lights, partitions, and bulk paper supplies. (NRC File Report, 1993, and CNSI, 1990).

The GSA also leased parts of the Site for use by private organizations. The fenced area immediately north of the buildings was leased to Oste Chevrolet and Peter Fuller from 1985 to 1988 for the storage of motor vehicles and mechanical work, and Building 237 was used for tire storage. Building 236 was leased to the television production company Spencer for Hire from 1986 to 1988. A pistol range was housed in Building 234 (CNSI 1990), and decontaminated (non-radiological) in 1989 by Dennison Oil, under contract to GSA.

## 2.3 Current Usage

The Site is protected by a locked chain link security fence and is not currently in use. The paved area surrounding Buildings 234 and 235, which is outside the secured area of the Site, has been leased to a paving contractor for the storage of heavy equipment and raw materials. The tenant does not have access to any of the buildings, or to the fenced areas. The remainder of the Site is heavily overgrown and not easily accessible. Within the perimeter fence, there are four areas cordoned off due to elevated radioactivity concentrations in the soil.

The properties abutting the GSA site are a mixture of recreational, residential, light industrial, and commercial areas. The area west of the Site is zoned for heavy industry, the area to the north is zoned residential, and to the east and the southeast the classification is open space conservancy. Upgradient properties along Coolidge Avenue contain light industrial and commercial uses, as well as two condominium complexes, a parking lot, and tennis courts. The area to the east of the Site contains recreational pedestrian paths and open and wetland areas (CNSI 1990).

## 2.4 Existing Knowledge of the Residual Radioactivity at the Site

Derivation of an appropriate DCGL requires specific knowledge or judgment about the nature and extent of the residual radioactivity expected to be present at the site. Key aspects concerning the nature and extent of the residual radioactivity in soil that must be evaluated are:

- Radionuclides present
- Relative concentrations of the radionuclides present
- Chemical composition, or form, of the radionuclides present
- Radioactivity deposition mechanisms at the site
- Arial and depth dispersion

Knowledge concerning these aspects is derived from historical process knowledge of the operations that occurred at the site, an understanding of the physical and chemical limitations inherent to source material handled at the site, and from pertinent analytical data collected to characterize the site.

### 2.4.1 Historical Process Knowledge

As already described above in Section 2.0, the historical knowledge of the operations conducted and the materials handled at the site are well known. The suite of radionuclides found in depleted uranium is fixed by the physical and chemical processes used to produce DU and by the laws of physics describing radioactive decay. The same physical laws govern the relative concentrations of these radionuclides, making their proportions known with a high degree of certainty. Isotopically, depleted uranium does not vary substantially by batch or treatment process.

The deposition mechanisms likely include aerial dispersion of DU particles in relatively close proximity to the burn area and evidence that suggests non-discrete spillage of DU fragments, perhaps during transport from the arsenal to the burn area. There is no evidence to support a supposition that discrete on-site disposal of DU waste has ever occurred at the site.

### 2.4.2 Previous Characterization and Remediation Activities

In addition to historical and process knowledge, a number of radiological characterization and remediation activities have been undertaken at the site over the years. These efforts have yielded a reasonably well-defined understanding of many site features that are used to derive the appropriate site-specific DCGL. A brief summary of the characterization activities to date is provided below. Detailed descriptions of the characterization and remedial actions described below are contained in the report entitled *Historical Site Assessment, GSA Property, Watertown, Massachusetts* (Harding ESE, 2000).

#### 2.4.2.1 Army Characterization and remediation (1966-1967)

Arsenal personnel under the direction of the Army performed decontamination activities at the Site in late 1966. These activities included radiological surveys and soil removal. The area surrounding the burn pad was gridded and surveyed for radiological contamination. Contaminated soil (generally from the top 6 to 12 inches of surface soil) identified by the survey was collected using bulldozers and payloaders, placed in waste containers and shipped offsite to the Maxey Flats, Kentucky low-level radioactive waste disposal facility.

#### 2.4.2.2 1973 Radiological Survey

Army Materials and Mechanics Research Center (AMMRC) personnel performed a follow-up radiological survey, the results of which are documented in a report from October of 1973. The survey was undertaken only within the burn area, and found measurable residual surface radioactivity levels. Surveys included penetrating radiation measurements, both on-contact and at 3 feet above the ground surface. The concrete pad in the burn area was surveyed for fixed alpha and beta-gamma surface activity levels. The burn area was surveyed for beta-gamma soil radiation levels, and soil samples were collected. An unknown quantity of soils and fill materials identified as contaminated were removed from the burn area and disposed of offsite. Subsequent samples indicated the highest uranium concentration in soil was 9.5 μg/g. The ground area surveyed measured 70 by 100 feet and included the 20 by 30 foot concrete pad.

As with the 1966/1967 projects, more specific detail on the surveying process is not available.

#### 2.4.2.3 DOE-Argonne National Laboratory Radiological Survey of the Watertown GSA Site

Argonne National Laboratory (ANL) undertook a radiological survey of the Site in 1981 at the request of the Department of Energy. The survey consisted of several parts.

Surveys were performed to measure surface radioactivity levels on all accessible building surface areas, interior and exterior, of Buildings 234, 235, 236, and 237. No radiological surface contamination was detected on or in any building on the Site.

Direct reading portable instrument surveys were conducted over the entire site. Within the burn area, elevated radioactivity was found at 13 locations and it was determined by subsequent mass spectrometric analyses of several samples that the contamination was due to DU.

A few localized spots in the area north of the burn area exhibited somewhat elevated radiation levels. The ANL report suggests that the slightly elevated levels may be the result of natural radioactivity in the fill material.

Soil samples were collected at representative locations, and subsurface soil sampling and borehole logging were performed at select locations. Throughout the Site, 23 soil corings were conducted in areas that had been identified by surface surveying as potentially contaminated. Soil core samples, 4 inches in diameter and 12 inches deep, were taken from selected undisturbed locations throughout the site (Harding ESE, 2000). Soil core samples were sectioned and analyzed for uranium (uranium fluorometric) as well as radium and thorium decay chains (gamma spectral analysis). The segmented coring technique was used to determine whether any contaminant migration had occurred, to reduce the dilution of lower-level soil with the upper-level segments with respect to the surface deposition of the contaminants (or vice-versa), and to reveal whether any overburden or backfill had been added.

Analysis of core samples collected at locations initially indicated by surface surveying to have elevated soil radioactivity revealed several areas with relatively high levels of soil radioactivity. Analysis of the soil core samples showed three samples having total uranium concentrations as high as $10^4$ pCi/g. Most samples indicated total uranium concentrations less than a few hundred pCi/g. None of the samples showed elevated levels of radium or thorium as determined by gamma spectral analysis of the radium and thorium decay chains. Based on the absence of radium and thorium sub-chains, the residual radioactivity in soil was determined to be consistent with depleted uranium.

Soil borings were advanced in locations where soil coring indicated the presence of elevated concentrations of depleted uranium in an effort to determine the vertical (depth) profile of the residual radioactivity in soil. Borings were drilled to a depth of 6 feet, down to the groundwater table at the site. Soil samples collected from several of the more highly contaminated soil boring samples were subjected to mass spectrometric analyses. These measurements were made to determine whether the uranium contamination resulted from DU, as had been reported. All of the samples except one (a rock sample taken from an outcropping) were depleted in the U-235 isotope relative to U-238, confirming that the radioactivity in soil was due to DU. Elevated radiation levels in the rock outcropping sample were determined to be indigenous to the site, having secular equilibrium concentrations of thorium, uranium, and radium isotopes expected for natural uranium.

#### 2.4.2.4 Comprehensive Site Assessment Survey and Remediation, 1990

Chem-Nuclear Services Inc. (CNSI) conducted a study covering both chemical and radiological contamination in the burn area.

The CNSI field investigation was conducted in accordance with the MCP requirements in effect at the time. The investigation consisted of:

- the installation of 31 shallow (10 to 17 foot) and 4 deep (48-51 foot) borings;

- installation of 11 shallow and 4 deep monitoring wells in selected borings to evaluate the aquifer and analyze the ground water quality in the two uppermost hydrologic units;
- groundwater sampling;
- marsh and sediment sampling;
- surface water sampling;
- a topographic elevation survey; and
- aquifer hydraulic conductivity tests.

Shallow soil borings were continued through an upper fill layer into an underlying peat and terminated at depths of 10 to 17 feet. Four deep borings were driven to depths of 48 to 51 feet, into the stratified sand layer beneath the peat, and completed as monitoring wells. Twenty shallow borings, B-1 through B-20, were completed solely to collect samples for radiological and or chemical analysis and geologic characterization of the shallow overburden. Eleven additional shallow borings were to facilitate the installation of shallow monitoring wells.

Samples were collected for total uranium analysis from each sample interval of all borings in which there was sufficient sample recovery. All total uranium results were below 35 pCi/g except for one sample, the 0 to 2 foot interval in a single boring which measured 330 pCi/g. Previous samples collected at depth in the burn area indicated much higher levels of uranium to be present at a depth of 8 to 10 feet, but samples collected by this field investigation in the burn area did not indicate elevated uranium levels at depths below the original undisturbed grade of the site.

Groundwater sampling in the installed wells was performed to assess the nature and extent of possible groundwater contamination on the site. Four ground water samples (three from shallow wells and one from a deep well) exhibited detectable total uranium concentrations at or near the expected background concentrations in groundwater. All other groundwater well samples were below detection limits. The groundwater detection of uranium occurred in areas removed from the burn area, while many samples collected in the immediate vicinity of the burn area contained undetectable concentrations of dissolved uranium. Together, these factors suggest that the depleted uranium residue on the site (and notably the highest concentrations associated with the burn area) is not contributing uranium to the groundwater.

Sediment and surface water samples were collected at 4 marsh locations along Greenough Boulevard and at two locations in Sawins Pond Brook, one set of samples 20 feet down gradient of the existing bridge and a second at the mouth of the culvert in the southwest portion of the Site, two days after a rainfall event. No detectable concentrations of uranium were found in any samples indicating that surface is an insignificant mechanism for transport of depleted uranium residue in on-site soils to areas offsite.

#### 2.4.2.5 Radiological Characterization and Survey, January, 1993-1995

Morrison-Knudsen/Scientific Ecology Group (MK/SEG) performed additional investigations in October and November of 1993, including characterization and termination surveys. At NRC's request, additional characterization and termination surveys were performed from August through December of 1994. These additional surveys included the riverbank of the Charles River to determine potential windborne DU contamination, Property 20 because of elevated surface radiation levels that were measured on the property, and boundary areas due to contamination found outside the burn area fence. In 1995, *in-situ* gamma spectroscopy surveys were conducted in boundary areas that had not been previously surveyed in 1994 due to inclement weather, and also in large portions of the interior. The final phase of MK/SEG work consisted of documentation of estimates made for background natural uranium, total uranium contamination at the site, and potential groundwater contamination at the site.

The continued excavation of the burn area confirmed that the material in and around the burn area was 6 inches to 2 feet of topsoil over 5 to 8 feet of construction debris. Debris terminated at an organic peat layer. The water table at the site was determined to lie from 0 to 2 feet beneath the surface, depending on the seasonal conditions. The construction debris on top of the peat layer was found to have DU residue. Excavation was halted because of the large volume of waste being generated and the possibility that the remediation effort might be spreading contamination into new areas.

Two non-naturally occurring nuclides were identified during the remediation of the burn area – Cs-137, which was determined to be within local background, and Th-234, which is an index for the presence of DU (MK/SEG used a procedure for determining DU concentration based on the concentration of other radionuclides. See the HSA [Harding ESE, 2000] for detailed explanation of the method). Th-234 concentrations ranged into thousands of pCi/g in soil removed from the burn pit, with the upper 2 feet of soil showing the highest activity. The overlying debris had concentrations ranging from approximately 14 to 330 pCi/g, and no activity was detected in the peat.

A Gamma Exposure Rate Survey was performed on the GSA Property and in the building interiors. The gamma radiation was determined to be fairly uniform throughout the Site, with elevated areas near the center of the clinker area (grids E-16 through E-20) and near the access road on the southwestern edge of the Site (L-3). Random soil samples showed the source of these elevated readings to be natural radioactivity. The Site as a whole was shown not to be significantly contaminated with radioactivity.

As a result of the MK/SEG surveys and the ANL surveys from 1983, the buildings themselves are determined to be unaffected, and formal application to the NRC is being prepared recommending their release from radiological controls.

Random soil samples were collected over the entire site to provide an unbiased estimate of the soil concentration at the site. Samples were collected at the surface and at 2 feet below the ground surface (bgs) and were analyzed by gamma spectroscopy. Average concentrations of all nuclides on the Site were found to be generally low, although, as expected, several samples contained elevated uranium concentrations. MK/SEG results indicated that contamination by DU is higher on the surface than below 1-foot bgs.

To obtain information about the depth profile of the DU chip distribution, five areas, each about 60 $m^2$, were scraped and repeatedly scanned. The results of the survey indicate that there are DU chips at all levels down to a depth of approximately 1 foot in the burn area.

To evaluate the relative contribution to total radioactivity in soil from various soil size fractions, three bulk soil samples were collected from the surface, at 0 to 3.5 inches bgs, and three from 1 to 12 inches bgs. Each sample was separated into coarse (>1 inch), medium (1/16 to 1 inch), and fine (<1/16 inch) size fractions. DU chips were contained in the large and medium size fractions. The medium and large fractions were then ground to less than ¼ inch, and analyzed for Th-234, Ra-226, Ac-228, and U-235 by gamma spectroscopy. The sample results showed that the surface soils contained the highest concentrations of DU, and that the fines fraction from each zone had a higher DU concentration than the middle and coarse fractions. Thus, it is evident that in spite of the presence of some visible DU chips in the soil, the radioactivity present tends to be associated with the fine fraction of the upper soil layer. The higher DU concentrations in the fines fraction is attributed to:

- the presence of some fines in the originally generated waste,
- *in-situ* oxidation and particle size breakdown of the larger chips, and
- the oxidation and breakdown of DU scrape in the burning process.

Due to previously identified elevated concentrations (from August of 1994), Property 20 was resurveyed using *in-situ* gamma spectroscopy and surface soil sampling. In-Situ Gamma spectroscopy served to identify the nuclide mixture for each sample and provide a large area average measurement directly. There were 19 *in-situ* survey locations, measuring overlapping areas both near and further away from the known locations of higher exposure rates. Soil samples were collected at each *in-situ* location, and several samples were collected just beyond the estimated boundary of the contaminated region to verify that the area was correctly delineated. The survey determined that elevated concentrations of Th-234 (indicating DU) and U-235 and Ra-226 (indicating uranium series nuclides from a source other than DU) existed within Property 20. The extent of the contamination was determined to be approximately 15 meters by 45 meters. The contaminated material in this area was estimated to average approximately 1 meter thick. MK/SEG suggested that the radionuclide profile was consistent with that of uranium mill tailings and hypothesized that it might have been associated with prior Arsenal activities. A search of the available records, however, provides no evidence that the GSA Property or Property 20 were ever used to dispose of tailings waste materials. Nonetheless, based on the analytical method used, the possibility that uranium tailings might be present must be taken into account in the development of a DGCL for the site. The impact of tailings residue commingled with DU is evaluated for scenario in Appendix F of this report.

To determine whether windborne transport and deposition had occurred offsite, soil samples were collected from the 0 to 1 foot interval from 5 locations east of the Site across Greenough Boulevard, and analyzed for several radionuclides, including U-235, K-40, Cs-137, Ac-228, Ra-226, and Th-234. No radionuclides associated with the site were detected in any of the samples.

Sediment and water samples were collected from the sewer system on site. Th-234 was not present above the MDA in any sewer system sample and it was concluded that DU was not present.

GTS Duratek (formerly SEG) calculated the total background uranium concentration present at the Site and found the background concentration of natural uranium in the fill soil to be 2.12 ± 0.64 pCi/g.

Surveys have shown the area outside the perimeter fence to be free of radiological contamination.

## 2.5 Radiological Characteristics of Depleted Uranium

Not withstanding the *in-situ* gamma measurements made by MK/SEG at Property 20, the site characterization data, a search of the available historical records, and the documented knowledge of the processes that have taken place at the site all point to depleted uranium isotopes as the radiological constituents present at the site. The processes used to convert uranium in ore to the zero-valent metallic uranium form handled and processed at the Watertown Arsenal serve to produce a consistent isotopic fingerprint. Added to this, the long radioactive half-life of the uranium isotopes in DU means that there is little difference in the isotopic abundance of radionuclides in freshly produced DU compared with that in aged DU.

The radiological characterization survey performed by ANL in 1981 included soil samples that were collected in areas with locally elevated radioactivity concentrations and analyzed by mass spectrometry. As an isotopic differentiation method, mass spectrometry is expensive, but has a clear detection and resolution advantage when the radioactive signal is difficult to detect or when the radioactive half-life is very long as is the case with uranium species. Table 2-1 presents the uranium isotopic fractions in on-site soil samples as measured by mass spectrometry. Table 2-2 presents the typical uranium isotopic abundance (percent by weight) for both natural and depleted uranium in comparison with the mean GSA site-specific data.

From the site-specific data, it is clear that the relative contributions from each of the five uranium species analyzed is dramatically consistent from sample to sample. Since these samples were collected from across the site, albeit biased toward areas having more elevated concentrations, it is credible to conclude that the isotopic profile across the site is consistent. When the average site-specific concentrations are compared with the isotopic abundances associated with naturally occurring uranium (such as would be present in uranium ore and uranium mill tailings) and depleted uranium, it is clear that the radionuclide profile on the site is typical of depleted uranium. The exceedingly small uncertainty in the relative isotopic abundance typical of natural uranium virtually eliminates an interpretation owing to other than DU.

*Table 2-1. GSA Site Specific Uranium Isotopic Data by Mass Spectrometry*

| **Summary of Watertown GSA Site Soil Samples** | | | | | | |
|---|---|---|---|---|---|---|
| | **% of Uranium Atoms Present** | | | | | **Sum** |
| **Sample** | U-233 | U-234 | U-235 | U-236 | U-238 | % of U Atoms |
| 1-S47-A | 0.000% | 0.001% | 0.228% | 0.005% | 99.766% | 100.000% |
| 1-S47-D | 0.000% | 0.001% | 0.235% | 0.005% | 99.759% | 100.000% |
| 1-S48-A | 0.000% | 0.001% | 0.237% | 0.005% | 99.757% | 100.000% |
| 1-S48-D | 0.000% | 0.001% | 0.273% | 0.005% | 99.721% | 100.000% |
| 1-S49-A | 0.000% | 0.001% | 0.230% | 0.005% | 99.764% | 100.000% |
| 1-S49-D | 0.000% | 0.001% | 0.236% | 0.005% | 99.758% | 100.000% |
| 1-S50-A | 0.000% | 0.001% | 0.227% | 0.005% | 99.767% | 100.000% |
| 1-S50-D | 0.000% | 0.001% | 0.228% | 0.005% | 99.766% | 100.000% |
| 1-S76 | 0.000% | 0.001% | 0.226% | 0.005% | 99.768% | 100.000% |
| 1-S103-A | 0.000% | 0.001% | 0.226% | 0.005% | 99.768% | 100.000% |
| 1-S105-A | 0.000% | 0.001% | 0.225% | 0.006% | 99.768% | 100.000% |
| Avg. | 0.000% | 0.001% | 0.234% | 0.005% | 99.760% | 100.000% |

*Table 2-2. Comparison of Natural and DU Isotopic Abundance with GSA Uranium Fractions*

| **Isotope** | **Natural Abundance (%)** | **Typical DU Abundance (%)** | **Average abundance at GSA Site (%)** |
|---|---|---|---|
| U-238 | 99.2739 +/-0.0007 | 99.75 | 99.760 |
| U-235 | 0.7204 +/-0.0007 | 0.25 | 0.234 |
| U-234 | 0.0057 +/-0.0002 | 0.0005 | 0.001 |
| Source: Schleien 1992 | | | |

While, in the case of the Watertown GSA site, mass spectrometry is superior as an analytical method for differentiating uranium radionuclides, cost and the lack of a real time field analytical instrument have precluded its use a field method. Instead, radio-analytical methods have been employed. Radio-analytical measurements made on the site also compare favorably with that expected from depleted uranium (See Table 2-3).

*Table 2-3. Comparison of Natural and DU Isotopic Abundance with GSA Uranium Fractions*

| **%Activity as a Function of Total Mass** | | | |
|---|---|---|---|
| **Isotope** | **% Activity in Natural Abundance** | **% Activity in Typical DU Abundance** | **% Activity at GSA Site** |
| U-238 | 47.29 | 84.70% | 82.55% |
| U-234 | 50.51 | 14.20% | 15.39% |
| U-235 | 2.21 | 1.10% | 1.24% |
| Sources: Schleien 1992, Wise 2000 | | | |

From Table 2-3, it is again evident that the most plausible and credible evaluation of the site-specific uranium data points to a depleted uranium isotopic mixture. The typical isotopic abundance present in DU is used to apportion the uranium activity used to derive the depleted uranium DCGL in lieu of the GSA site-specific uranium fractions. The typical isotopic abundance provides a slightly more conservative measure of the amount of the U-238 isotope, which is the isotope in depleted uranium with the greatest dose producing potential. While it is extremely unlikely that the series of chemical extraction and physical separation processes involved in the production of depleted uranium would leave measurable quantities of uranium progeny such as thorium and radium, the isotopic mixture used to derive the DCGL does allow for 0.1% contributions from both Ra-226 and Th-230. Inclusion of these adds an additional measure of conservatism to the DCGL (Ra-226 is the most potent dose producer among all of the radionuclides in the mixture) and accounts for minor amounts of naturally occurring radioactive material that might be present in fill materials imported to the site. Figure 2-1 presents the isotopic mixture used to derive the $DCGL_W$ for DU contaminated soil.

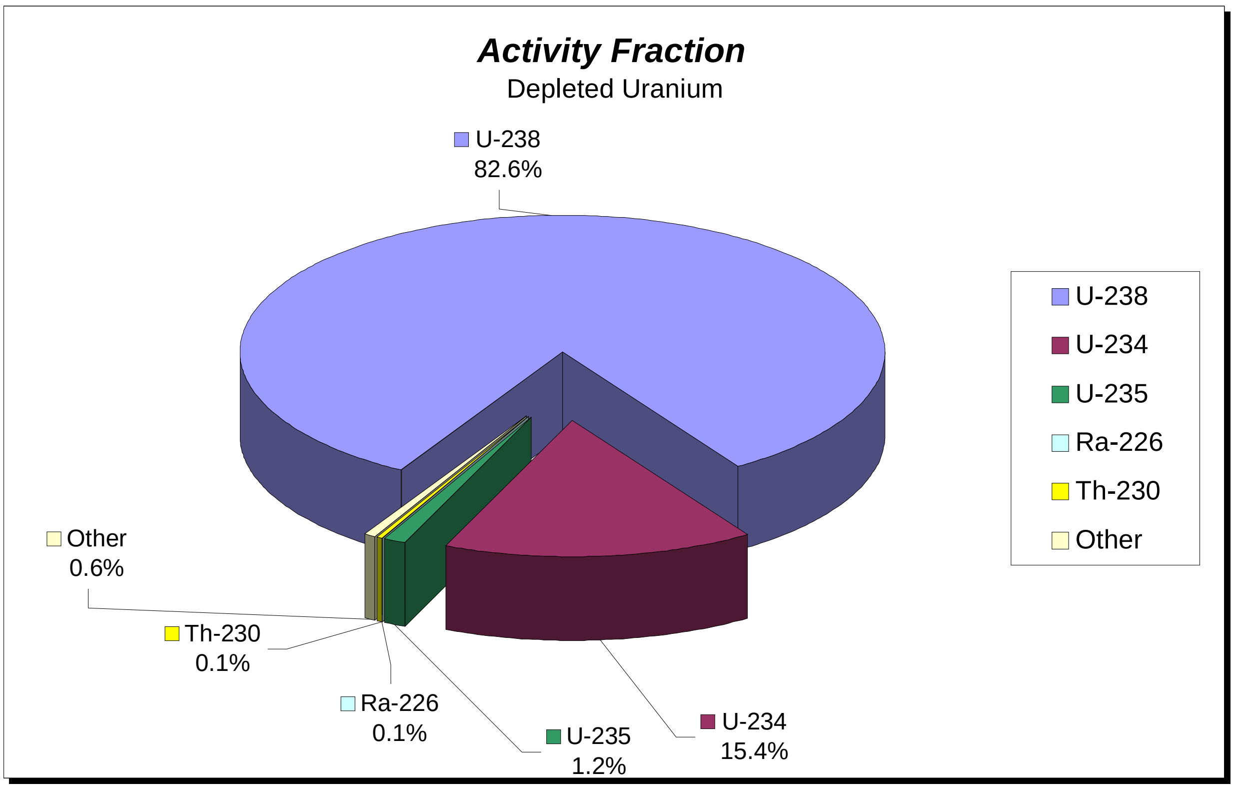


*Figure 2-1. Radionuclide Activity Fraction—Depleted Uranium*

Because there is some uncertainty about the presence of uranium tailings in a small area in the north part of the site between the burn area and the north fence line on Property 20, a contingency “tailings” $DCGL_W$ is also being proposed (see Section 6.0 and Appendix F). In the unlikely event that soil activity consistent with uranium mill tailings is encountered in this area, the contingency “tailings” DCGL will be applied. To derive the contingency $DCGL_W$, it was assumed that residual Ra-226 and Th-230 activity in soil could each be reduced to a concentration no greater than 5 pCi/g, while allowing for soil with slightly elevated depleted uranium to remain in place. Figure 2-2 presents the isotopic mixture used to derive the $DCGL_W$ for DU + Tailings contaminated soil.

## 2.6 Other Than Radiological Hazards

The site HSA indicates the presence of a number of non-radiological (chemical) contaminants. These contaminants are evaluated in the Supplemental Phase II Comprehensive Site Assessment and Method 3 Risk Characterization (Harding ESE, 2001). The scope of this document pertains only to the derivation of the radiological DCGL, but is logically consistent with the concepts and assumptions used to assess the risk from other than radiological hazards at the site.

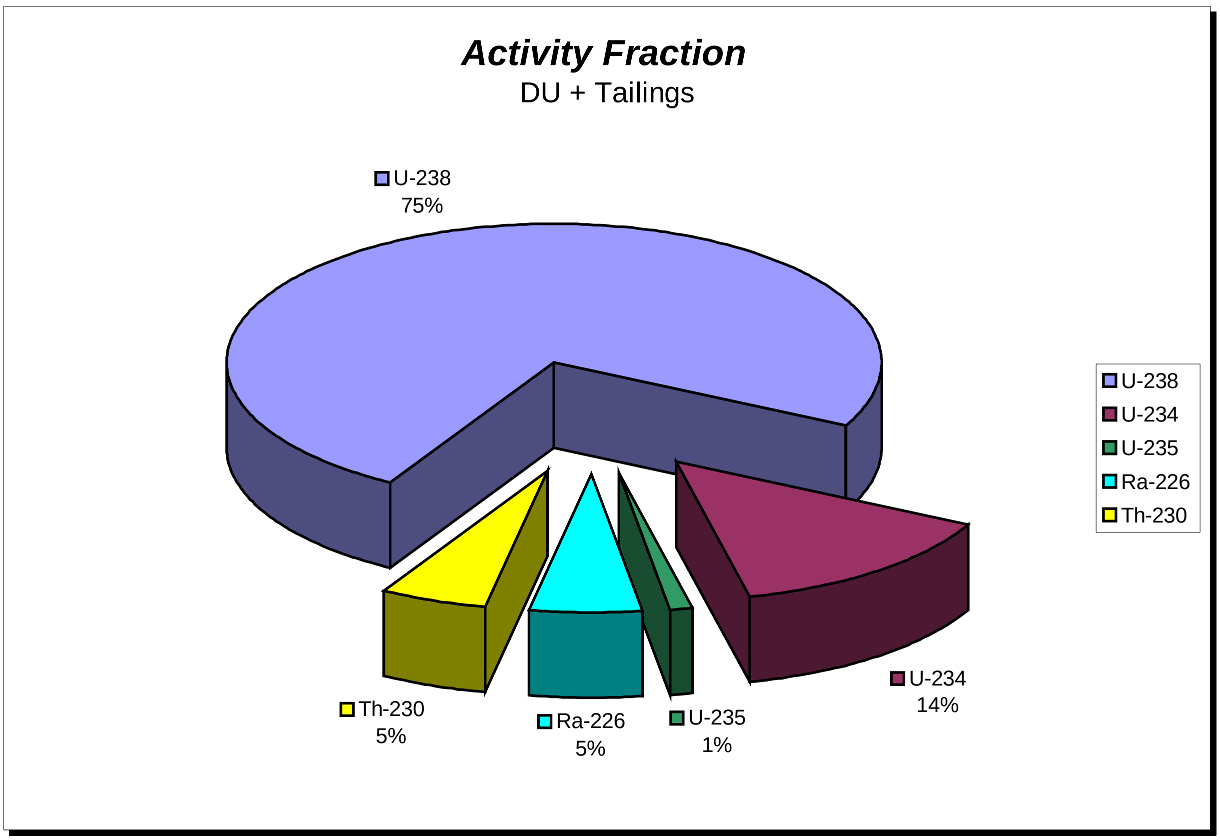


*Figure 2-2. Radionuclide Activity Fraction—Depleted Uranium + Tailings*

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# 3.0 Development of the Derived Concentration Guideline Level

## 3.1 Selection of the Annual Public Dose Limit

The NRC has established federal regulation limiting the permissible dose from residual radioactivity at its licensee's sites to 25 mrem/y (10 CFR 20, FR Doc. 97-17752). Further, the Commonwealth of Massachusetts has adopted the NRC's decommissioning rule into state regulation governing license termination (105 CMR 120). Massachusetts, however, has imposed a limit of 10 mrem/y. These limits require that all GSA site sources of radiation and all pathways be considered in demonstrating compliance with the post decommissioning annual dose limit.

It should be noted that there is an appreciable safety margin built in to the selection of the 25 mrem/y post decommissioning annual dose limit specified by the NRC. A number of federal regulations and agencies as well as nationally and internationally recognized bodies recommending safe levels for public exposure (ICRP 1990, NCRP 1993) specify that radiation dose contribution to members of the general public could safely be as high as 100 mrem in any single year (the basic public dose limit). The decommissioning annual dose limit then serves as a constraint measure designed to account for other potential sources of radiation exposure in the public environment. On the weight of these relevant public laws and the opinion of public health experts on the GSA site project steering group an annual public dose limit of 10 mrem TEDE was adopted as the dose basis for the DCGL[3].

### 3.1.1 Excess Lifetime Cancer Risk Criterion

As described in Section 1.0 of this report, the GSA site is subject to the requirements of the MCP. MADEP has determined that the allowable risk criterion (on the order of 1 x 10-5) is applicable to the radiological constituents present at the GSA site and has requested that the DCGL be derived to be protective of the risk criterion. Risk from exposure to radionuclides is considered independently of risk from other hazardous constituents. Appendix C provides additional documentation that the DCGL has been derived using methodology that meets the performance standards for risk characterization, as stipulated in the MCP.

Thus, there are essentially three criteria that are considered in the derivation of the site-specific DCGL for the GSA site:

1. 25 mrem/y — Urban residential scenario (NRC)
2. 10 mrem/y — All other credible scenarios (MADPH)

[3] In order to achieve an unrestricted release decision, the NRC has required that an urban residential scenario be evaluated to determine the potential impact of a future residential use setting on this property. The Commonwealth of Massachusetts, while further constraining the permissible annual public dose limit to 10 mrem, has determined that a residential scenario is implausible at this location and as a result has not required that the DCGL be derived to demonstrate that a future residential use will be protective of the 10 mrem/y limit (CENAE 2000b).

3. ELCR on the order of 1 x 10-5— All credible scenarios (MADEP)

## 3.2 Dose/Risk–Concentration Relationship

The process to correlate a radioactivity concentration to dose or risk can proceed after the annual public dose limit or excess cancer risk factor has been established. As in any health risk assessment, the process involves defining the source(s), the site conceptual model, the pathways for potential human exposure, and the availability of a receptor to receive a dose (see Figure 3–1).

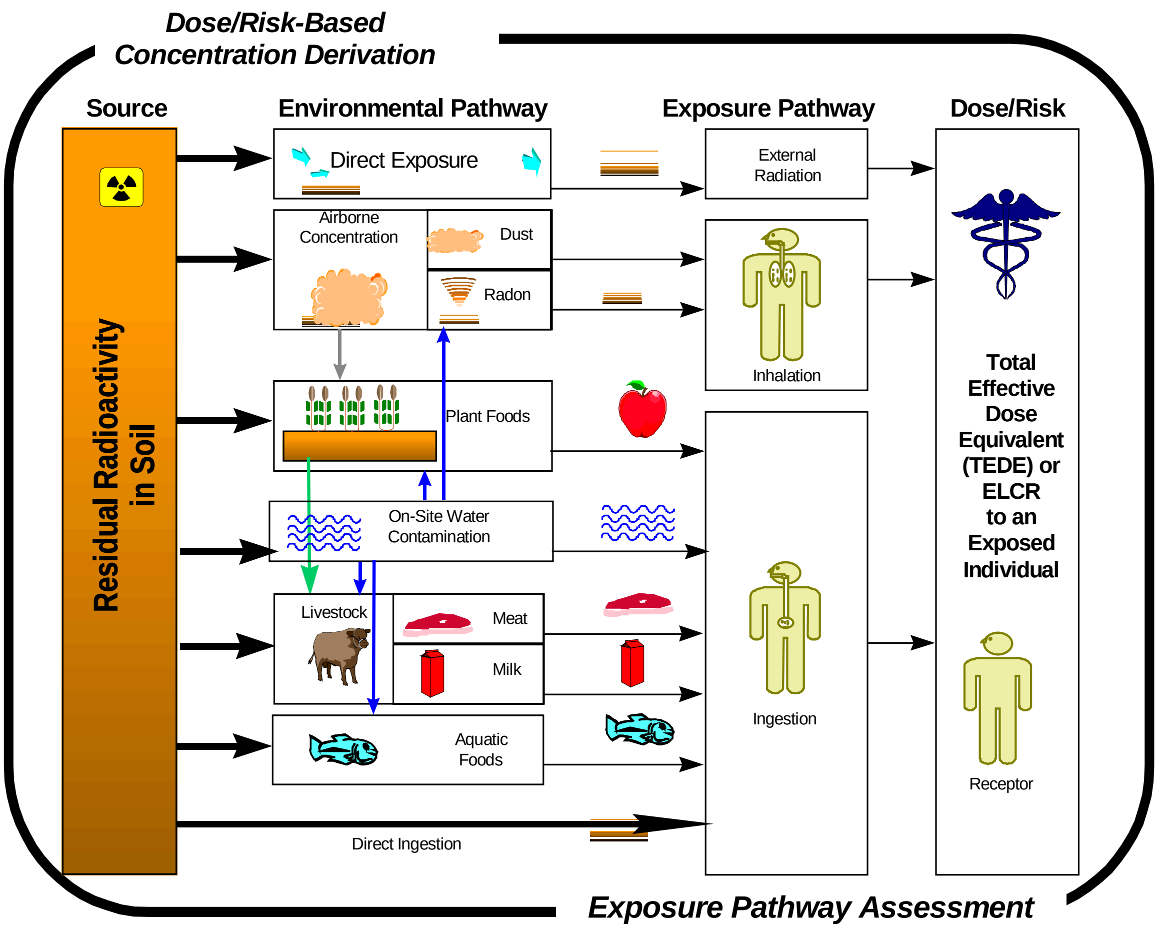


*Figure 3-1. Conceptual Human exposure Assessment Model*

The relationships between factors involved in defining the mechanisms for human exposure are complex and often mutually dependent. The aid of a computer program to model the plausible human exposure scenarios and to perform complex sets of computations is warranted. Nonetheless, the model portrayed in the computer code must sufficiently represent the actual site-specific case in order to achieve realistic correlation between dose and concentration. As source concentrations and pathway factors affecting concentrations to receptors vary, then the potential for dose also varies.

Factors affecting the mechanisms for, and intensity of, human exposure must be identified, and appropriate values must be defined. Many of these factors are highly dependent upon site-specific conditions (e.g., wind velocity), while others are more related to fundamental physical properties independent of the specific site location (e.g., mass loading for inhalation). Many others are dependent upon the availability and projected activities of receptors (e.g., hours per day at the site). To accurately determine the values to be used for many of these factors that become input parameters to the computer modeling codes, the risk assessor must first envision and characterize the plausible future exposure scenarios that a potential receptor may encounter. Clearly defining the expected future human exposure scenarios is key to obtaining a realistic correlation between projected future dose/risk and existing source concentrations.

After human exposure scenarios are conceived, the second key element to be considered in constructing representative exposure models is determining which pathways are potentially complete from source to receptor. The conceptual pathway model shown in Figure 3–1 above includes all conceivable pathways for human exposure to residual radioactivity associated with the GSA site. Not all of those pathways are potentially complete for a variety of reasons. Tables explaining which of the specific pathways are complete for each scenario evaluated are contained in the subsequent sections detailing each scenario.

The following section outlines the potential future human exposure scenarios developed with the input of the Watertown GSA site steering group. These scenarios are considered to be credible and plausible.

## 3.3 Potential Future Exposure Scenarios

A number of potential future use scenarios were proposed and entertained by CENAE and the site steering group and were evaluated to assess their plausibility. Scenarios considered ranged from the ultra conservative rural family farm, commercial agricultural site uses, urban residential uses, open public space, and community gardening to a proposed future use as a community sporting and recreation complex hosting ball fields and an aquatic/ice rink facility. A construction scenario was also developed and evaluated to gauge the exposure potential to construction workers engaged in site filling and grading operations that would likely be involved in preparing the site for any of these other future uses. It was acknowledged among members of the steering group that the most likely potential future uses of the site were those associated with some form of public or recreational use. The land title transfer process provides for ownership to revert to the Commonwealth of Massachusetts under the oversight of the MAMDC. The MAMDC has published a long-range plan calling for the development of the site into a recreational facility for public use. The municipality of Watertown has also expressed interest in the property for like use. From among the many scenarios and variants considered, a suite of five scenarios emerged as plausible and credible. Conceptually, the human exposure scenarios are divided into three groups, each corresponding to a phase in the future life cycle of the site. The three groups are:

- Current Use
- Construction
- Projected Future Use

The current condition of the site makes it practically unusable and any use in the current condition is limited to very short exposure duration. Thus, no scenario for use of the site in its current condition was determined to represent a credible exposure situation[4]. In addition, any conceivable current use of the site is comparable to and bounded by the scenarios evaluated in the projected future uses of the site.

Structures on site have already been shown to have no measurable concentrations of residual radioactivity. However, future earthwork on the site, such as backfilling, utility and foundation installations, and grading warrants consideration of a potential exposure scenario for a construction worker. A single scenario evaluates the potential future exposure to site construction workers.

- Construction Worker

Four separate future use category scenarios have been projected. The future use scenarios evaluated include:

- Urban residential[5]
- Workers exposed while working at the site's recreation facilities
- Users of the recreational facility
- Urban community gardeners

Collectively, five scenarios emerge as credible and plausible. Each is evaluated to arrive at a single, site-specific, residual radioactivity concentration in soil that will be protective of human health in accordance with state and federal guidelines. Table 3–1 presents the matrix of scenarios and applicable public health limits that must be satisfied to arrive at the DCGL. Figure 3–2 illustrates the five scenarios evaluated and depicts the overall conceptual approach to deriving a DCGL that will satisfy the annual public dose limits and the ELCR limit for the population potentially exposed in each of the scenarios.

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4 The U.S. Army Corps of Engineers and GSA presently maintain physical access control over the site, effectively eliminating protracted potential public exposure situations.

5 The urban residential scenario is evaluated as a measure of the overall uncertainty in the assumption of future site use. As previously discussed, the steering group members concurred that a residential scenario, while possible, was highly improbable considering the property ownership (present and future), the stated and documented plans for the site, and the sentiments and wishes of the residents in the nearby community. The MADPH determined that the residential scenario need not be considered. MADEP concurred, wit the stipulation of an Activity and Use Limitation (AUL) consistent with MCP requirements. However, the NRC requested that an urban residential setting be evaluated, not as a scenario for limiting the DCGL, but as an indicator of the extent of radiation exposure that might occur in the event that the credible land use assumptions proved to be different in the foreseeable future.

*Table 3-1. Scenarios and the Their Applicable Public Health Limitations*

| Scenario | Applicable Public Health Limit | | |
|---|---|---|---|
| | **U.S. NRC (25 mrem/y)** | **MADPH (10 mrem/y)** | **MADEP ($1 \times 10^{-5}$ ELCR)** |
| Construction Worker | | | |
| Occupational Worker | | | |
| Recreational Visitor | | | |
| Community Gardener | | | |
| Urban Resident | a | a | b |

a. The urban residential scenario is not used to derive the DCGL because it is considered to be exceedingly improbable given the circumstances surrounding the land transfer options and future use plans for the site. It is evaluated to gauge the extent of annual dose potential in the event that assumptions about future use prove inaccurate.

b. MADEP requires the application of an "Activity Use Limitation" (AUL) prohibiting the future residential use of the site based upon the risk presented in such a scenario, including constituents on site other than residual radioactivity.


*Figure 3-2. Potential Future Exposure Scenarios Evaluated*

A screening process is used to compare activity concentrations derived for each scenario. Ultimately, the scenario yielding the smallest activity concentration corresponding to either the dose or risk criterion is selected as the limiting scenario. The limiting scenario, in turn, drives the derivation and selection of the DCGL.

### 3.3.1 Coordinating Competing Methodologies

The objective, or endpoint, for this portion of the project is to arrive at a concentration (the DCGL), which, if left in place, will be adequately protective of human health in reasonably foreseeable future uses of the GSA site. CENAE, NRC, MADPH, and MADEP share this objective. However, the dual regulatory framework (see Section 1.3) and their associated methodologies are not specifically consistent.

Many of the values for exposure factor parameters used to define exposure scenarios are prescribed by MADEP methodology (MADEP 1995). This methodology is designed to capture the reasonable maximum exposure (RME) condition in a deterministic health risk assessment rather than the mean or most likely exposure to an exposed member of the critical group as described in the dose assessment methodology presented by the NRC (NRC 1997, 2000). By contrast, the NRC and MADPH methodology addresses extreme case exposure potential through a probabilistic analysis taking the range and distribution of individual parameters into consideration. Table 3–2 summarizes the principle differences that exist and will be addressed throughout this report.

*Table 3-2. Comparison of Methodologies*

| | ***NRC / MADPH*** | ***MADEP*** |
|---|---|---|
| Measure of Human Health Detriment | Annual Radiation Dose measured in millirems per year | Excess Lifetime Cancer Risk measured as the probability of cancer mortality. |
| Health Risk Methodology | Probabilistic | Deterministic |
| Parameter Value Basis | Mean value for critical group | Reasonable Maximum Value picked from accepted default values |
| Calculation Method | Computer Modeling Code | Algebraic summation using Spreadsheet. |
| Time Integration | Yes. Integration intervals vary to allow for radioactivity in growth, decay and transport. | No. Point estimate, considering initial (time zero) site conditions |

Rather than using two different and discreet approaches to the derivation of the DCGL, a more holistic approach has been used. For example, where the MADEP method specifies a value to be used for a given class of exposure scenario, that value has been adopted even if it is judged to be more conservative than the average value for the critical group. The use of such MADEP specified parameter values for the GSA site health risk assessment has resulted in a more conservative estimate of the dose or risk resulting from potential human exposure to a source of radiation. At the same time, a probabilistic analysis will also be presented using the range and distribution of values expected for the site-specific exposure conditions considered. Such an analysis will satisfy the NRC/MADPH requirements and will provide an estimate of the degree of conservatism in the set of deterministic values employed to derive the DCGL. While yielding slightly more conservative DCGLs, this approach allows for an internally consistent description of the scenarios and parameters used to measure human health risk[6]. The probabilistic analysis of the uncertainty involved in the deterministic values employed is presented in Section 5.0. The RESRAD code is capable of calculating both deterministic and probabilistic risk estimates from the data set defining a specific

[6] Recall from Section 1.0 that human health risks from constituents other than residual radioactivity are required for evaluation of this site.

parameter. At the request of the MADEP, Appendix C presents the risk calculations for a single scenario using the algebraic summation (spreadsheet) method familiar to the MADEP for comparison with the results of the RESRAD code. The two methods have been tailored to yield consistent results.

### 3.3.2 Construction Worker Exposure Scenario

#### 3.3.2.1 Conceptual Site Model for the Construction Worker Scenario

In describing the exposure scenario, it is necessary to establish the site conceptual model, which defines the physical and geological conditions at the site. Figure 3-3 illustrates the conceptual description of the Watertown GSA site conditions.

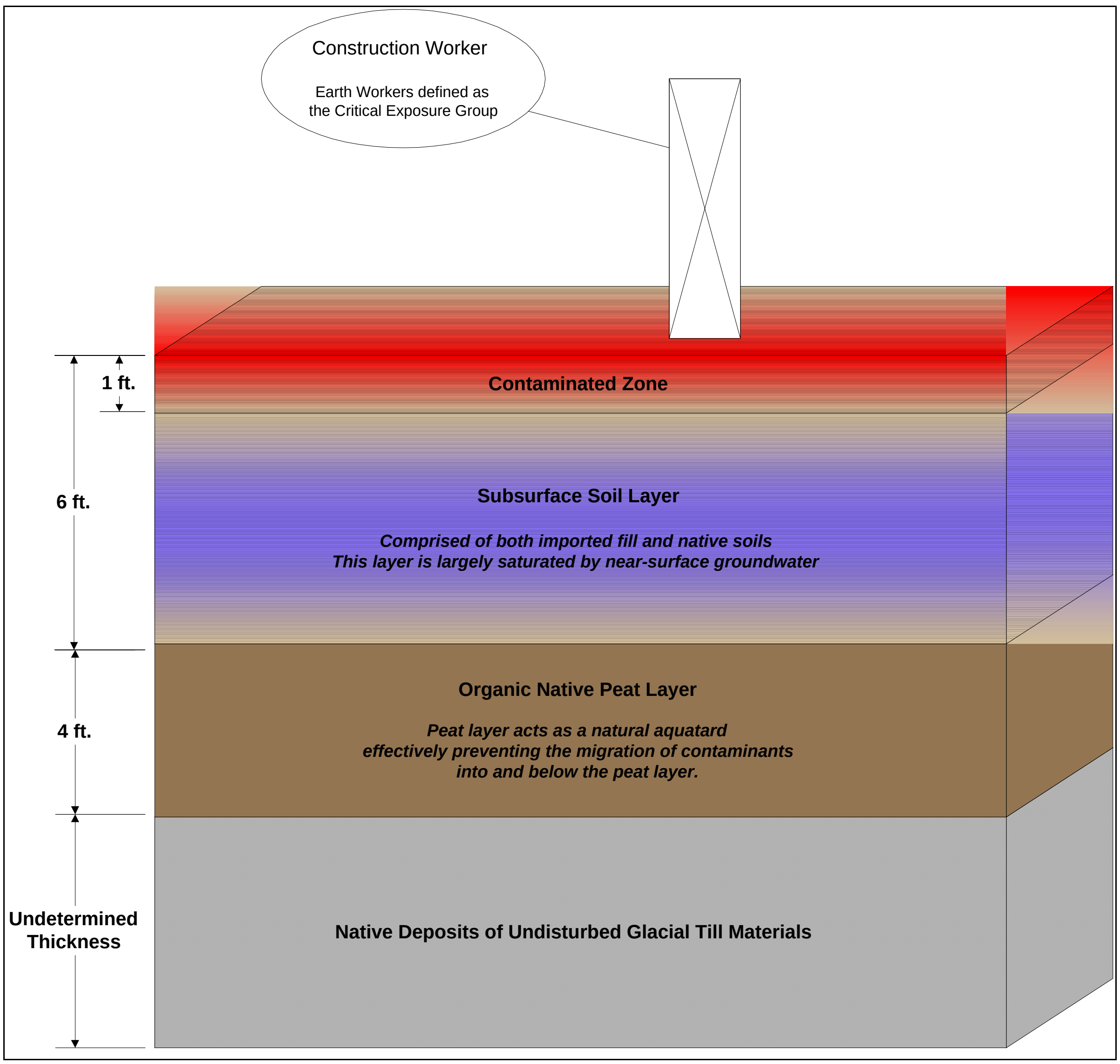


*Figure 3-3. Conceptual Site Model Describing the Construction Worker Scenario*

### 3.3.2.2 Pathways Included in the Construction Worker Scenario

Table 3–3 identifies the pathways that have been retained for the analysis and provides explanation for those pathways that were not retained.

*Table 3-3. Evaluation of Pathways for the Construction Worker Scenario*

| Pathway | Retained | Remark |
|---|---|---|
| Direct Exposure | Yes | The source term found in the site soils produces penetrating gamma radiation. Exposure from direct penetrating radiation is expected to be a significant contributor to the overall dose/risk. |
| Particulate Inhalation | Yes | Allowance is made for soils containing radiological constituents of the source being liberated and suspended in the breathing air of construction workers. |
| Radon | No | Radon is specifically excluded from consideration within the framework of the governing regulations. In addition, the source term found in the soil is not a significant producer of radon due the extremely long half-life of the isotopes found in depleted uranium. |
| Plant Ingestion | No | Ingestion of plant foods addresses those plant foods grown in the radioactivity or irrigated with water containing radioactivity from on site. Since construction workers are not expected to raise plants on site for food consumption, this pathway is incomplete. |
| Drinking Water | No | Ingestion of drinking water addresses the drinking water source. The potentially impacted groundwater source on this site is not classified as a potable drinking water source or protected aquifer according to the State of Massachusetts. Potable drinking water is immediately available nearby off site. Therefore, it is prohibitively unlikely that drinking water might be drawn from onsite surface or ground water, and this pathway is incomplete. |
| Meat Ingestion | No | Ingestion of meat addresses the dose received from consuming the meat of livestock animals that have grazed on plant foods containing radioactivity liberated from the soil or have incidentally ingested the radioactivity in soils. The fact that this site is located in a highly populated urban area makes the consideration of livestock activities at the site incredible. Since livestock are not expected to be raised for food at this site, this pathway is incomplete. |
| Milk Ingestion | No | Milk ingestion pathway is incomplete since it is incredible to consider that cows might be grazed on this site. |
| Aquatic Foods Ingestion | No | This pathway is incomplete since there is no source of aquatic foods available on the site. No water system capable of supporting an ecosystem including aquatic foods is currently present or viable on this site. |
| Direct Ingestion | Yes | This pathway is conceivable because of the nature of the construction work. Earth workers on the site may ingest relatively small amounts of soils through incidental oral contact with their hands and nasal-pharynx migration of inhaled particles. |

### 3.3.2.3 Exposure Factor Parameters

There is a vast array of crafts and skills employed on a construction site. Many of these are characterized by short on-site durations and light or non-intensive contact with soils having concentrations of residual radioactivity. Among the various groups of construction workers that might be exposed on this site, it is the earth workers that have the greatest potential for exposure because of the combination of the contact-intensive nature of their tasks and the relatively longer exposure duration potential. These factors make the earth workers the *critical exposure group* for the construction worker exposure scenario. The construction worker scenario involves typical construction workday and work place exposure factors attributable to members of the critical group. Key parameters used to define the construction worker exposure scenario are presented in Table 3–4 below along with specific remarks explaining the values selection, which shows the RESRAD input.

*Table 3-4. Key Parameters—Construction Worker Scenario*

*(Earth Workers Defined as the Critical Exposure Group)*

| Parameter | | Unit | Value Selected | RESRAD Default | Remark |
|---|---|---|---|---|---|
| **Description** | **Code** | | | | |
| **Receptor Exposure Factors** | | | | | |
| Exposure Period (Duration) | **ED** | Years | 1 | 30 | Factor used to establish the period over which risk is summed. Note that the exposure duration is set to one year even though the duration is expected to be only six months long. This value does not affect the calculations in that it is only used to determine the number of years over which a cumulative ELCR is to be summed. The exposure frequency and time define the exposure period for calculation purposes. |
| Exposure Frequency | **EF** | Days per year | 125 | NA | Assumes earthwork occurs for a six-month period (25 weeks) with no allowance for weather, sickness, vacation, or site condition interruptions. MADEP 1996. |
| Exposure Time | **ET** | Hours per Day | 8 | NA | Assumes 8-hour outdoor workday. All exposure is conservatively assumed to be outdoors and on site. |
| Indoor Time Fraction | **FIND** | 0 to 1 | 0 | 0.5 | The fraction of a total year (8760 hr) that is spent indoors on site. No credit is taken for the amount of time a construction worker may spend indoors (perhaps in a construction trailer office). In addition, this parameter is used to determine the application of the external gamma shielding factor. By setting this parameter to zero, no credit is taken for the attenuating effect of the earth moving equipment. |
| Outdoor Time Fraction | **FOTD** | 0 to 1 | 0.114 | 0.25 | The fraction of a total year (8760 hr) that is spent outdoors on site. |
| Inhalation Rate | **INHALR** | $m^3$/yr | 21,900 | 8,400 | Annualized inhalation rate based on the geometric mean rate for short-term exposures of outdoor workers engaged in heavy activities (EPA 1997). |
| Mass Loading for Inhalation | **MLINH** | $g/m^3$ | 0.00006 | 0.0001 | Mass loading in air describes the airborne dust loading conditions on the site. Value selected is approximately 2 times the median mass loading measured in Massachusetts accounting for the typically dustier conditions expected on construction site. MADEP 1996 specified value (60 $\mu g/m^3$) for construction workers. |
| Soil Ingestion Rate | **SOIL** | g/y | 73.0 | 36.5 | MADEP default value (200 mg/d) for adults engaged in contact-intensive activities (MADEP 1995). |
| Calculation Times | **T(n)** | Yrs. | 0 & 0.5 | Not Specified | Brackets the period of time expected for construction activities. |

| Parameter | | Unit | Value Selected | RESRAD Default | Remark |
|---|---|---|---|---|---|
| Description | Code | | | | |
| **Site Parameters** | | | | | |
| Area of Contaminated Zone | **AREA** | $m^2$ | 42,850 | 10,000 | Area selected corresponds to the entire site (11.91 acres). |
| Thickness of Contaminated Zone | **THICK0** | m | 0.3 | Not Specified | Site characterization data indicates that the residual radioactivity on site (outside of the burn area) is confined to the top foot of soil on average. Sensitivity analysis performed with DU isotopes indicates that a thickness greater than 0.3 meters is self-attenuating and results in no increase in dose rate. |
| Time Since Placement of materials | **TI** | year | 50 | 0 | Activity at the site with depleted uranium began as early as the mid-1950s. 50 years since placement allows for RESRAD to account for the in-growth of progeny in the uranium decay chain. (Harding ESE 2000) |
| Cover depth (thickness) | **COVER0** | m | 0 | 0 | Given the very near surface groundwater table and the marshy areas on the site, it is extremely unlikely that construction activities that might preface any future use would not involve the import of a substantial amount of fill. Still, the DCGL has been derived assuming no advantage that would be associated with the attenuating nature of cover material overlying the source layer. |
| Contaminated Zone Density | **DENSCZ** | $g/cm^3$ | 1.6 | 1.5 | Typical density for material type present at GSA site. |
| Contaminated zone erosion rate | **VCZ** | m/yr | 0.001 | 0.001 | Default |
| Average Annual Wind Speed | **WIND** | m/sec | 5.4 | 2.0 | Site-specific value, equal to 12 mph. (Harding ESE 2000) |
| Precipitation Rate | **PRECIP** | m/year | 1.08 | 1.0 | Annual average in Boston from 1941 to 1980. Equals 42.5 inches per year. (Harding ESE 2000) |
| **Source Term Factors** | | | | | |
| Cancer Risk Slope Factors | **SLPF(n)** | 1/pCi | All SLPFs used are RESRAD defaults | | RESRAD defaults from EPA Heast tables 1997 (EPA 1997) and are derived on the basis of the ICRP 30 dosimetry model. Risk from short-lived (<180 days) radioactive progeny isotopes are accounted for through the use of the "parent+D" slope factors. The units for external penetrating radiation are: 1/year per pCi/g. |
| Dose Conversion Factors | **DCFX(n)** | mrem/pCi | All DCFs used are RESRAD defaults | | RESRAD defaults from FGR #11 (EPA, 1988) and FGR #12 (EPA,1993) and are derived using ICRP 30 dosimetry model. Short-lived (<180 days) radioactive progeny isotopes are accounted for through the use of the "parent+D" DCFs. |
| Source Isotopes | | | Isotopic Mix | | This isotopic mix is derived from site-specific data and is consistent with the mixture expected for depleted uranium. The radium and thorium content generously allow for 0.1% residue in DU owing to less than perfect efficiency in the production of depleted uranium and small contributions of radium and thorium present in fill materials. All percentages calculated as the fraction of total uranium activity in the mixture. |
| $^{226}$Ra | **S1(4)** | pCi/g | 0.1% | | |
| $^{230}$Th | **S1(5)** | pCi/g | 0.1% | | |
| $^{234}$U | **S1(6)** | pCi/g | 14.2% | | |
| $^{235}$U | **S1(7)** | pCi/g | 1.1% | | |
| $^{238}$U | **S1(8)** | pCi/g | 84.7% | | |

### 3.3.3 Occupational Worker Exposure Scenario

#### 3.3.3.1 Conceptual Site Model for the Occupational Worker Scenario

The site conceptual model describing the occupational worker scenario includes the same physical and geological parameters described for the construction worker scenario, but adds green space, ball fields, paved parking lots, and a building to house an indoor recreation facility such as an ice rink. Figure 3-4 illustrates the conceptual description of the site conditions expected with the occupational worker scenario.

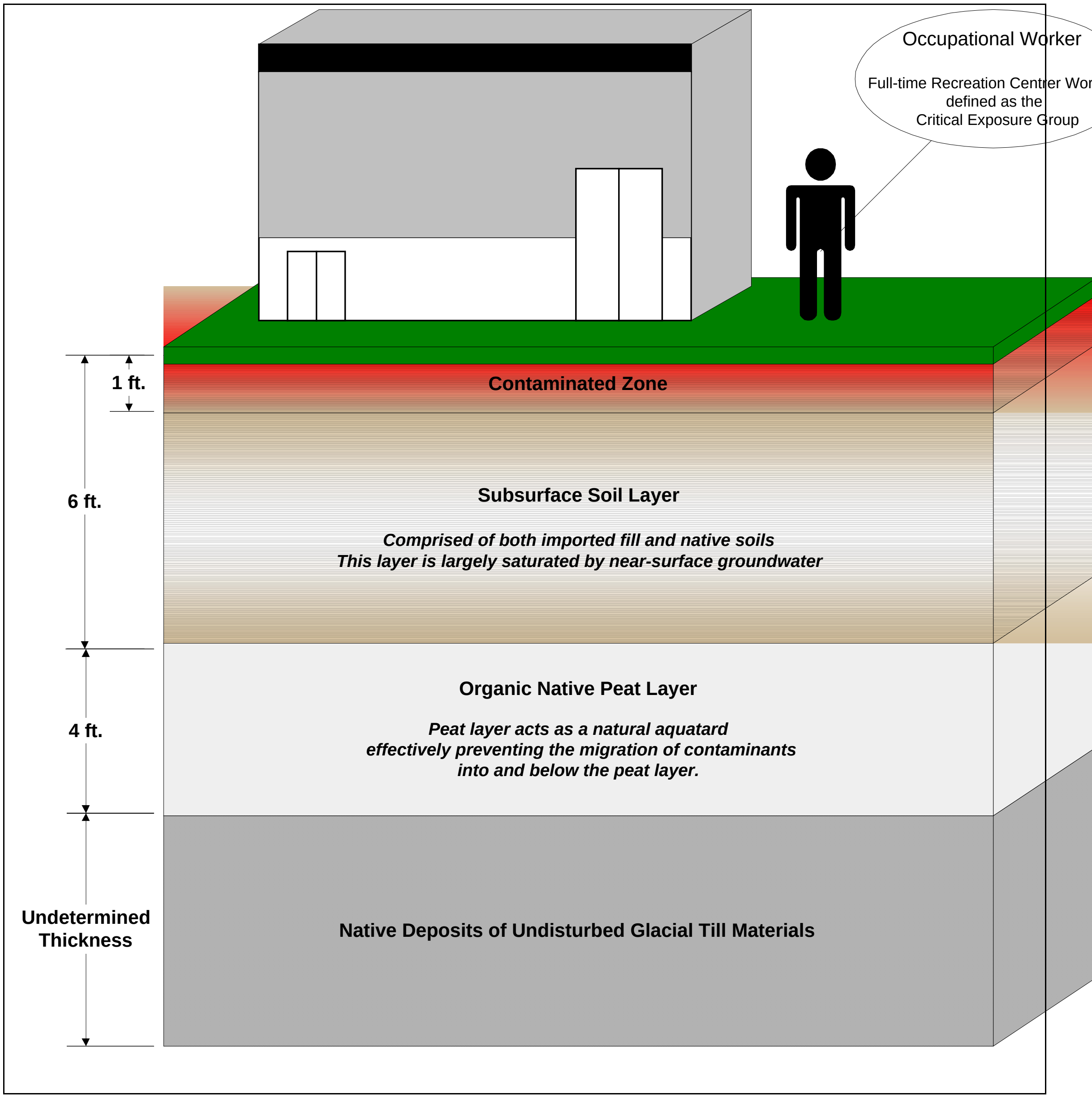


*Figure 3-4. Conceptual Site Model Describing the Occupational Worker Scenario*

#### 3.3.3.2 Pathways Included in the Occupational Worker Scenario

Table 3–5 identifies the pathways that have been retained for the analysis and provides explanation for those pathways that were not retained.

*Table 3-5. Evaluation of Pathways for the Occupational Worker Scenario*

| Pathway | Retained | Remark |
|---|---|---|
| Direct Exposure | Yes | The source term found in the site soils produces penetrating gamma radiation. Exposure from direct penetrating radiation is expected to be a significant contributor to the overall dose/risk. |
| Particulate Inhalation | Yes | Allowance is made for soils containing radiological constituents of the source being liberated and suspended in the breathing air of occupational workers. |
| Radon | No | Radon is specifically excluded from consideration within the framework of the governing regulations. In addition, the source term found in the soil is not a significant producer of radon due the extremely long half-life of the isotopes found in depleted uranium. |
| Plant Ingestion | No | Ingestion of plant foods addresses those plant foods grown in the radioactivity or irrigated with water containing radioactivity from on site. Since occupational workers are not expected to raise plants on site for food consumption, this pathway is incomplete. |
| Drinking Water | No | The potentially impacted groundwater source on this site is not classified as a potable drinking water source and is not a protected aquifer according to the State of Massachusetts. A municipal potable drinking water supply system is available in the immediate vicinity of the site. The most probable source for drinking water to a facility constructed at this urban site is the local municipal water system. Further, the potentially impacted groundwater is very shallow, perched in a very thin layer, and of such poor quality (as most near surface aquifers are) that it is unlikely that efforts would be made to process the water to achieve drinking water standards even if an on site well was employed. These facts make it prohibitively unlikely that drinking water might be drawn from potentially impacted surface or ground water, and so this pathway is considered to be incomplete. |
| Meat Ingestion | No | The fact that this site is located in a highly populated urban area makes the consideration of livestock activities at the site incredible. Since livestock are not expected to be raised for food at this site, this pathway is incomplete. |
| Milk Ingestion | No | Milk ingestion pathway is incomplete since it is incredible to consider that cows might be grazed on this site. |
| Aquatic Foods Ingestion | No | This pathway is incomplete since there is no source of aquatic foods available on the site. No water system capable of supporting an ecosystem including aquatic foods is currently present or viable on this site. |
| Direct Ingestion | Yes | This pathway is conceivable because the entire site is not expected to be paved or constructed over. Portions of the site where green space or ball fields are placed present the possibility for contact with soils and incidental ingestion. |

#### 3.3.3.3 Exposure Factor Parameters

As with the construction worker scenario, there are a number of crafts and laborers that might be employed at a recreational property such as has been proposed. The likelihood, for example, is that groundskeepers would care for the lawns and ball fields only one or maybe two days per week. Others would plow and clear snow while still others would provide janitorial services. These activities are characterized by short on-site durations and light or non-intensive contact with soils having concentrations of residual radioactivity. The potential longer exposure durations is the key to identifying the critical exposure group in this scenario. The worker having the longest exposure duration for this occupational setting is the one that works full-time at the recreational complex, managing and caring for the building facilities. The same worker might be assigned during summer months to perform some outdoor maintenance activities, such as those described above. These factors make the full-time facility workers the *critical exposure group* for the occupational worker exposure scenario. The occupational worker scenario involves typical workdays and non-contact intensive work place exposure factors attributable to members of the critical group. Key parameters used to define the occupational worker exposure scenario are presented in Table 3–6 below along with specific remarks explaining the values selection.

*Table 3-6. Key Parameters—Occupational Worker Scenario*

*(Full-time Facility Workers Defined as the Critical Exposure Group)*

| Parameter | | Unit | Value Selected | RESRAD Default | Remark |
|---|---|---|---|---|---|
| **Description** | **Code** | | | | |
| **Receptor Exposure Factors** | | | | | |
| Exposure Period (Duration) | **ED** | Years | 25 | 30 | Factor used to establish the period over which risk is summed. Twenty-five years exposure duration is the default value specified by MADEP and represents a worst-case scenario value for occupational setting (MADEP 1995). Workplace statistics support a much lower expected exposure duration corresponding to the average length of time a person stays employed at the same job. |
| Exposure Frequency | **EF** | Days per year | 250 | NA | Assumes full-time year around employment period (50 weeks) with two weeks allowance for sickness and vacation. MADEP 1995. |
| Exposure Time | **ET** | Hours per Day | 8 | NA | Assumes 8-hour workday. Exposure time is divided between time spent indoors (8 hours during winter months, 7 hours during summer months) and time spent outdoors (1 hr during summer months). |
| Indoor Time Fraction | **FIND** | 0 to 1 | 0.2117 | 0.5 | The fraction of a total year (8760 hr) that is spent indoors on site. In addition, this parameter is used to determine the application of the inhalation and external gamma shielding factors. Equals 1855 hrs indoors on site divided by 8760 hours. |
| Outdoor Time Fraction | **FOTD** | 0 to 1 | 0.0166 | 0.25 | The fraction of a total year (8760 hr) that is spent outdoors on site. Equals 145 hrs outdoors on site divided by 8760 hours. |
| Shielding Factor, External Gamma | **SHF1** | unit less | 0.05 | 0.7 | The structure itself provides an attenuating effect during indoor exposure periods. Value calculated with MicroShield gamma attenuation software (Appendix B). Based on regional construction practices and requirements, a structure housing a recreation complex supporting a hockey rink is likely to have at least 12" of compacted fill underlying a 4 to 8" thick concrete slab (Grove 1996). |

| Parameter | | Unit | Value Selected | RESRAD Default | Remark |
|---|---|---|---|---|---|
| Description | Code | | | | |
| Inhalation Rate | **INHALR** | $m^3$/yr | 5500 | 8400 | Annual inhalation rate based on geometric mean rate for long-term exposure to adult males (EPA 1997, MADEP 1995). |
| Shielding Factor, Inhalation | **SHF3** | unit less | 0.25 | 0.4 | Median of the range (0.2-0.3) from study designed to investigate the fraction of indoor dust relative to outdoor dust. (Rutz 1997) |
| Mass Loading for Inhalation | **MLINH** | g/$m^3$ | 0.000032 | 0.0001 | Mass loading in air describes the airborne dust loading conditions on the site. Value selected is the median mass loading measured in Massachusetts. MADEP 1995 specified value (32 μg/$m^3$) for typical receptors in open field. |
| Soil Ingestion Rate | **SOIL** | g/y | 18.3 | 36.5 | MADEP default value for adults engaged in non-contact intensive activities (50 mg/day). MADEP 1995. |
| Calculation Times | **T(n)** | Yrs. | 0, 1, 10, 30, & 1000 | Not Specified | Evaluation at these time segments allows for consideration of the potential for conditions at the site to evolve from the initial conditions specified (e.g., soil erosion impacts the source thickness) and projects the changing site conditions to the required 1000-year outlook (NRC 1997, 2000). |
| **Site Parameters** | | | | | |
| Area of Contaminated Zone | **AREA** | $m^2$ | 42,850 | 10,000 | Area selected corresponds to the entire site (11.91 acres). |
| Thickness of Contaminated Zone | **THICK0** | m | 0.3 | Not Specified | Site characterization data indicates that the residual radioactivity on site (outside of the burn area) is confined to the top foot of soil on average. Sensitivity analysis performed with DU isotopes indicates that a thickness greater than 0.3 meters is self-attenuating and results in no increase in dose rate. |
| Time Since Placement of Materials | **TI** | years | 50 | 0 | Activity at the site with depleted uranium began as early as the mid-1950s. 50 years since placement allows for RESRAD to account for the in-growth of progeny in the uranium decay chain. (Harding ESE 2000) |
| Cover Depth (thickness) | **COVER0** | m | 0 | 0 | Given the very near surface groundwater table and the marshy areas on the site, it is extremely unlikely that construction activities that might preface any future use would not involve the import of a substantial amount of fill. Still, the DCGL has been derived assuming no advantage that would be associated with the attenuating nature of cover material overlying the source layer. |
| Contaminated Zone Density | **DENSCZ** | g/$cm^3$ | 1.6 | 1.5 | Typical density for material type present at GSA site. |
| Contaminated Zone Erosion Rate | **VCZ** | m/yr | 0.000003 | 0.001 | Typical value for Eastern U.S. site with ~2% slope and non-agricultural use (Yu, 1993b). |
| Average Annual Wind Speed | **WIND** | m/sec | 5.4 | 2.0 | Site-specific value, equal to 12 mph. (Harding ESE 2000) |
| Precipitation Rate | **PRECIP** | m/year | 1.08 | 1.0 | Annual average in Boston from 1941 to 1980. Equals 42.5 inches per year. (Harding ESE 2000) |

| Source Term Factors | | | | |
|---|---|---|---|---|
| Cancer Risk Slope Factors | **SLPF(n)** | 1/pCi | All SLPFs used are RESRAD defaults | RESRAD defaults from EPA Heast tables 1997 (EPA 1997) and are derived on the basis of the ICRP 30 dosimetry model. Risk from short-lived (<180 days) radioactive progeny isotopes are accounted for through the use of the "parent+D" slope factors. The units for external penetrating radiation are: 1/year per pCi/g. |
| Dose Conversion Factors | **DCFX(n)** | mrem/pCi | All DCFs used are RESRAD defaults | RESRAD defaults from FGR #11 (EPA, 1988) and FGR #12 (EPA, 1993) and are derived using ICRP 30 dosimetry model. Short-lived (<180 days) radioactive progeny isotopes are accounted for through the use of the "parent+D" DCFs. |
| Source Isotopes | | | Isotopic Mix | This isotopic mix is derived from site-specific data and is consistent with the mixture expected for depleted uranium. The radium and thorium content generously allow for 0.1% residue in DU owing to less than perfect efficiency in the production of depleted uranium and small contributions of radium and thorium present in fill materials. All percentages calculated as the fraction of total uranium activity in the mixture. |
| $^{226}$Ra | **S1(4)** | pCi/g | 0.1% | |
| $^{230}$Th | **S1(5)** | pCi/g | 0.1% | |
| $^{234}$U | **S1(6)** | pCi/g | 14.2% | |
| $^{235}$U | **S1(7)** | pCi/g | 1.1% | |
| $^{238}$U | **S1(8)** | pCi/g | 84.7% | |

### 3.3.4 Recreational Visitor Exposure Scenario

#### 3.3.4.1 Conceptual Site Model for the Recreational Visitor Scenario

The site conceptual model describing the recreational visitor scenario is identical to the site model described for the occupational worker scenario (Figure 3-4). No soil cover (e.g., asphalt in parking areas, or topsoil, clay and sod on playing fields) is considered even though it would be required in such a scenario. This factor alone adds a substantial conservatism in the derivation of the DCGL. The differences in this scenario are found not in the site conceptual model but in the exposure factors related to the receptors and their activities.

#### 3.3.4.2 Pathways Included in the Recreational Visitor Scenario

Table 3–7 identifies the pathways that have been retained for the analysis and provides explanation for those pathways that were not retained.

*Table 3-7. Evaluation of Pathways for the Recreational Visitor Scenario*

| Pathway | Retained | Remark |
| --- | --- | --- |
| Direct Exposure | Yes | The source term found in the site soils produces penetrating gamma radiation. Exposure from direct penetrating radiation is expected to be a significant contributor to the overall dose/risk. |
| Particulate Inhalation | Yes | Allowance is made for soils containing radiological constituents of the source being liberated and suspended in the breathing air of recreational users of and visitors to the site. |
| Radon | No | Radon is specifically excluded from consideration within the framework of the governing regulations. In addition, the source term found in the soil is not a significant producer of radon due the extremely long half-life of the isotopes found in depleted uranium. |
| Plant Ingestion | No | Ingestion of plant foods addresses those plant foods grown in the radioactivity or irrigated with water containing radioactivity from on site. Since recreational visitors are not expected to raise plants or consume food grown on the site, this pathway is incomplete. |
| Drinking Water | No | The potentially impacted groundwater source on this site is not classified as a potable drinking water source and is not a protected aquifer according to the State of Massachusetts. A municipal potable drinking water supply system is available in the immediate vicinity of the site. The most probable source for drinking water to a facility constructed at this urban site is the local municipal water system. Further, the potentially impacted groundwater is very shallow, perched in a very thin layer, and of such poor quality (as most near surface aquifers are) that it is unlikely that efforts would be made to process the water to achieve drinking water standards even if an on site well was employed. These facts make it prohibitively unlikely that drinking water might be drawn from potentially impacted surface or ground water, and so this pathway is considered to be incomplete. |
| Meat Ingestion | No | The fact that this site is located in a highly populated urban area makes the probability of livestock activities at the site remote. Since livestock are not expected to be raised for food at this site, this pathway is incomplete. |
| Milk Ingestion | No | Milk ingestion pathway is incomplete since it is not realistic to consider that cows might be grazed on this site. |
| Aquatic Foods Ingestion | No | This pathway is incomplete since there is no source of aquatic foods available on the site. No water system capable of supporting an ecosystem including aquatic foods is currently present or viable on this site. |
| Direct Ingestion | Yes | This pathway is conceivable because the entire site is not expected to be paved or constructed over. Portions of the site where green space or ball fields are placed present the possibility for contact with soils and incidental ingestion. |

#### 3.3.4.3 Exposure Factor Parameters

There is likely to be a great variety in the uses and frequency of visits to a recreational facility as envisioned and considered herein. Possible uses range from passive activities such as walks, reading, picnicking, and sun-bathing to more active uses such as participation in sporting events and use of playground equipment. Considering the possible range of uses along with the expected frequency and duration of exposure associated with specific uses identifies the critical exposure group from among all those visitors potentially exposed at the site. Adults are far more likely to engage in the passive activities anticipated at the site. These are characterized by seasonal availability, are typically engaged in less frequently than scheduled activities such as league play, and light or non-intensive contact with soils having concentrations of residual radioactivity.

Children (6 years and older) and young adults are more likely to be engaged in organized sporting activities that might occur at the site such as youth hockey leagues, little league baseball, soccer, or swimming lessons and meets. The combination of year-around availability for such activities, and the possibility that a person may engage in frequent scheduled activities at the site make the sporting facility user the *critical exposure group* for the recreational visitor exposure scenario.

The recreational visitor scenario involves high usage and non-contact intensive exposure factors attributable to members of the critical group. Key parameters used to define the recreational visitor exposure scenario are presented in Table 3–8 below along with specific remarks explaining the values selection.

*Table 3-8. Key Parameters—Recreational Visitor Scenario*

*(Sporting Facility Users Defined as the Critical Exposure Group)*

| Parameter | | Unit | Value Selected | RESRAD Default | Remark |
|---|---|---|---|---|---|
| **Description** | **Code** | | | | |
| **Receptor Exposure Factors** | | | | | |
| Exposure Period (Duration) | **ED** | Years | 15 | 30 | The recreational visitor receptor evaluated in this assessment is assumed to be an older child/adolescent ages 6 through 20 who lives in the area and uses the MAMDC recreational facility as the primary location for their athletic recreational activities. Children younger than age 6 are not included in the critical group because young children are not likely to participate in athletic events such as baseball, soccer, swimming, and ice skating with as great a frequency or consistency. It is unlikely that a person would remain in the same neighborhood that they are raised in and continue to use the same MAMDC recreational complex with the same frequency or consistency as through early adulthood. Therefore, adults, ages 21 through 30, are not members of the critical exposure group. |
| Exposure Frequency | **EF** | Days per year | 134 | NA | This scenario involves seasonably variable exposure. When the weather is not inclement and the soil is not frozen or snow-covered (7 months: April through October), it is assumed that the recreational visitor uses the site facilities three days per week for 30.3 weeks (91 days). During the months when weather is inclement (5 months: November through March) it is assumed that the recreational visitor uses the site facilities two days per week for 21.6 weeks (43 days). |

| Parameter Description | Parameter Code | Unit | Value Selected | RESRAD Default | Remark |
|---|---|---|---|---|---|
| Exposure Time | **ET** | Hours per Day | 2 | NA | The exposure time of two hours was selected because typical games and practice sessions (e.g., baseball, soccer, ice hockey, swimming sessions) would not likely exceed two hours per exposure event. |
| Indoor Time Fraction | **FIND** | 0 to 1 | 0.0098 | 0.5 | The fraction of a total year (8760 hr) that is spent indoors on site. In addition, this parameter is used to determine the application of the inhalation and external gamma shielding factors. Equals 86 hrs indoors on site divided by 8760 hours. |
| Outdoor Time Fraction | **FOTD** | 0 to 1 | 0.0208 | 0.25 | The fraction of a total year (8760 hr) that is spent outdoors on site. Equals 191 hrs outdoors on site divided by 8760 hours. |
| Shielding Factor, External Gamma | **SHF1** | unit less | 0.05 | 0.7 | The structure itself provides an attenuating effect during indoor exposure periods. Value calculated with MicroShield gamma attenuation software (Appendix B). Based on regional construction practices and requirements, a structure housing a recreation complex supporting a hockey rink is likely to have at least 12" of compacted fill underlying a 4 to 8" thick concrete slab (Grove 1996). |
| Inhalation Rate | **INHALR** | $m^3/yr$ | 21,900 | 8,400 | Annualized inhalation rate based on the geometric mean rate for short-term exposures of outdoor workers engaged in heavy activities. This rate is conservative for children engaged in sporting activities who have a geometric mean inhalation rate of 16,000 $m^3/yr$ (EPA 1997). |
| Shielding Factor, Inhalation | **SHF3** | unit less | 0.25 | 0.4 | Median of the range (0.2-0.3) from study designed to investigate the fraction of indoor dust relative to outdoor dust. (Rutz 1997) |
| Mass Loading for Inhalation | **MLINH** | $g/m^3$ | 0.000032 | 0.0001 | Mass loading in air describes the airborne dust loading conditions on the site. Value selected is the median mass loading measured in Massachusetts. MADEP 1995 specified value (32 $\mu g/m^3$) for typical receptors in open field. |
| Soil Ingestion Rate | **SOIL** | g/y | 18.3 | 36.5 | Based typical ingestion rate for adults (50 mg/day). MADEP 1995. |
| Calculation Times | **T(n)** | Yrs. | 0, 1, 10, 30, & 1000 | Not Specified | Evaluation at these time segments allows for consideration of the potential for conditions at the site to evolve from the initial conditions specified (e.g., soil erosion impacts the source thickness) and projects the changing site conditions to the required 1000-year outlook (NRC 1997, 2000). |
| **Site Parameters** | | | | | |
| Area of Contaminated Zone | **AREA** | $m^2$ | 42,850 | 10,000 | Area selected corresponds to the entire site (11.91 acres). |
| Thickness of Contaminated Zone | **THICK0** | m | 0.3 | Not Specified | Site characterization data indicates that the residual radioactivity on site (outside of the burn area) is confined to the top foot of soil on average. Sensitivity analysis performed with DU isotopes indicates that a thickness greater than 0.3 meters is self-attenuating and results in no increase in dose rate. |

| Parameter Description | Parameter Code | Unit | Value Selected | RESRAD Default | Remark |
|---|---|---|---|---|---|
| Time Since Placement of materials | TI | years | 50 | 0 | Activity at the site with depleted uranium began as early as the mid-1950s. 50 years since placement allows for RESRAD to account for the in-growth of progeny in the uranium decay chain. (Harding ESE 2000) |
| Cover depth (thickness) | COVER0 | m | 0 | 0 | Given the very near surface groundwater table and the marshy areas on the site, it is extremely unlikely that construction activities that might preface any future use would not involve the import of a substantial amount of fill. Still, the DCGL has been derived assuming no advantage that would be associated with the attenuating nature of cover material overlying the source layer. |
| Contaminated Zone Density | DENSCZ | $g/cm^3$ | 1.6 | 1.5 | Typical density for material type present at GSA site. |
| Contaminated zone erosion rate | VCZ | m/yr | 0.000003 | 0.001 | Typical value for Eastern U.S. site with ~2% slope and non-agricultural use (Yu, 1993). |
| Average Annual Wind Speed | WIND | m/sec | 5.4 | 2.0 | Site-specific value, equal to 12 mph. (Harding ESE 2000) |
| Precipitation Rate | PRECIP | m/year | 1.08 | 1.0 | Annual average in Boston from 1941 to 1980. Equals 42.5 inches per year. (Harding ESE 2000) |
| **Source Term Factors** | | | | | |
| Cancer Risk Slope Factors | SLPF(n) | 1/pCi | All SLPFs used are RESRAD defaults | | RESRAD defaults from EPA Heast tables 1997 (EPA 1997) and are derived on the basis of the ICRP 30 dosimetry model. Risk from short-lived (<180 days) radioactive progeny isotopes are accounted for through the use of the "parent+D" slope factors. The units for external penetrating radiation are: 1/year per pCi/g. |
| Dose Conversion Factors | DCFX(n) | mrem/pCi | All DCFs used are RESRAD defaults | | RESRAD defaults from FGR #11 (EPA, 1988) and FGR #12 (EPA, 1993) and are derived using ICRP 30 dosimetry model. Short-lived (<180 days) radioactive progeny isotopes are accounted for through the use of the "parent+D" DCFs. |
| Source Isotopes | | | Isotopic Mix | | This isotopic mix is derived from site-specific data and is consistent with the mixture expected for depleted uranium. The radium and thorium content generously allow for 0.1% residue in DU owing to less than perfect efficiency in the production of depleted uranium and small contributions of radium and thorium present in fill materials. All percentages calculated as the fraction of total uranium activity in the mixture. |
| $^{226}Ra$ | S1(4) | pCi/g | 0.1% | | |
| $^{230}Th$ | S1(5) | pCi/g | 0.1% | | |
| $^{234}U$ | S1(6) | pCi/g | 14.2% | | |
| $^{235}U$ | S1(7) | pCi/g | 1.1% | | |
| $^{238}U$ | S1(8) | pCi/g | 84.7% | | |

### 3.3.5 Community Gardener Exposure Scenario

#### 3.3.5.1 Conceptual Site Model for the Recreational Visitor Scenario

One variation on the theme of future public recreational use involves the developing trend for setting aside garden space for community use in urban areas. While there are no stated or described plans for the use of the GSA site property for such a purpose, the predisposition factors for this type of use are in place for this setting. This scenario requires a slight modification to the previously described recreational visitor site conceptual model and as a result is evaluated as a distinct scenario. The Site conceptual model incorporates the cultivation and ingestion of consumable vegetation with root depths of 0.5 meters. Figure 3-5 illustrates the variation in the site conceptual model for this scenario.

If community gardens are placed on the GSA property, area residents without the benefit personal garden space may take advantage of the opportunity for recreational gardening, perhaps renting a small plot of land to raise homegrown vegetables or flowers. The gravelly fill at the Site is not suitable for gardening and cultivating produce. To make the site suitable for gardening, at least a foot or two of topsoil would need to be placed on top of the existing site fill material. This would effectively isolate the subsurface materials from receptors and would provide substantial attenuation of any gamma radiation emitted. In addition, it would significantly retard the plant uptake process, all but eliminating the transfer of radionuclides from soil to plant. Nonetheless, the recreational gardener scenario incorporates the assumption that no topsoil is placed at the Site, and that potential exposures to the existing site soil would occur. This factor alone adds a substantial conservatism in the derivation of the DCGL.

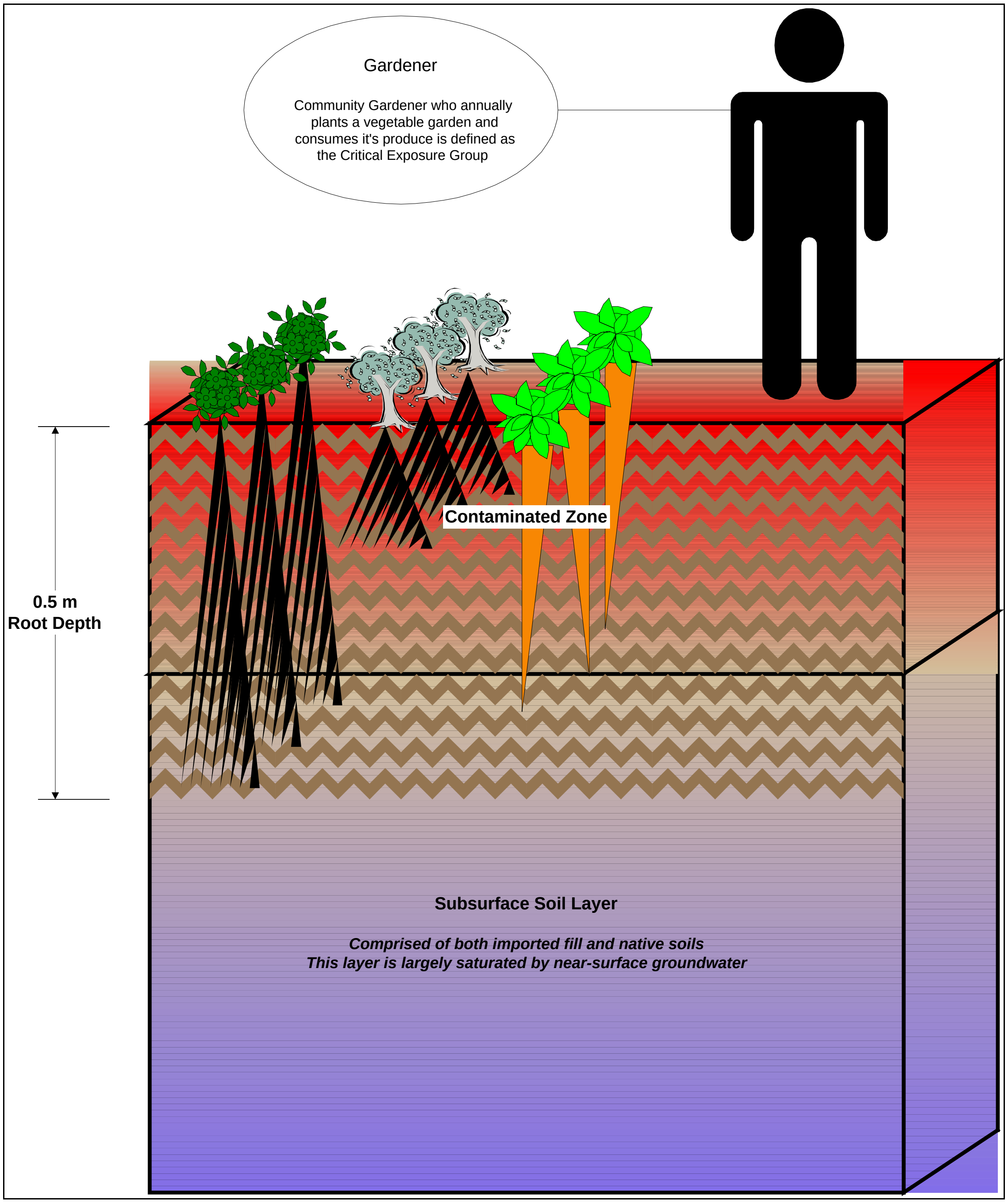


*Figure 3-5. Conceptual Site Model Describing the Community Gardener Scenario*

### 3.3.5.2 Pathways Included in the Community Gardener Scenario

Table 3–9 identifies the pathways that have been retained for the analysis and provides explanation for those pathways that were not retained.

*Table 3-9. Evaluation of Pathways for the Community Gardener Scenario*

| Pathway | Retained | Remark |
|---|---|---|
| Direct Exposure | Yes | The source term found in the site soils produces penetrating gamma radiation. Exposure from direct penetrating radiation is expected to be a significant contributor to the overall dose/risk. |
| Particulate Inhalation | Yes | Allowance is made for soils containing radiological constituents of the source being liberated and suspended in the breathing air of gardener. |
| Radon | No | Radon is specifically excluded from consideration within the framework of the governing regulations. In addition, the source term found in the soil is not a significant producer of radon due the extremely long half-life of the isotopes found in depleted uranium. |
| Plant Ingestion | Yes | Ingestion of plant foods addresses those plant foods that might be grown in the radioactivity or might be irrigated with water containing radioactivity from on site. (The use of potentially contaminated groundwater for irrigation is not considered credible for this site). Since community gardener scenario specifically involves a receptor that raises plants and consumes food grown on the site, this pathway is complete. |
| Drinking Water | No | The potentially impacted groundwater source on this site is not classified as a potable drinking water source and is not a protected aquifer according to the State of Massachusetts. A municipal potable drinking water supply system is available in the immediate vicinity of the site. The most probable source for drinking water to a facility constructed at this urban site is the local municipal water system. Further, the potentially impacted groundwater is very shallow, perched in a very thin layer, and of such poor quality (as most near surface aquifers are) that it is unlikely that efforts would be made to process the water to achieve drinking water standards even if an on site well was employed. These facts make it prohibitively unlikely that drinking water might be drawn from potentially impacted surface or ground water, and so this pathway is considered to be incomplete. |
| Meat Ingestion | No | The fact that this site is located in a highly populated urban area makes the consideration of livestock activities at the site incredible. Since livestock are not expected to be raised for food at this site, this pathway is incomplete. |
| Milk Ingestion | No | Milk ingestion pathway is incomplete since it is incredible to consider that cows might be grazed on this site. |
| Aquatic Foods Ingestion | No | This pathway is incomplete since there is no source of aquatic foods available on the site. No water system capable of supporting an ecosystem including aquatic foods is currently present or viable on this site. |
| Direct Ingestion | Yes | This pathway is conceivable because the garden scenario requires that access to the soil is available presenting the possibility for contact with, and incidental ingestion of, soils containing residual radioactivity. It further addresses the direct ingestion of radioactivity in soils resulting from foliar deposition of contaminated soils on vegetables consumed. |

### 3.3.5.3 Exposure Factor Parameters

This scenario is very discrete in that it addresses a very special variation of a recreational visitor/user scenario. The variability in the exposure factors is essentially limited to a rather distinct group of potentially exposed persons who make up the critical group for this scenario. Adults are far more likely to engage in gardening activities than are very young children. Consequently, exposure parameters associated with very young children are not considered in the evaluation of this scenario. This potential exposure setting is characterized by seasonal availability.

The community gardener scenario involves seasonal exposure factors attributable to members of the critical group. Key parameters used to define the recreational visitor exposure scenario are presented in Table 3–10 below along with specific remarks explaining the values selection.

*Table 3-10. Key Parameters—Community Gardener Scenario*

*(Adult Seasonal Vegetable Gardener Defined as the Critical Exposure Group)*

| Parameter | | Unit | Value Selected | RESRAD Default | Remark |
|---|---|---|---|---|---|
| Description | Code | | | | |
| **Receptor Exposure Factors** | | | | | |
| Exposure Period (Duration) | **ED** | Years | 30 | 30 | The recreational community gardener receptor evaluated in this assessment is assumed to be an adult who lives in the nearby area and uses a plot of land set aside by the MAMDC as a community gardening facility. Children younger than age 6 are not included in the critical group because young children are not likely to participate in gardening activities, at least not with as great a frequency or consistency. |
| Exposure Frequency | **EF** | Days per year | 52 | NA | This scenario involves seasonal exposure corresponding to the four month growing season in New England (June through September). It is assumed that the recreational gardener uses the site facilities three days per week for 17.3 weeks (52 days). |
| Exposure Time | **ET** | Hours per Day | 2 | NA | It is estimated that an exposure time of two hours per visit would be more than the average gardener would need to spend to care for a small vegetable garden. Perhaps the most avid gardener would spend as much as two hours per exposure event on average. |
| Indoor Time Fraction | **FIND** | 0 to 1 | 0.00 | 0.5 | It is assumed that no indoor exposure occurs for this scenario. |
| Outdoor Time Fraction | **FOTD** | 0 to 1 | 0.0119 | 0.25 | The fraction of a total year (8760 hr) that is spent outdoors on site. Equals 104 hrs outdoors on site divided by 8760 hours. |
| Inhalation Rate | **INHALR** | $m^3$/yr | 13,000 | 8,400 | Annualized inhalation rate based on the geometric mean rate for short-term exposures of outdoor workers engaged in moderate activities (EPA 1997). |
| Mass Loading for Inhalation | **MLINH** | $g/m^3$ | 0.000032 | 0.0001 | Mass loading in air describes the airborne dust loading conditions on the site. Value selected is the median mass loading measured in Massachusetts. MADEP 1995 specified value (32 $\mu g/m^3$) for typical receptors in open field. |
| Soil Ingestion Rate | **SOIL** | g/y | 18.3 | 36.5 | Based on an average value (50 mg/day) ingestion potential for gardeners. |

| Parameter | | Unit | Value Selected | RESRAD Default | Remark |
|---|---|---|---|---|---|
| Description | Code | | | | |
| Mass Loading for Foliar Deposition | MLFD | g/m$^3$ | 1 E-4 | 1 E-4 | Accounts for the residual soil deposition on consumable plants. Default used. |
| Contaminated Fraction of Plant Food | FPLANT | Unit less | 0.17 | -1 | Percentage that is home-grown (17%) is calculated from data presented in MADEP 1995, Appendix B. |
| Fruits, Vegetables, and Grain Consumption | DIET1 | kg/y | 3.28 | 160 | Value includes vegetables and berries but does not include grains since these are not typically grown in recreational gardens in New England. Default values include crops not grown in New England or in recreational gardens. Total value (4.1 kg/y) is calculated from data presented in MADEP 1995, Appendix B with 80% attributed to non-leafy fruits and vegetables, and 20% to leafy vegetables. |
| Leafy Vegetable Consumption | DIET2 | kg/y | 0.82 | 14 | |
| Calculation Times | T(n) | Yrs. | 0, 1, 10, 30, & 1000 | Not Specified | Evaluation at these time segments allows for consideration of the potential for conditions at the site to evolve from the initial conditions specified (e.g., soil erosion impacts the source thickness) and projects the changing site conditions to the required 1000-year outlook (NRC 1997, 2000). |
| **Site Parameters** | | | | | |
| Area of Contaminated Zone | AREA | m$^2$ | 42,850 | 10,000 | Area selected corresponds to the entire site (11.91 acres). |
| Thickness of Contaminated Zone | THICK0 | m | 0.3 | Not Specified | Site characterization data indicates that the residual radioactivity on site (outside of the burn area) is confined to the top foot of soil on average. Sensitivity analysis performed with DU isotopes indicates that a thickness greater than 0.3 meters is self-attenuating and results in no increase in dose rate. |
| Time Since Placement of materials | TI | years | 50 | 0 | Activity at the site with depleted uranium began as early as the mid-1950s. 50 years since placement allows for RESRAD to account for the in-growth of progeny in the uranium decay chain. (Harding ESE 2000) |
| Depth of Roots | DROOT | m | 0.5 | 0.9 | The annual varieties of plants grown in a vegetable garden have root depths limited by the length of the growing season and the depth of the loosened soil provided during preparation for planting. Perennial plants that provide for consumable foods are not considered in this scenario. |
| Cover depth (thickness) | COVER0 | m | 0 | 0 | Given the very near surface groundwater table, the unsuitable gravely soil, and the marshy areas on the site, it is extremely unlikely that gardening activities could be carried out without first importing 1 to 2 feet of topsoil. Still, the DCGL has been derived assuming no advantage that would be associated with the attenuating nature of cover material overlying the source layer. |
| Contaminated Zone Density | DENSCZ | g/cm$^3$ | 1.6 | 1.5 | Typical density for material type present at GSA site. |
| Contaminated zone erosion rate | VCZ | m/yr | 0.001 | 0.001 | Default value (Yu, 1993). |
| Average Annual Wind Speed | WIND | m/sec | 5.4 | 2.0 | Site-specific value, equal to 12 mph. (Harding ESE 2000) |

| Parameter Description | Parameter Code | Unit | Value Selected | RESRAD Default | Remark |
|---|---|---|---|---|---|
| Precipitation Rate | **PRECIP** | m/year | 1.08 | 1.0 | Annual average in Boston from 1941 to 1980. Equals 42.5 inches per year. (Harding ESE 2000) |
| **Source Term Factors** | | | | | |
| Cancer Risk Slope Factors | **SLPF(n)** | 1/pCi | All SLPFs used are RESRAD defaults | | RESRAD defaults from EPA Heast tables 1997 (EPA 1997) and are derived on the basis of the ICRP 30 dosimetry model. Risk from short-lived (<180 days) radioactive progeny isotopes are accounted for through the use of the "parent+D" slope factors. The units for external penetrating radiation are: 1/year per pCi/g. |
| Dose Conversion Factors | **DCFX(n)** | mrem/pCi | All DCFs used are RESRAD defaults | | RESRAD defaults from FGR #11 (EPA, 1988) and FGR #12 (EPA, 1993) and are derived using ICRP 30 dosimetry model. Short-lived (<180 days) radioactive progeny isotopes are accounted for through the use of the "parent+D" DCFs. |
| Source Isotopes | | | Isotopic Mix | | This isotopic mix is derived from site-specific data and is consistent with the mixture expected for depleted uranium. The radium and thorium content generously allow for 0.1% residue in DU owing to less than perfect efficiency in the production of depleted uranium and small contributions of radium and thorium present in fill materials. All percentages calculated as the fraction of total uranium activity in the mixture. |
| $^{226}$Ra | **S1(4)** | pCi/g | 0.1% | | |
| $^{230}$Th | **S1(5)** | pCi/g | 0.1% | | |
| $^{234}$U | **S1(6)** | pCi/g | 14.2% | | |
| $^{235}$U | **S1(7)** | pCi/g | 1.1% | | |
| $^{238}$U | **S1(8)** | pCi/g | 84.7% | | |

### 3.3.6 Urban Residential Exposure Scenario

As previously discussed, the steering group members concurred that a residential scenario, while possible, was highly improbable considering the property ownership (present and future), the stated and documented plans for the site, and the sentiments and wishes of the residents in the nearby community. However, the NRC requested that an urban residential setting be evaluated, not as a scenario for limiting the DCGL, but as an indicator of the extent of radiation exposure that might occur in the event that the credible land use assumptions proved inaccurate. In this capacity, the urban residential scenario serves as a measure of the upper range of the uncertainty in the assumption of future site use.

#### 3.3.6.1 Conceptual Site Model for the Urban Residential Scenario

The urban residential scenario differs from a "default" rural family farm class of residential scenario due to the logistic and demographic limitations imposed by the urban setting of the GSA site. A residence in this setting is likely to consist of a multi-level, multi-unit condominium or apartment type facility. The site conceptual model describing the urban residential scenario includes the same physical and geological conditions described for the occupational worker scenario except that the building serves as a residence rather than a sporting complex. In all likelihood, the site preparation and structural foundation necessary to support a multi-level residency building would be far more extensive than that required to construct a single level open bay structure such as would be expected for an aquatic center and ice rink facility. Figure 3-6 illustrates the conceptual description of the site conditions expected with the urban residential exposure scenario.

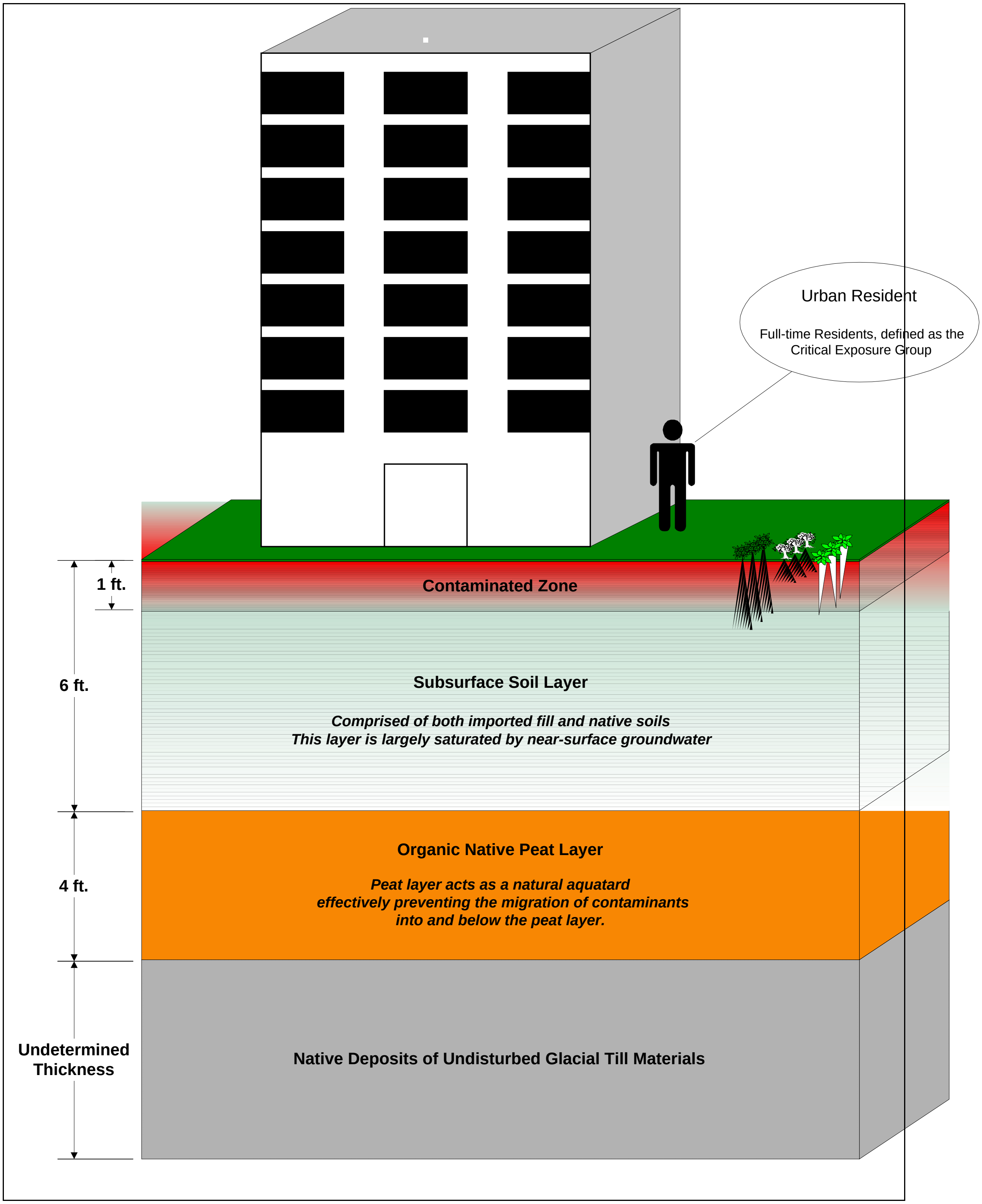


*Figure 3-6. Conceptual Site Model Describing the Urban Residential Scenario*

### 3.3.6.2 Pathways Included in the Urban Residential Scenario

Table 3–11 identifies the pathways that have been retained for the analysis and provides explanation for those pathways that were not retained.

*Table 3-11. Evaluation of Pathways for the Community Gardener Scenario*

| Pathway | Retained | Remark |
|---|---|---|
| Direct Exposure | Yes | The source term found in the site soils produces penetrating gamma radiation. Exposure from direct penetrating radiation is expected to be a key contributor to the overall dose/risk. |
| Particulate Inhalation | Yes | Allowance is made for soils containing radiological constituents of the source being liberated and suspended in the breathing air of residents. Allowance is made for the differences in airborne dust loading indoors and outdoors. |
| Radon | No | Radon is specifically excluded from consideration within the framework of the governing regulations. In addition, the source term found in the soil is not a significant producer of radon due the extremely long half-life of the isotopes found in depleted uranium. |
| Plant Ingestion | Yes | Ingestion of plant foods addresses those plant foods grown in the radioactivity or irrigated with water containing radioactivity from on site. While unlikely, the urban residential scenario allows for a resident to participate in a community garden where he raises plants and consumes food grown on the site, making this pathway complete. |
| Drinking Water | No | The potentially impacted groundwater source on this site is not classified as a potable drinking water source and is not a protected aquifer according to the State of Massachusetts. A municipal potable drinking water supply system is available in the immediate vicinity of the site. The most probable source for drinking water to a facility constructed at this urban site is the local municipal water system. Further, the potentially impacted groundwater is very shallow, perched in a very thin layer, and of such poor quality (as most near surface aquifers are) that it is unlikely that efforts would be made to process the water to achieve drinking water standards even if an on site well was employed. These facts make it prohibitively unlikely that drinking water might be drawn from potentially impacted surface or ground water, and so this pathway is considered to be incomplete. |
| Meat Ingestion | No | The fact that this site is located in a highly populated urban area makes the consideration of livestock activities at the site incredible. Since livestock are not expected to be raised for food at this site, this pathway is incomplete. |
| Milk Ingestion | No | Milk ingestion pathway is incomplete since it is incredible to consider that cows might be grazed on this site. |
| Aquatic Foods Ingestion | No | This pathway is incomplete since there is no source of aquatic foods available on the site. No water system capable of supporting an ecosystem including aquatic foods is currently present or viable on this site. |
| Direct Ingestion | Yes | This pathway is conceivable because the scenario assumes that access to the soil is available presenting the possibility for contact with, and incidental ingestion of, soils containing residual radioactivity. It further addresses the direct ingestion of radioactivity in soils resulting from foliar deposition of contaminated soils on vegetables consumed. |

### 3.3.6.3 Exposure Factor Parameters

This scenario supports a range of possible exposure durations as some spend more time at home than others. Also, few residents would be expected to participate in a community gardening project if it were available. The exposure frequency and duration provide the greatest variability in the annual dose and ELCR received by an exposed receptor. Consequently, the critical exposure group for this scenario is an adult who spends the majority of their day at home on the site. Examples of members of this group include retired people, those who work at home, as well as stay-at-home persons such as homemakers. It is also assumed that the same adult engages in seasonal gardening on the site, growing and consuming some fraction of their vegetables in such a garden. This setting is characterized by yearlong exposure weighted for the seasonal variability prevalent in New England.

The urban residential exposure scenario involves annualized exposure factors attributable to members of the critical group. Key parameters used to define the residential exposure scenario are presented in Table 3–12 below along with specific remarks explaining the values selection.

*Table 3-12. Key Parameters—Urban Residential Scenario*

*(Stay-at Home Adult Residents Defined as the Critical Exposure Group)*

| Parameter | | Unit | Value Selected | RESRAD Default | Remark |
|---|---|---|---|---|---|
| **Description** | **Code** | | | | |
| **Receptor Exposure Factors** | | | | | |
| Exposure Period (Duration) | **ED** | Years | 30 | 30 | The residential receptor evaluated in this assessment is assumed to be an adult who lives in a multi-level, multi-unit facility and who uses a small communal plot of land set aside as a gardening plot. |
| Exposure Frequency | **EF** | Days per Year | 350 | NA | This scenario involves yearlong exposure corresponding to seven days per week for 50 weeks (350 days). It allows for two weeks per year spent away from the residence and off site while engaged in activities such as vacation. The average adult today spends almost four weeks away from their primary residence. |
| Exposure Time | **ET** | Hours per Day | 21 | NA | It is assumed that the average member of the critical group will spend 21 hours per day at the residence. This value corresponds to the typical time spent indoors by persons >12 years old (EPA 1997). This allows for time spent off site for such activities as shopping, walking, traveling or visiting family and friends. |

| Parameter | | Unit | Value Selected | RESRAD Default | Remark |
|---|---|---|---|---|---|
| Description | Code | | | | |
| Indoor Time Fraction | FIND | 0 to 1 | 0.723 | 0.5 | The fraction of a total year (8760 hr) that is spent indoors on site. During the inclement weather season (147 days per year), it is assumed that all exposure occurs indoors. On days when weather permits (203 days per year), 5 of the 21 hours spent on site is attributed to outdoor exposure while 16 of the 21 hours are assumed to be spent indoors. Value selected equals (16*203 + 21*147) hrs indoors on site divided by 8760 hours. |
| Outdoor Time Fraction | FOTD | 0 to 1 | 0.116 | 0.25 | The fraction of a total year (8760 hr) that is spent outdoors on site. Equals 1015 hours (5*203) outdoors on site divided by 8760 hours. |
| Shielding Factor, External Gamma | SHF1 | unit less | 0.05 | 0.7 | The structure itself provides an attenuating effect during indoor exposure periods. Value calculated with MicroShield gamma attenuation software (Appendix B). Assumptions based on regional construction practices and requirements for a structure housing a recreation complex supporting a hockey rink is likely to have at least 12” of compacted fill underlying a 4 to 8” thick concrete slab (Grove 1996). Foundation and ground preparation requirements to support a multi-level, multi-unit urban residency building would be more substantial than those assumed herein. |
| Inhalation Rate | INHALR | $m^3$/yr | 5500 | 8,400 | Annual inhalation rate based on geometric mean rate for long-term exposure to adult males (EPA 1997, MADEP 1995). |
| Shielding Factor, Inhalation | SHF3 | unit less | 0.25 | 0.4 | Median of the range (0.2-0.3) from study designed to investigate the fraction of indoor dust relative to outdoor dust. (Rutz 1997) |
| Mass Loading for Inhalation | MLINH | g/$m^3$ | 0.000032 | 0.0001 | Mass loading in air describes the airborne dust loading conditions on the site. Value selected is the median mass loading measured in Massachusetts. MADEP 1995 specified value (32 µg/$m^3$) for typical receptors in open field. |
| Soil Ingestion Rate | SOIL | g/y | 21.3 | 36.5 | Based on a 30-year weighted average value (equal to 58 mg/day) considering greater ingestion for children (100 mg/day) together with typical ingestion rate for adults (50 mg/day). MADEP 1995. |
| Mass Loading for Foliar Deposition | MLFD | g/$m^3$ | 1 E-4 | 1 E-4 | Accounts for the residual soil deposition on consumable plants. Default used. |
| Contaminated Fraction of Plant Food | FPLANT | Unit less | 0.17 | -1 | Percentage that is home-grown (17%) is calculated from data presented in MADEP 1995, Appendix B. |
| Fruits, Vegetables, and Grain Consumption | DIET1 | kg/y | 3.28 | 160 | Value includes vegetables and berries but does not include grains since these are not typically grown in recreational gardens in New England. Default values include crops not grown in New England or in recreational gardens. Total value (4.1 kg/y) is calculated from data presented in MADEP 1995, Appendix B with 80% attributed to non-leafy fruits and vegetables, and 20% to leafy vegetables. |
| Leafy Vegetable Consumption | DIET2 | kg/y | 0.82 | 14 | |

| Parameter Description | Parameter Code | Unit | Value Selected | RESRAD Default | Remark |
|---|---|---|---|---|---|
| Calculation Times | **T(n)** | Yrs. | 0, 1, 10, 30, & 1000 | Not Specified | Evaluation at these time segments allows for consideration of the potential for conditions at the site to evolve from the initial conditions specified (e.g., soil erosion impacts the source thickness) and projects the changing site conditions to the required 1000-year outlook (NRC 1997, 2000). |
| **Site Parameters** | | | | | |
| Area of Contaminated Zone | **AREA** | $m^2$ | 42,850 | 10,000 | Area selected corresponds to the entire site (11.91 acres). |
| Thickness of Contaminated Zone | **THICK0** | m | 0.3 | Not Specified | Site characterization data indicates that the residual radioactivity on site (outside of the burn area) is confined to the top foot of soil on average. Sensitivity analysis performed with DU isotopes indicates that a thickness greater than 0.3 meters is self-attenuating and results in no increase in dose rate. |
| Time Since Placement of materials | **TI** | years | 50 | 0 | Activity at the site with depleted uranium began as early as the mid-1950s. 50 years since placement allows for RESRAD to account for the in-growth of progeny in the uranium decay chain. (Harding ESE 2000) |
| Depth of Roots | **DROOT** | m | 0.5 | 0.9 | The annual varieties of plants grown in a vegetable garden have root depths limited by the length of the growing season and the depth of the loosened soil provided during preparation for planting. Perennial plants that provide for consumable foods are not considered in this scenario. |
| Cover depth (thickness) | **COVER0** | m | 0 | 0 | Given the very near surface groundwater table, the unsuitable gravely soil, and the marshy areas on the site, it is extremely unlikely that construction activities that might preface any future use would not involve the import of a substantial amount of fill or that gardening activities could be carried out without first importing 1 to 2 feet of topsoil. Still, the DCGL has been derived assuming no advantage that would be associated with the attenuating nature of cover material overlying the source layer. |
| Contaminated Zone Density | **DENSCZ** | $g/cm^3$ | 1.6 | 1.5 | Typical density for material type present at GSA site. |
| Contaminated zone erosion rate | **VCZ** | m/yr | 0.000003 | 0.001 | Typical value for Eastern U.S. site with ~2% slope and non-agricultural use (Yu, 1993). |
| Average Annual Wind Speed | **WIND** | m/sec | 5.4 | 2.0 | Site-specific value, equal to 12 mph. (Harding ESE 2000) |
| Precipitation Rate | **PRECIP** | m/year | 1.08 | 1.0 | Annual average in Boston from 1941 to 1980. Equals 42.5 inches per year. (Harding ESE 2000) |
| **Source Term Factors** | | | | | |
| Cancer Risk Slope Factors | **SLPF(n)** | 1/pCi | All SLPFs used are RESRAD defaults | | RESRAD defaults from EPA Heast tables 1995, 97 (EPA 1995) and are derived on the basis of the ICRP 30 dosimetry model. Risk from short-lived (<180 days) radioactive progeny isotopes are accounted for through the use of the "parent+D" slope factors. The units for external penetrating radiation are: 1/year per pCi/g. |

| Parameter Description | Parameter Code | Unit | Value Selected | RESRAD Default | Remark |
|---|---|---|---|---|---|
| Dose Conversion Factors | DCFX(n) | mrem/pCi | All DCFs used are RESRAD defaults | | RESRAD defaults from FGR #11 (EPA, 1988) and FGR #12 (EPA, 1993) and are derived using ICRP 30 dosimetry model. Short-lived (<180 days) radioactive progeny isotopes are accounted for through the use of the "parent+D" DCFs. |
| Source Isotopes | | | Isotopic Mix | | This isotopic mix is derived from site-specific data and is consistent with the mixture expected for depleted uranium. The radium and thorium content generously allow for 0.1% residue in DU owing to less than perfect efficiency in the production of depleted uranium and small contributions of radium and thorium present in fill materials. All percentages calculated as the fraction of total uranium activity in the mixture. |
| $^{226}$ Ra | S1(4) | pCi/g | 0.1% | | |
| $^{230}$ Th | S1(5) | pCi/g | 0.1% | | |
| $^{234}$ U | S1(6) | pCi/g | 14.2% | | |
| $^{235}$ U | S1(7) | pCi/g | 1.1% | | |
| $^{238}$ U | S1(8) | pCi/g | 84.7% | | |

## 3.4 Computer Modeling Codes

The computer modeling code selected to evaluate the annual dose and ELCR potential to individuals from residual radioactive materials at the GSA site was selected on the basis of its ability to represent the conditions of the scenarios being evaluated and their acceptance within the regulatory and health physics communities as effective and suitable modeling tools.

The temptation in using models of any description to predict the potential future exposure conditions associated with an actual site is to ascribe or imply some measure of "accuracy" to the results it provides. In reality, it is difficult to effectively measure the accuracy of any model. In fact, it is principally because accurate, direct measurements within a reasonable time frame cannot be made that a model is used to make a prediction in the first place. It is the selection of the model that most closely approximates the scenario to be evaluated and the use of realistic and plausible input parameters describing the exposure scenario that determines the confidence one has about the modeled results. For these reasons the RESRAD modeling code was selected to model the scenarios relative to the GSA site.

The RESRAD code has been in use in various versions for several years and has been extensively employed for applications such as the GSA site DCGL derivation. The NRC has approved the use of RESRAD and RESRAD-BUILD for demonstrating compliance with the license termination criteria for its licensees and has recently sponsored the addition of probabilistic modules to new versions of both codes. The EPA has used the RESRAD code to develop soil cleanup standards for radionuclides (EPA, 1994). The EPA has accepted the use of RESRAD on sites having residual radioactivity. The calculations and algorithms in RESRAD have been extensively verified and validated. The RESRAD modeling used in this analysis incorporates cancer slope factor values published in HEAST (EPA, 1997c) to enable quantification of radionuclide-specific and pathway-specific excess lifetime cancer risk in the derivation of the DCGL. The steering group unanimously agreed that the most current, approved, non-beta version of the RESRAD code (version 6.0) should be used to evaluate potential future doses from exposure to residual radioactivity at the GSA site.

### 3.4.1 RESRAD Computer Code

The RESRAD computer code is a pathway analysis model designed to evaluate the potential radiological dose incurred by an individual exposed to concentrations of radionuclides in soil. The code was developed by Argonne National Laboratory for DOE to implement DOE requirements (DOE Order 5400.5) for developing site-specific guidelines for allowable residual concentrations of radionuclides in soil. The most currently available version of the code (RESRAD for Windows, Version 6.0 [Yu, 2000]) has been used to evaluate the exposure scenarios described above and to calculate the DCGL for the GSA site.

The transport of radioactive material through the environment is calculated and the annualized, time integrated doses and cumulative ELCR to potential receptors are determined in the modeling code. The code also has a design advantage that permits the user to calculate the concentration in soil that yields a specific dose eliminating the need to perform multiple iterative runs to arrive at a DCGL value. The model considers the dose from all isotopes in the suite entered and compensates for radioactive decay and ingrowth over the evaluation period. All significant exposure pathways are considered in the RESRAD code, including:

- External exposure (penetrating gamma) directly from contaminated soil.
- External exposure due to air submersion.
- Inhalation of airborne radioactive particulates.
- Inhalation of aerosol radon and radon progeny.
- Ingestion of radioactive material directly from the soil.
- Ingestion of radioactive material contained in food and drinking water supplies contaminated through transport of radionuclides in the environment.

Additionally, version 6.0 of the RESRAD code has the capability of performing both deterministic and probabilistic calculations for the scenarios evaluated. The results of the deterministic calculations of the DCGL for depleted uranium in soil using RESRAD 6.0 are summarized in Section 4.0 of this report. Complete reports detailing the calculations of dose and risk for each scenario are contained in Appendix A. An uncertainty analysis is presented in Section 5.0. Additionally, analyses evaluating the impact of uranium tailings residues (should they be encountered) are contained in Appendix F.

# 4.0 Results of Computer Modeling

In order to evaluate the DCGLs, the computer modeling codes were run iteratively for each of the selected scenarios to arrive at the maximum uniform (average) concentrations that yield a maximum total dose of 10 mrem (25 millirem for the residential scenario) to a single receptor in 1 year or ELCR on the order of 1 x 10-5. The computer code was set up to model each scenario with the input parameters identified and explained in Section 3.0. The following sections present the results of the computer modeling relating depleted uranium source concentrations with potential future doses and cumulative ELCR in each of the three scenarios evaluated.

## 4.1 Construction Worker

Table 4–1 summarizes the results of modeling the projected future exposure potential for a scenario involving extensive earthwork on the site, such as might occur in the case where a major construction project was undertaken at the site. The critical exposure group was identified as the workers who performed earth moving and excavation activities. The isotope mixture used is typical of depleted uranium and consistent with the mixture measured at the GSA site.

*Table 4–1. Construction Worker Scenario*

| **Public Health Limit** | **Average Residual Radioactivity Concentration in Soil (**pCi/g**)** | |
|---|---|---|
| | Total Uranium | Uranium-238 |
| Annual Dose (10 mrem/y) | 560 | 474 |
| Risk (1 x $10^{-5}$) | 1330 | 1127 |
| Computer printouts showing source term, dose, and radionuclide contribution distributions are in Appendix A.<br>Since the MADPH limit of 10 mrem/y is less than the NRC's 25 mrem/y limit, only the concentration corresponding to 10 mrem/y TEDE is presented.<br>The isotopic mix appears in Figure 2-1 and Table 3–4. | | |

For the Construction worker exposure scenario, the MADPH annual radiation dose limit (TEDE) for members of the public is limiting. Excess lifetime cancer risk is comparatively low, yielding higher allowable soil concentrations, due to the short exposure duration (6 months) compared with other scenarios. A review of the computer modeling printouts (Appendix A) reveals that direct gamma exposure is by far the principal exposure pathway and that the uranium 238 isotope is the most significant contributor to total effective annual dose and risk. Figures 4–1 & 4–2 illustrate the relative pathway and isotopic contributions.

## 4.2 Occupational Worker

A recreational complex that includes facilities such as an indoor aquatic center and ice rink, as well as outdoor playing fields, would presumably require staff comprised of groundskeepers, pool and ice rink attendants, lifeguards, maintenance personnel, and a facility manager. Whereas the persons associated with each of these occupations would spend different amounts of time at the facility (perhaps all occupations are part-time only), and potentially be responsible for only indoor or only outdoor facilities, the critical exposure group for this scenario is comprised of "composite" receptors (full-time occupational workers performing the full range of tasks at the facility) that provide a conservative evaluation for all these potential occupational needs[7].

Table 4–2 summarizes the results of modeling the projected future exposure potential for a scenario involving exposure while occupationally employed at the proposed future recreation complex on the site. The isotope mixture used is typical of depleted uranium and consistent with the mixture measured at the GSA site.

*Table 4–2. Occupational Worker Scenario*

| **Public Health Limit** | **Average Residual Radioactivity Concentration in Soil (**pCi/g**)** | |
|---|---|---|
| | Total Uranium | Uranium-238 |
| Annual Dose (10 mrem/y) | 2150 | 1820 |
| Risk (1 x $10^{-5}$) | 340 | 288 |
| Computer printouts showing source term, dose, and radionuclide contribution distributions are in Appendix A.<br>Since the MADPH limit of 10 mrem/y is less than the NRC's 25 mrem/y limit, only the concentration corresponding to 10 mrem/y TEDE is presented.<br>The isotopic mix appears in Figure 2-1 and Table 3–6. | | |

For the occupational recreation center worker, the MADEP excess lifetime cancer risk is more limiting than the annualized radiation dose limit for members of the public. In contrast with the construction worker scenario which is characterized by short exposure durations, the comparatively long exposure duration evaluated in the occupational worker setting yields higher cumulative lifetime risk leading to lower allowable soil concentrations. A review of the computer modeling printouts (Appendix A) reveals that direct gamma exposure is by far the principal exposure pathway and that the uranium 238 isotope is the most significant contributor to total effective annual dose and risk. Figures 4–3 & 4–4 illustrate the relative pathway and isotopic contributions.

## 4.3 Recreational Visitor

Under the anticipated future use of the site as a recreational complex, recreational visitors (users) would be expected to frequent the property. The critical exposure group evaluated in this assessment is defined by the recreational visitor receptor that is assumed to be an

[7] The values for the parameters used to perform the modeling are protective for a groundskeeper who may maintain the property in the event the MAMDC only uses the GSA property for passive green-space. A groundskeeper might be expected to perform landscaping activities (e.g., flower, shrub, tree watering) and lawn mowing on average 1 day per week, 4 to 8 hours per day, over the typical growing season (May through September).

older child/adolescent who lives in the area and uses the MAMDC recreational facility year-round as the primary location for their athletic recreational activities[8].

Table 4–3 summarizes the results of modeling the projected future exposure potential for a scenario involving recreational uses of the site after development. The isotope mixture used is typical of depleted uranium and consistent with the mixture measured at the GSA site.

*Table 4–3. Recreation Complex Visitor/User Scenario*

| **Public Health Limit** | **Average Residual Radioactivity Concentration in Soil (**pCi/g**)** | |
|---|---|---|
| | Total Uranium | Uranium-238 |
| Annual Dose (10 mrem/y) | 3350 | 2837 |
| Risk (1 x $10^{-5}$) | 725 | 614 |
| Computer printouts showing source term, dose, and radionuclide contribution distributions are in Appendix A.<br>Since the MADPH limit of 10 mrem/y is less than the NRC's 25 mrem/y limit, only the concentration corresponding to 10 mrem/y TEDE is presented.<br>The isotopic mix appears in Figure 2-1 and Table 3–8. | | |

Again, the comparatively long exposure duration evaluated in the recreation facility user setting makes the MADEP excess lifetime cancer risk the more limiting public health limit. It is notable, however, that both the risk and dose for the recreational visitor are smaller than for the occupational worker by more than a factor of two. A review of the computer modeling printouts (Appendix A) reveals that direct gamma exposure is by far the principal exposure pathway and that the uranium 238 isotope is the most significant contributor to total effective annual dose and risk. Figures 4–5 & 4–6 illustrate the relative pathway and isotopic contributions.

## 4.4 Community Gardener

If community gardens are placed on the GSA property, area residents may take advantage of the opportunity for recreational gardening. The critical exposure group for the community gardener scenario is an adult potentially exposed annually while recreationally gardening on site and through consumption of vegetables grown on the site.

Table 4–4 summarizes the results of modeling the projected future exposure potential for a scenario involving recreational uses of the site after development. The isotope mixture used is typical of depleted uranium and consistent with the mixture measured at the GSA site.

[8] These variables are protective for a passive recreational visitor who may use the property activities (e.g., reading, picnicking, sun-bathing) in the event the MAMDC only uses the GSA property for passive green-space.

*Table 4–4. Community Recreational Gardener Scenario*

| Public Health Limit | Average Residual Radioactivity Concentration in Soil (pCi/g) | |
|---|---|---|
| | Total Uranium | Uranium-238 |
| Annual Dose (10 mrem/y) | 5175 | 4383 |
| Risk (1 x $10^{-5}$) | 635 | 538 |
| Computer printouts showing source term, dose, and radionuclide contribution distributions are in Appendix A.<br>Since the MADPH limit of 10 mrem/y is less than the NRC's 25 mrem/y limit, only the concentration corresponding to 10 mrem/y TEDE is presented.<br>The isotopic mix appears in Figure 2-1 and Table 3–10. | | |

The community gardener scenario yields risk and dose estimates comparable to those observed with the recreational visitor scenario with ELCR again emerging as the limiting public health limit. Consistent with other scenarios, a review of the computer modeling printouts (Appendix A) reveals that direct gamma exposure is by far the principal exposure pathway and that the uranium 238 isotope is the most significant contributor to total effective annual dose and risk. Figures 4–7 & 4–8 illustrate the relative pathway and isotopic contributions.

## 4.5 Urban Resident

Ownership of the property at the GSA site is stipulated to revert[9] to the ownership of the Commonwealth of Massachusetts' MAMDC. According to the MAMDC's master plan, they plan to construct a recreational facility at the site. The recreational facility is anticipated to consist of outdoor playing fields (e.g., soccer and/or baseball fields), an indoor ice rink and aquatic facility, and a paved parking area (CENAE 2000a). The site configuration for this use has not yet been established, but based on topography, wetlands, and site access considerations, it is likely that the indoor facility will be placed at the southern end of the site, the paved parking area will be placed in the central portion of the site, and the playing fields will be placed at the northern end of the site. In the event that the MAMDC cannot complete the anticipated development, MAMDC has indicated that the GSA property will be used as "green space" as part of the green belt that runs along the Charles River. Under this use, the property would function as a passive recreational park.

Although unlikely, if the GSA property does not revert to ownership of the MAMDC, the Town of Watertown would have an option to acquire the property. The Town of Watertown has also expressed interest in developing more recreational ball fields (e.g., soccer fields) at the site should the property be available.

Given the anticipated future ownership of the GSA property it is substantially more likely that, the property will be used for recreational purposes, as opposed to

[9] There is a "reverter clause" in the property title, stating that MAMDC has legal right to title of the GSA property when the federal government determines that it no longer has need for the property.

commercial/industrial or residential purposes. Added to this, additional considerations including local sentiment against structures that would obscure views of the river make it unlikely that a residential setting would come to fruition.

The urban residential scenario is evaluated as a gauge of the extent of potential annual dose that might be accrued by a receptor in the event that the projected and anticipated credible future land uses (those listed in the sections 4.1 through 4.4 above) prove inaccurate. The critical exposure group for the urban residential scenario is a stay-at-home adult potentially exposed while residing at a multi-level, multi-unit housing structure on the site. The same individual engages in recreational gardening on the site and consumes vegetables grown in that garden. While not considered to be very likely, this scenario is plausible and serves well to gauge to maximum exposure potential at the site.

Table 4–5 summarizes the results of modeling the projected future exposure potential for receptors exposed in the urban residential setting. The isotope mixture used is typical of depleted uranium and consistent with the mixture measured at the GSA site.

*Table 4–5. Urban Residential Scenario*

| **Public Health Limit** | **Average Residual Radioactivity Concentration in Soil (**pCi/g**)** | |
|---|---|---|
| | Total Uranium | Uranium-238 |
| Annual Dose (25 mrem/y) | 1010 | 855 |
| Computer printouts showing source term, dose, and radionuclide contribution distributions are in Appendix A.<br>The residential scenario is being evaluated at the request of the NRC as a measure of the extent of potential exposure in the event that the anticipated future uses of the site prove to be inaccurate. Therefore, it is not used to derive the DCGL but as a benchmark for risk managers to evaluate the conservatism embodied in the DCGL. The NRC's 25 mrem/y limit is presented for comparison only.<br>The isotopic mix appears in Figure 2-1 and Table 3–12. | | |

From the uranium concentration in soil corresponding to 25 mrem/y TEDE, it is apparent that the residential scenario, while incorporating substantial exposure time, does not limit the selection of the DCGL. Since the concentration in soil corresponding to an ELCR on the order of $1 \times 10^{-5}$ in the occupational worker scenario is approximately a factor of three smaller than the 1010 pCi/g corresponding to 25 mrem/y in the urban residential scenario, the residential scenario would not be an NRC concern in the unlikely event that a residential setting evolves at this site.

## 4.6 Summary of Modeling Results

The results obtained above are used to select the depleted uranium in soil concentration that will be protective of all of the envisioned exposure scenarios. Based on annual public dose limits (MADPH), the limiting concentration is 560 pCi/g total uranium, which yields 10 mrem in the year that a major construction event occurs on the site.

Based on the risk criterion (MADEP), the limiting concentration is 340 pCi/g total uranium, which yields an ELCR on the order of $1 \times 10^{-5}$.

The impact that uranium tailings residue might have on the DCGLs presented here in this section is discussed in Section 6.0 and in Appendix F. The concentration in soil to be designated as the DCGL is recommended in Section 6.0.

# 5.0 Uncertainty Analysis

There is an inherent uncertainty in any projection of a future condition. Thus scientists, statisticians, and even weather forecasters have developed tools to help them model or project a future condition.

In the past, dose assessments in support of NRC decommissioning requirements relied primarily on the use of deterministic (single point estimate) analyses. The deterministic approach has the advantage of being simple to implement and easy to communicate to a non-specialist audience. However, it has a significant drawback in not allowing consideration of the combinatory effects of input parameters. It also fails to provide information on the degree of uncertainty in the results, which would be helpful to the decision-maker. To overcome these weaknesses and to ensure that the deterministic analysis had a high probability of erring conservatively, risk dose/risk assessors often relied on the use of pessimistic (grossly conservative) estimates of each parameter of the model, typically leading to overly conservative evaluations and unnecessarily restrictive DCGLs.

The alternative to the deterministic approach is the probabilistic approach in which the overall uncertainty in the assessment is evaluated to arrive at a better estimate of the correspondence between residual radioactive concentration and the extent of incremental dose or risk to an exposed receptor. Uncertainty analysis imparts more information to the decision maker than deterministic analysis. It characterizes a range of potential doses/risks and the likelihood that a particular dose/risk would be exceeded.

Regardless of the method, uncertainty is inherent in all dose/risk assessment calculations and should be considered in determining whether a selected DCGL concentration will satisfy the regulatory decision-making criteria. In general, there are three primary sources of uncertainty in a dose/risk assessment (Bonano et.al., 1988, and Kozak et al., 1991):

- Uncertainty in the models,
- Uncertainty in scenarios, and
- Uncertainty in the parameters

Models are simplifications of reality, and in general, several alternative models may be consistent with available data. Computer modeling software codes have permitted the analyst to increasingly refine the models they use because the computer is handling the complex calculations that result. The codes used in this evaluation have been developed and maintained using a stringent version control process. The models or components of them are tested for mathematical correctness, verified, and benchmarked against comparable models when available. Modeling in and of itself implies a degree of uncertainty in that direct measurements or standards are typically not available to compare to modeled results. It is in such cases that risk-managers resort to models. Perhaps the most important factor in building confidence in the predictions of a model is selecting the model that most closely approximates the scenario to be evaluated. Uncertainty in scenarios is the result of our lack of absolute knowledge about the future uses of the site. Parameter uncertainty results from incomplete knowledge of the coefficients that describe the model. However, with the selection of a suitable model for the site and scenario, and configuring the model with realistic and most probable input parameters, the risk-manager may be reasonably confident in the model's predictions.

The current regulatory philosophy is to evaluate the uncertainty in an estimate along with the severity of consequence and probability of exceeding a deterministic regulatory limit. Such a decision method is termed "risk-informed decision making." The advent of powerful personal computers and increasingly capable software tools coupled with increased knowledge of key physical, behavioral, and metabolic parameters used to make dose/risk assessments have brought probabilistic analysis to the state of the art. While not all regulating agencies currently expect that assessments will employ the probabilistic approach, with a quantitative assessment of the associated uncertainties, the NRC has adopted a risk-informed approach to regulatory decision-making suggesting that an assessment of uncertainty be included in dose assessments (NRC 2000). The NRC's Probabilistic Risk Assessment (PRA) Policy Statement (NRC 1995) states, in part, *"The use of PRA technology should be increased in all regulatory matters to the extent supported by the state of the art in PRA methods and data, and in a manner that complements the NRC's deterministic approach…."*

Even with the use of probabilistic analyses, it should be recognized that not all sources of uncertainty could be, nor need to be, considered in a dose/risk assessment. The primary emphasis in uncertainty analysis is to identify the important assumptions and parameter values that, when altered, could change the decision.

Sensitivity analysis performed in conjunction with the uncertainty analysis is used to identify parameters and assumptions that have the largest effect on the overall result and provides a tool for understanding and explaining the influence of these key assumptions and parameter values on the variability of the estimated dose.

## 5.1 Addressing Sources of Uncertainty

As mentioned above, an important issue in uncertainty and sensitivity analysis is that not all sources of uncertainty can be easily quantified. Of the three primary sources of uncertainty in dose/risk assessment analyses, parameter uncertainty analysis is most mature and will be dealt with quantitatively in the section.

However, mathematical approaches for quantifying the uncertainty in the site conceptual models and future use scenarios are not well developed. For example, it is difficult to predict with absolute certainty the characteristics of a future society. For these reasons, no attempt to formally quantify model or scenario uncertainty is made. To confront these uncertainties an acceptably complete suite of scenarios capturing the plausible range of future uses has been developed and is considered in the assessment (Flavelle 1992). In addition, conceptual site models have been designed and selected to represent the existing features at the GSA site and to conservatively represent the conditions that might be encountered in each scenario. A notable example of this strategy is seen in the decision to depict the site (conceptual site model) with no soil layer covering the existing contaminated layer, even though every future beneficial use conceived in scenarios described would necessitate backfilling the site, effectively introducing a cover layer.

In reality, the uncertainties in the conceptual site model and the scenario selections are captured, to a certain extent, in the parameter uncertainty analysis.

## 5.2 Interpreting Uncertainty Analysis Results

Because the result of the uncertainty analysis provides a distribution of doses and risks, it must be recognized that some percentage of the calculated doses may exceed the regulatory limit. At the same time, because not all parameter distributions are symmetrical and because some parameters are correlated, the mean dose calculated in the uncertainty analysis is not necessarily equal to the deterministic dose calculated[10]. In this analysis, no attempt has been made to derive the DCGL based upon a probabilistic assessment (MADEP specifically requested that the risk calculations be performed using a method they are familiar with—a deterministic method using algebraic mathematics).

A key issue that must be addressed in the treatment of uncertainty is specifying how to interpret the results from an uncertainty analysis in the context of the deterministic regulatory limit. There is no such thing as absolute assurance that the regulatory limit will be met, so regulatory compliance must be stated in terms of a metric of the distribution. Even for the deterministic analysis, it should be recognized that the reported dose or risk is simply one of a range of possible doses that could be calculated for the site. In this analysis, the mean, the $90^{th}$ percentile, and the $95^{th}$ percentile are presented for comparison with the deterministic regulatory limit. Strictly, the mean of distribution must be below the deterministic regulatory limit in order to be compliant and the percentile estimates are used to gauge the margin of safety in the DCGL or the magnitude and probability of potential dose or risk above the deterministic regulatory limit. Risk managers should keep in mind that the parameters used to perform the assessment were selected to represent the critical exposure group (analogous to the Reasonable Maximum Exposure concept), and as such already overstate the expected dose or risk to the average receptor at the site.

## 5.3 Method of Addressing Uncertainty

In the first meeting of the Watertown GSA Site Steering Group, it was agreed that the most current version of RESRAD available at the time the DCGL project began would be used (CENAE 2000a). It was known then that RESRAD version 6.0 had just been made available and that it contained a new probabilistic module that could be used to

[10] It should be noted here that the MADEP preferred risk calculation method is a deterministic method and that the most limiting concentration in soil corresponds to the MADEP regulatory risk limit on the order of $1 \times 10^{-5}$. While it would otherwise be acceptable to revise the concentration/dose relationship based upon the probabilistic measure of expected mean dose, the MADEP deterministic method would be compromised by such an action.

assess the uncertainty in the relationship between a concentration of radioactivity in soil and the dose it might produce. Thus, RERSRAD 6.0 is used as the platform to conduct the uncertainty analysis. It uses the Monte Carlo sampling method, in which input parameter variables are selected randomly from probability distribution functions (PDF). The uncertainty module in the code permits the analyst to define the PDF for each variable of interest by selecting the distribution and it's parameters, and to identify the parameter as either independent or correlated to other input variable.

The following describes the process used to evaluate uncertainty:

1. Each scenario was evaluated using the deterministic module to identify a concentration in soil corresponding to the deterministic regulatory limits (both risk and dose). Additionally, coarse scale sensitivity analysis was performed to zero in on the parameters that had the greatest potential to impact the dose/risk.

2. From these, it was shown that the Occupational Worker scenario yielded the smallest concentration corresponding to a regulatory limit. In fact, the Occupational Worker scenario yields a concentration almost two times lower than the next most limiting scenario.

3. Pathways of interest were identified through preliminary runs of the deterministic module in the code for all the scenarios. These identified the scenario specific pathways that most significantly contributed to dose/risk. The direct exposure pathway, or "ground" pathway was consistently the dominant pathway and by a significant margin. The ingestion of foodstuffs pathway is not included in the Occupational Worker scenario, but in the two scenarios where it is included, it provides very minor contribution to dose and risk. This fact combined with the fact that the Occupational Worker scenario yields a concentration almost two times lower than the next most limiting scenario justify the performance of uncertainty analysis only on the Occupational Worker scenario assessment.

4. Having narrowed the analysis to the Occupational Worker scenario, parameters for incomplete pathways were eliminated from consideration. Single parameter sensitivity analysis identified the remaining parameters that might have a significant impact on the resulting dose. These significant parameters (eighteen of them) were defined in the probabilistic module and contribute to the calculated uncertainty reported in the analysis.

5. Where site-specific knowledge was lacking or where the default parameter distributions were reasonably representative of site conditions or conditions being portrayed in the exposure scenario, the default was used. Where no default distribution is recommended or where discreet knowledge of site-specific conditions exists, an appropriate distribution considering the degree of knowledge of site-specific conditions was selected.

6. The Latin-Hypercube sampling algorithm (a variant of the Monte Carlo sampling technique which has an advantage in that it forces the sampling to occur over the entire range of possible values in the PDF rather than rely on pure random sampling ) was set to obtain three hundred samples (100 samples, repeated three times). The significant sampling takes advantage of the central limit theorem producing a very concise estimate of the central tendency value by use of the mean. This is evidenced by the almost equal measures of mean and median found on pages 19-21 of the uncertainty report in Appendix D.

## 5.4 Inputs to the Uncertainty Analysis

In all, the potential variability in eighteen input parameters was evaluated to arrive at a quantitative measure of the uncertainty in the dose/risk corresponding to the selected soil concentration value (340 pCi/g total uranium). Table 5–1 provides a list of the parameters.

Included in the probabilistic module. Each of the PDFs described in the table contains the deterministic value used in the evaluation. Details describing parameter correlation are identified in the uncertainty report in Appendix D.

*Table 5–1. Parameters Included in the Probabilistic Module for Evaluation of Uncertainty*

| | Parameter | Distribution | Range | Fit |
|---|---|---|---|---|
| **1** | Contaminated zone total porosity | TRUNCATED NORMAL | 0.001 to 0.999 quantiles | MU = 0.425<br>SIGMA = 0.0867 |
| **2** | Contaminated zone b parameter | BOUNDED LOGNORMAL-N | 0.5 to 30.0 | MU = 1.06<br>SIGMA = 0.660 |
| **3** | Contaminated zone erosion rate | CONTINUOUS LOGARITHMIC | Distribution with 4 points<br><br>X( 1) = 5.0E-08 CUM PROB( 1) = 0.0<br>X( 2) = 7.0E-04 CUM PROB( 2) = 0.22<br>X( 3) = 5.0E-03 CUM PROB( 3) = 0.95<br>X( 4) = 0.2 CUM PROB( 4) = 1.0 | |
| **4** | Contaminated zone hydraulic conductivity | BOUNDED LOGNORMAL-N | 4.0-03 to 9.25E+03 | MU = 2.30<br>SIGMA = 2.11 |
| **5** | Evapotranspiration coefficient | TRIANGULAR | 0.60 to 0.750 | MODE = 0.700 |
| **6** | Indoor dust filtration factor | TRIANGULAR | 0.15 to 0.350 | MODE = 0.250 |
| **7** | Runoff coefficient | TRIANGULAR | 0.25 to 0.750 | MODE = 0.470 |
| **8** | Wind Speed | BOUNDED LOGNORMAL-N | 4.00 to 6.80 | MU = 1.69<br>SIGMA = 0.200 |

| | | | | |
|---|---|---|---|---|
| **9** | Mass loading for inhalation | CONTINUOUS LINEAR | Distribution with 8 points<br><br>X( 1) = 0.000 CUM PROB( 1) = 0.000<br>X( 2) = 8.0E-06 CUM PROB( 2) = 0.0151<br>X( 3) = 1.6E-05 CUM PROB( 3) = 0.137<br>X( 4) = 3.0E-05 CUM PROB( 4) = 0.812<br>X( 5) = 4.0E-05 CUM PROB( 5) = 0.950<br>X( 6) = 6.0E-05 CUM PROB( 6) = 0.994<br>X( 7) = 7.6E-05 CUM PROB( 7) = 0.998<br>X( 8) = 1.0E-04 CUM PROB( 8) = 1.00 | |
| **10** | External gamma shielding factor | BOUNDED LOGNORMAL-N | 0.01 to 0.100 | MU = -3.50<br><br>SIGMA = 0.590 |
| **11** | Depth of soil mixing layer | TRIANGULAR | 0.00 to 0.60 | MODE = 0.150 |
| **12** | Density of contaminated zone | TRUNCATED NORMAL | 0.001 to 0.999 quintiles | MU = 1.52<br>SIGMA = 0.230 |
| **13** | Inhalation rate | TRIANGULAR | 4380 to 8400 | MODE = 5500 |
| **14** | Indoor time fraction | BOUNDED EXPONENTIAL | 0.10 to 0.228 | LAMBDA = 10.0 |
| **15** | Soil ingestion | TRIANGULAR | 10.0 to 26.5 | MODE = 18.3 |
| **16** | Outdoor time fraction | BOUNDED EXPONENTIAL | 0.0083 to 0.030 | LAMBDA = 100. |
| **17** | Thickness of contaminated zone | BOUNDED LOGNORMAL-N | 0.0750 to 1.00 | MU = -1.11<br>SIGMA = 0.750 |
| **18** | Exposure duration | BOUNDED EXPONENTIAL | 1.00 to 30.0 | LAMBDA = 0.100 |

## 5.5 Evaluating the Results of the Uncertainty Analysis

The peak dose (and risk) is shown to occur at time zero, that is at the current time, and to drop gradually over time, approaching zero within the 1000-year outlook timeframe. Figures 5–1 & 5–2 show the decreasing trend in the calculated mean and 95$^{th}$ percentile doses over time.

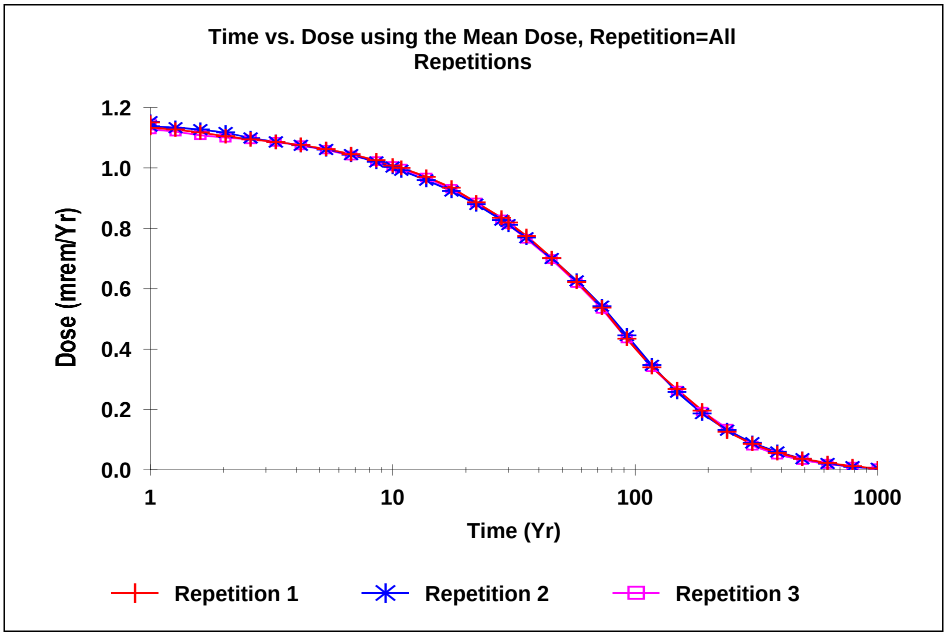


*Figure 5-1. Trend in Annual Dose (mean) vs. Time*

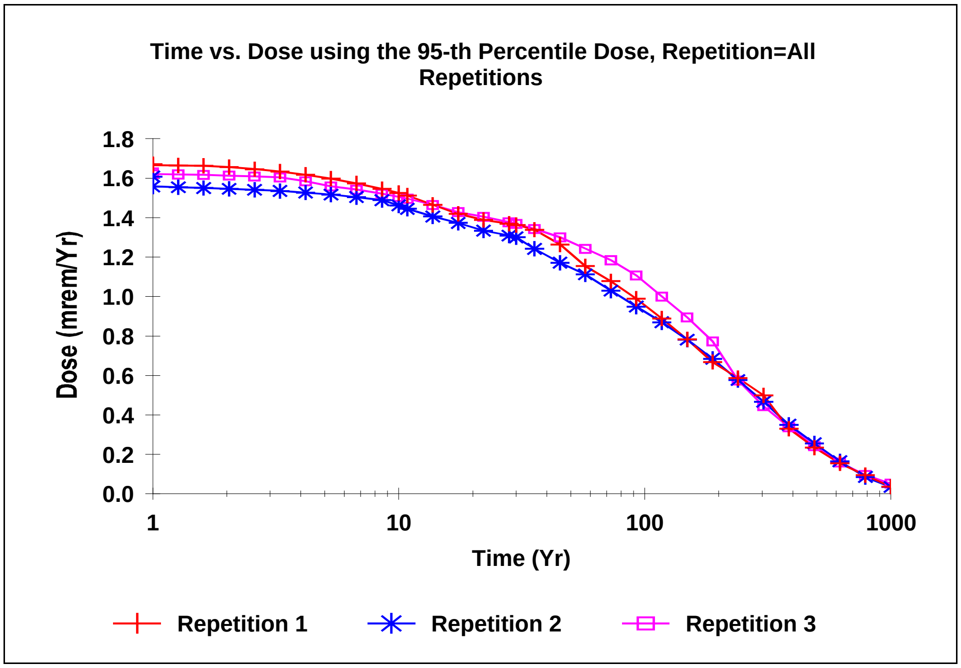


*Figure 5-2. Trend in Annual Dose (95$^{th}$ Percentile) vs. Time*

The mean and 95th percentile dose estimates (and any other percentile metric) are derived from the cumulative probability function that arises from the multiple sampling and calculation iterations performed in the Monte Carlo technique for uncertainty analysis. Graphic presentation of the cumulative probability distributions gives the risk-manager and decision makers an intuitively appealing view of the margin by which the projected doses fall below the regulatory limit. Figures 5–3 shows the cumulative probability for annual total effective dose equivalent for all pathways combined.

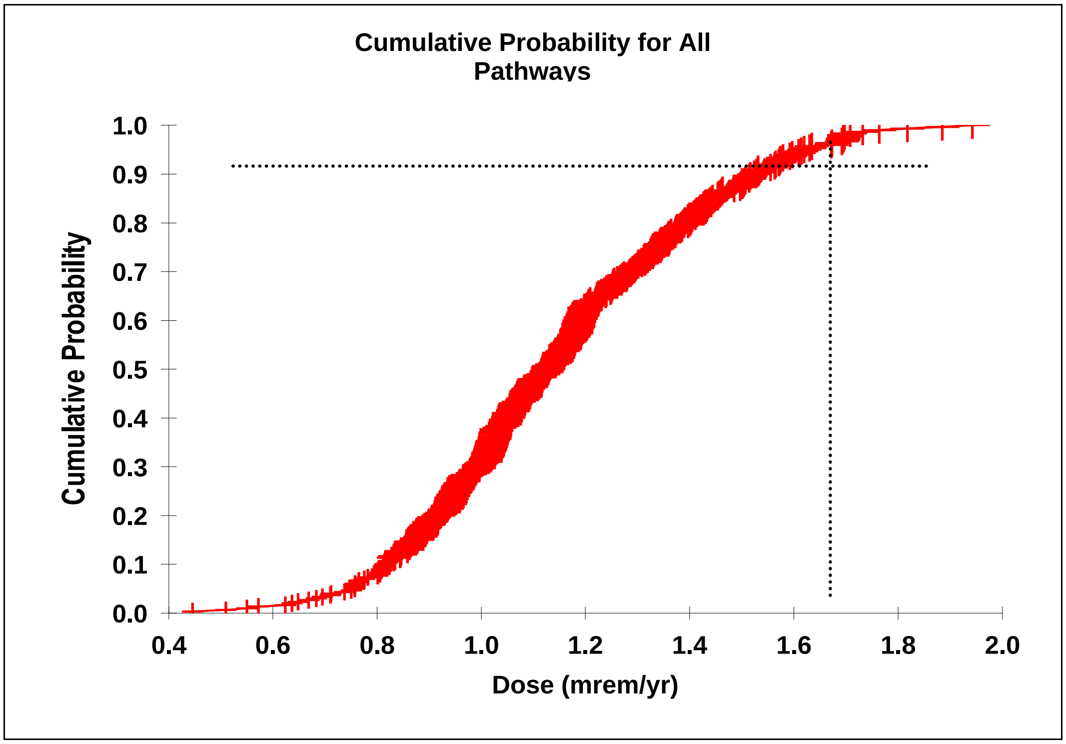


*Figure 5-3. Cumulative Probability for All Pathways*

Table 5–2 summarizes the overall uncertainty in the relationship between the permissible concentration of depleted uranium in soil (340 pCi/g total uranium used to perform the uncertainty analysis) at the GSA site and the calculated dose that might result from exposure at the site. Details describing the uncertainty by pathway, isotope, and measure of detriment (Risk and Dose) are contained in the uncertainty report in Appendix D.

*Table 5–2. Summary of the Measure of Overall Uncertainty*

| Metric | Annual TEDE (mrem/y) | Excess Lifetime Cancer Risk |
|---|---|---|
| Min | 0.45 | $2.95 \times 10^{-7}$ |
| Average | 1.15 +/- 0.27 | $4.38 \times 10^{-6}$ +/- $3.39 \times 10^{-6}$ |
| Maximum | 1.94 | $1.62 \times 10^{-5}$ |
| 80$^{th}$ Percentile | 1.40 | Not Calculated |
| 90$^{th}$ Percentile | 1.53 | Not Calculated |
| 95$^{th}$ Percentile | 1.63 | Not Calculated |
| Regulatory Limit | 25 (10, MADPH) | $1 \times 10^{-5}$ |
| Coefficient of Variation | 23.5% | 77.4% |
| All values shown are at time of peak dose/risk. | | |

Review of Table 5–2 reveals that the most likely annual dose to member of the critical exposure group is more than 8 times lower than the MADPH limit would require and over 20 times lower than the permissible and safe public dose standard specified by the NRC. Further, the best estimate of ELCR ($4.38 \times 10^{-6}$)is 2.3 times less than the permissible cancer risk limit required by the MADEP. In effect, this means that the maximum permissible concentration in soil as calculated with deterministic method is 2.3 times more conservative than the probabilistic method. This is owing to the selection of overly pessimistic values for input parameters in an attempt to control uncertainty on the conservative side of the limit. Having evaluated these uncertainties in a quantitative way, it would be conceivable and defensible to adjust the maximum permissible concentration up by the same factor of 2.3.

### 5.5.1 Contributions to Uncertainty

#### 5.5.1.1 Individual Pathway Contributions to Overall Uncertainty

A series of cumulative probability graphs show the relative contributions of the active pathways to the overall dose. Their range (x-axis) is a measure of the uncertainty attributable to a single pathway. By considering the range covered by each cumulative probability graph relative to the range in the graph shown in Figure 5–3 above, an appreciation for the degree of uncertainty contributed by the individual pathway is gained.

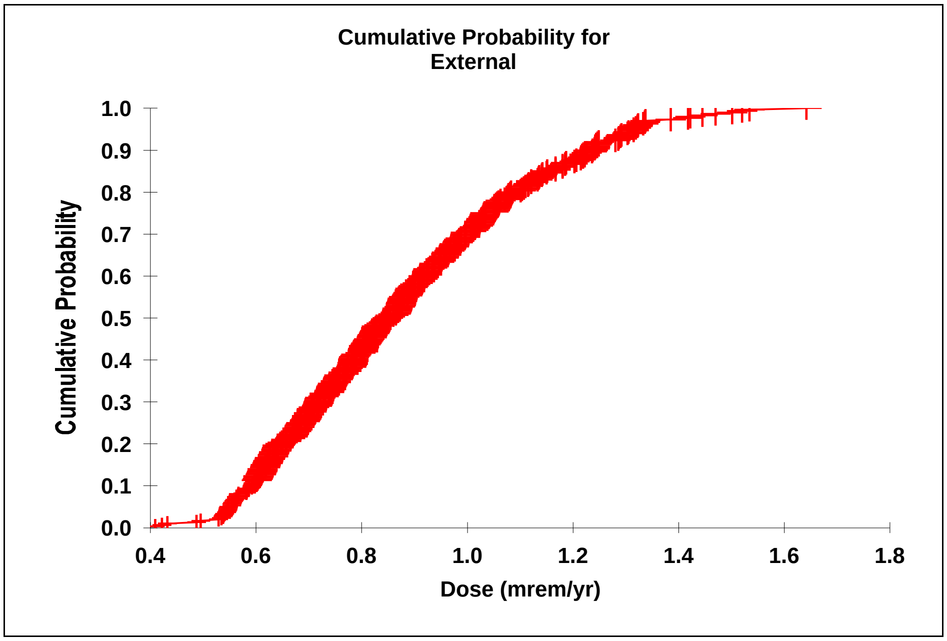


*Figure 5-4. Cumulative Probability for the External (Ground) Pathway*

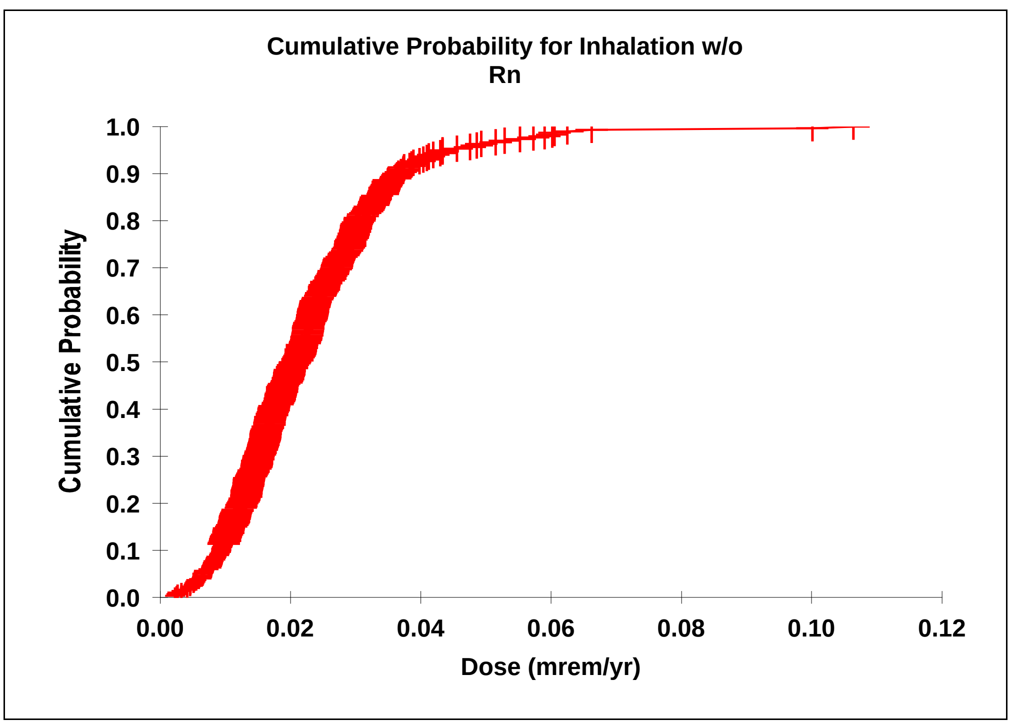


*Figure 5-5. Cumulative Probability for the Particulate Inhalation Pathway*

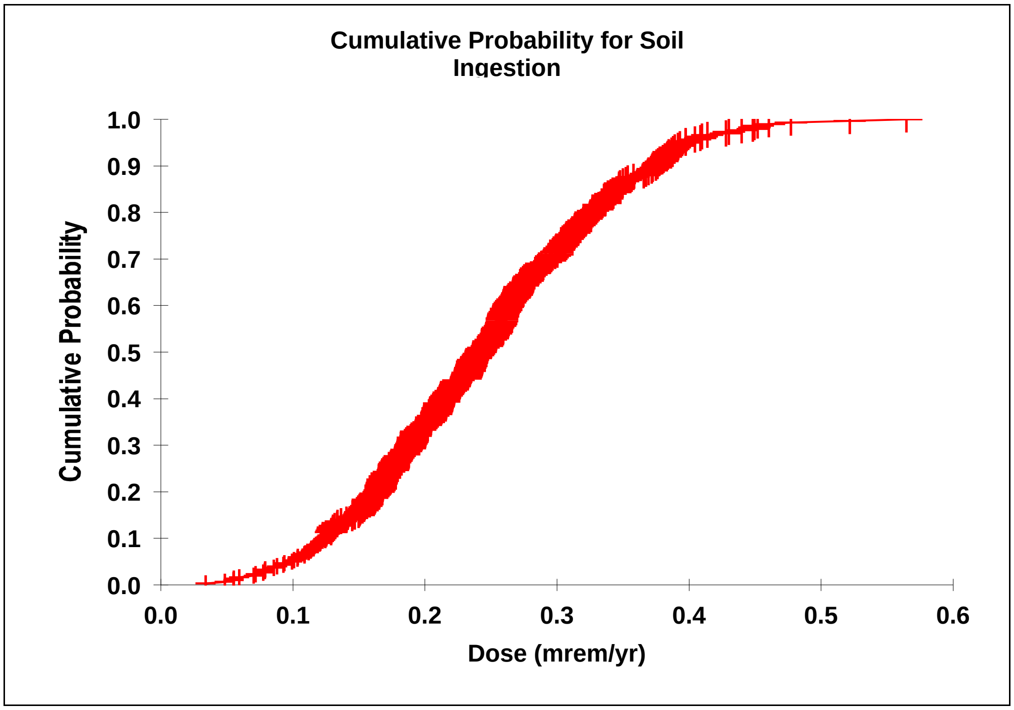


*Figure 5-6. Cumulative Probability for the Soil Ingestion Pathway*

Comparison of the graphs in Figures 5–4 through 5–6 with Figure 5–3 clearly show that the External (ground) pathway is the greatest contributor to dose and to uncertainty. Additional Graphics showing the relationship between the contributions to overall dose from each pathway and for each scenario are provided in Appendix E.

#### 5.5.1.2 Individual Isotope Contributions to Overall Uncertainty

A second series of cumulative probability graphs show the relative contributions of the individual isotopes to the overall dose. This information is subsequently important to the overall process to assess the residual radioactivity at the site because it underscores the isotopes in the depleted uranium mixture that have the greatest impact on dose. By again considering the range covered by each cumulative probability graph relative to the range in the graph shown in Figure 5–3 above, an appreciation for the degree of uncertainty contributed by the individual isotopes is gained.

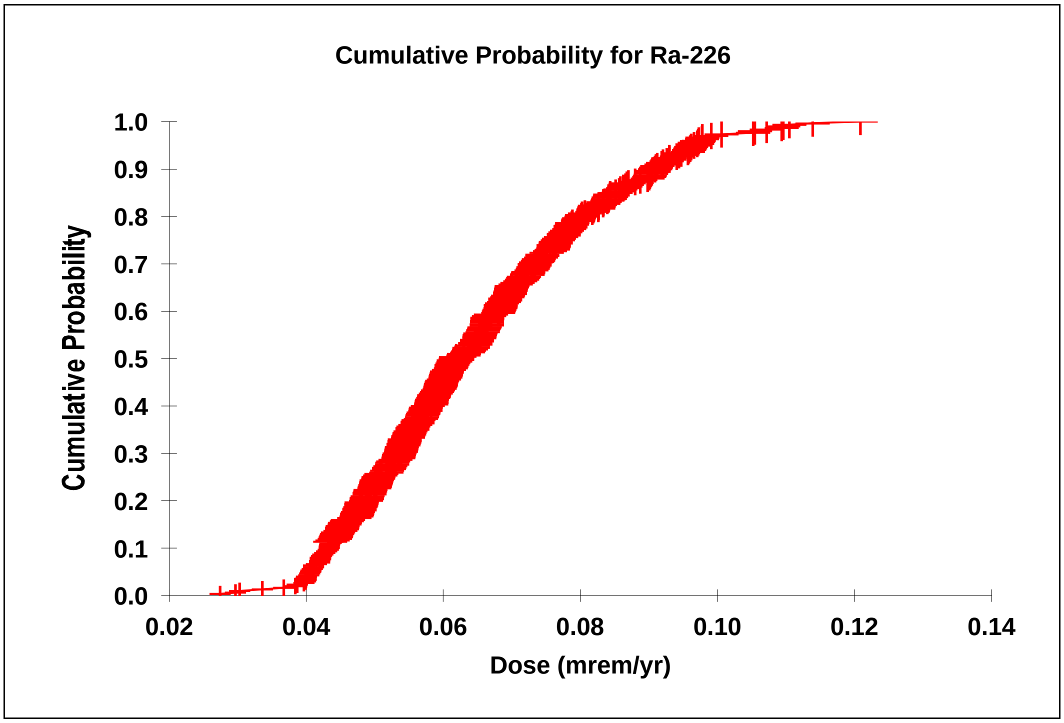


*Figure 5-7. Cumulative Probability for Ra-226*

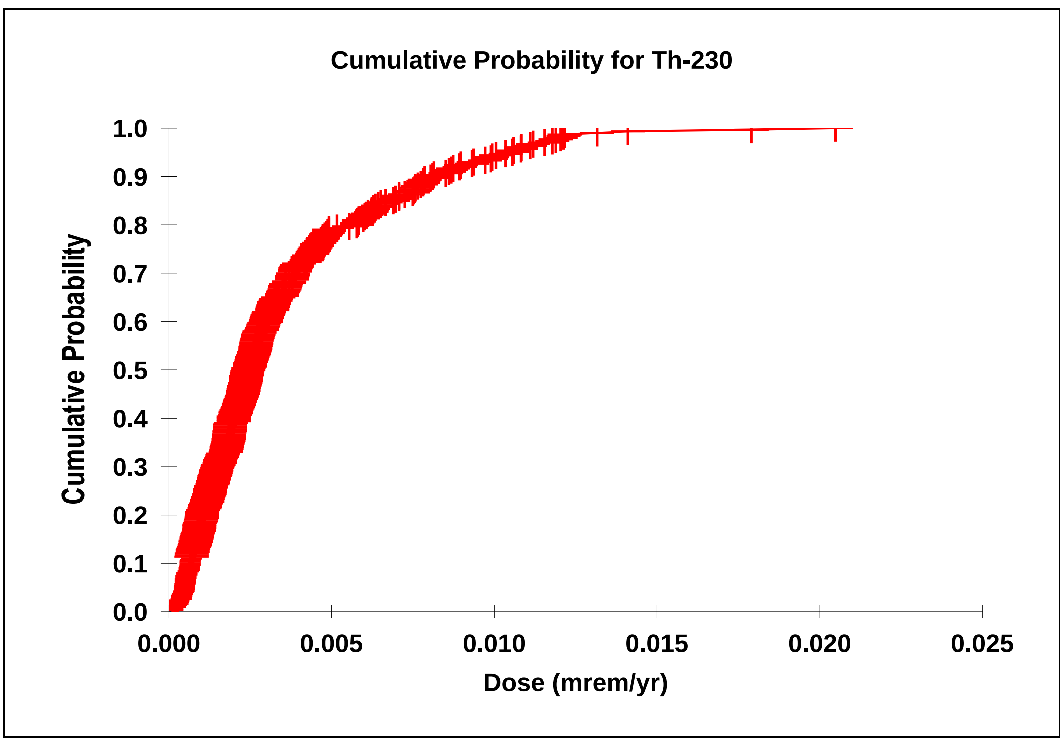


*Figure 5-8. Cumulative Probability for Th-230*

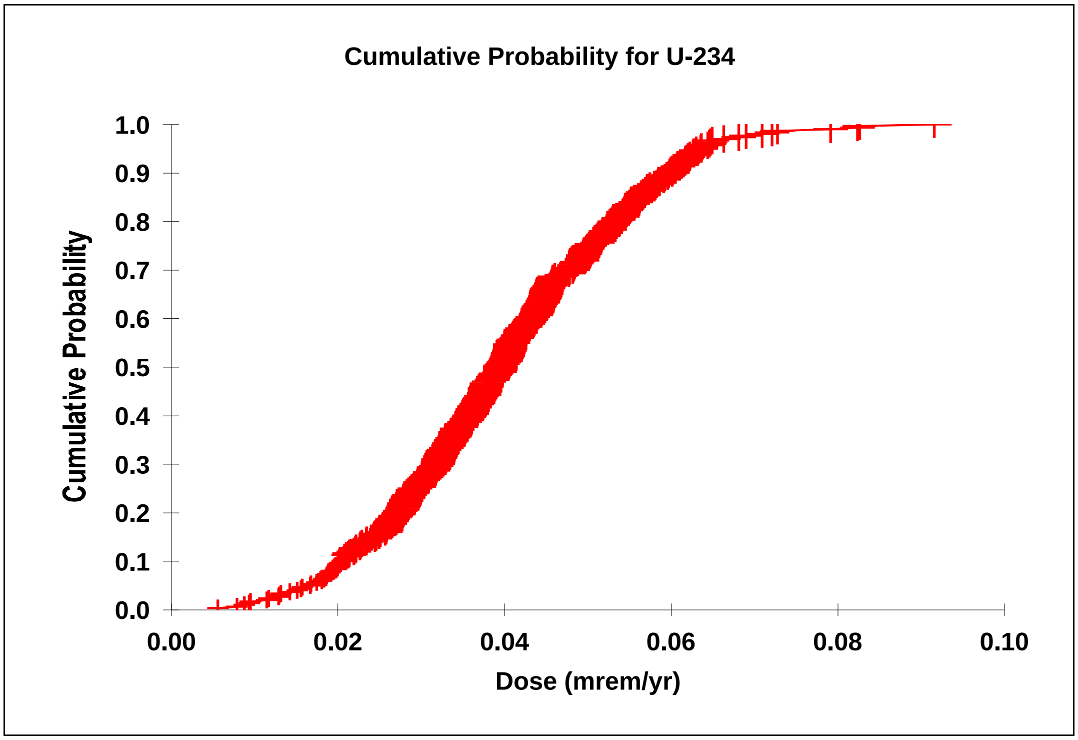


*Figure 5-9. Cumulative Probability for U-234*

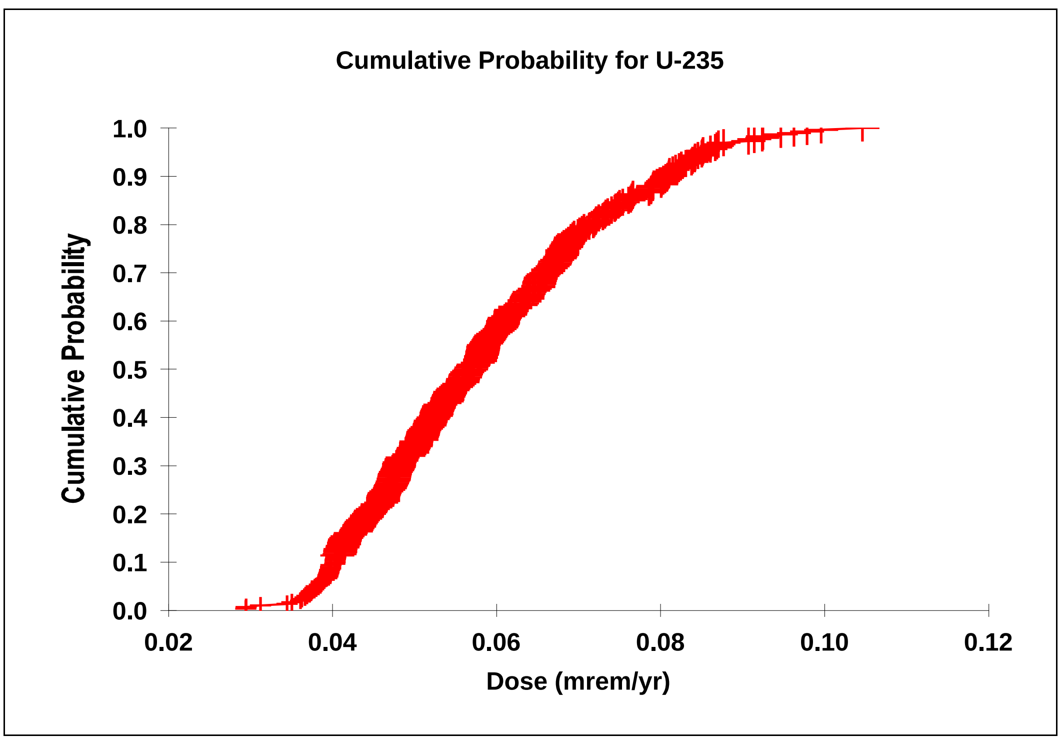


*Figure 5-10. Cumulative Probability for U-235*

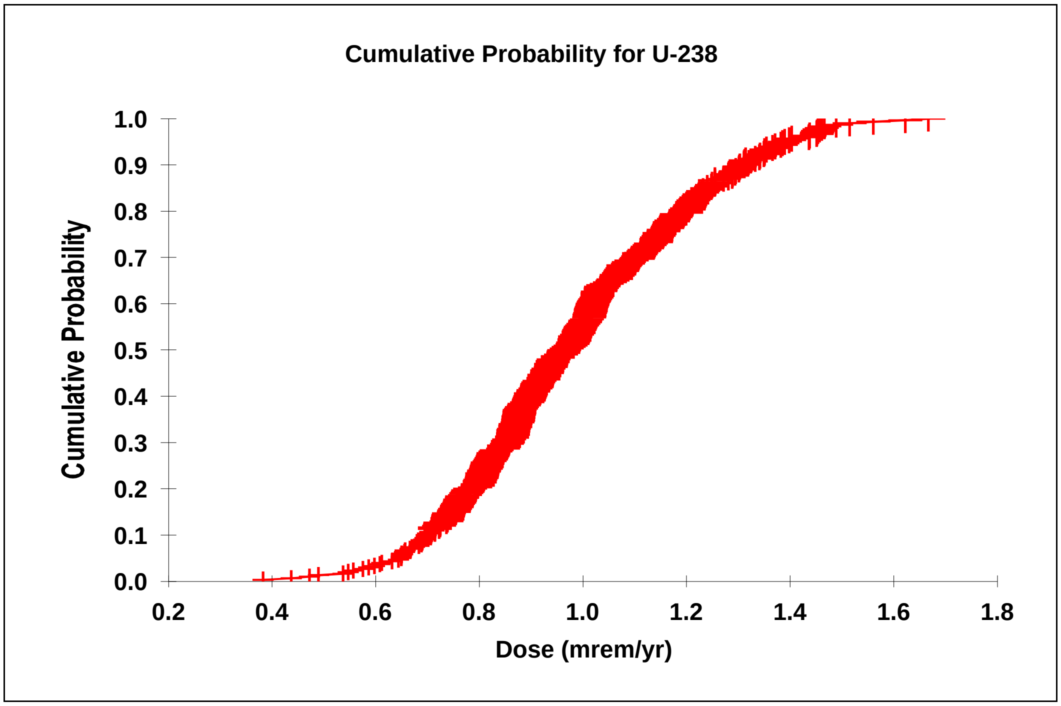


*Figure 5-11. Cumulative Probability for U-238*

Comparison of the graphs in Figures 5–7 through 5–11 with Figure 5–3 clearly shows that U-238 is by far the single isotope with the greatest impact on dose and uncertainty. Additional Graphics showing the relationship between the contributions to overall dose from each pathway and for each scenario are provided in Appendix E.

#### 5.5.1.3 Individual Parameter Contributions to Overall Uncertainty

Obviously, not all of the eighteen parameters included in the probabilistic uncertainty evaluation have the same impact on the resulting dose. Those that have the greatest impact on the calculated dose, however, do have the greatest impact on the uncertainty in the reported dose. The relative importance of the parameters under consideration is seen by their associated correlation coefficients (See Appendix D, Uncertainty Report pages coef. 1-3). The parameters that contribute most significantly to dose and thus to the uncertainty are:

- External gamma shielding factor
- Thickness of contaminated zone
- Indoor & Outdoor time fractions
- Depth of soil mixing layer

Scatter plots of these parameters relating the sampled value from the PDF with the overall dose calculated for that particular sampling event reveal the trend that describes their correlation. The tighter the response and greater the trend, the greater the significance that parameter has on calculation of overall dose and the contribution to overall uncertainty. Figures 5–12 through 5–17 show the scatter plots for the five significant parameters identified above.

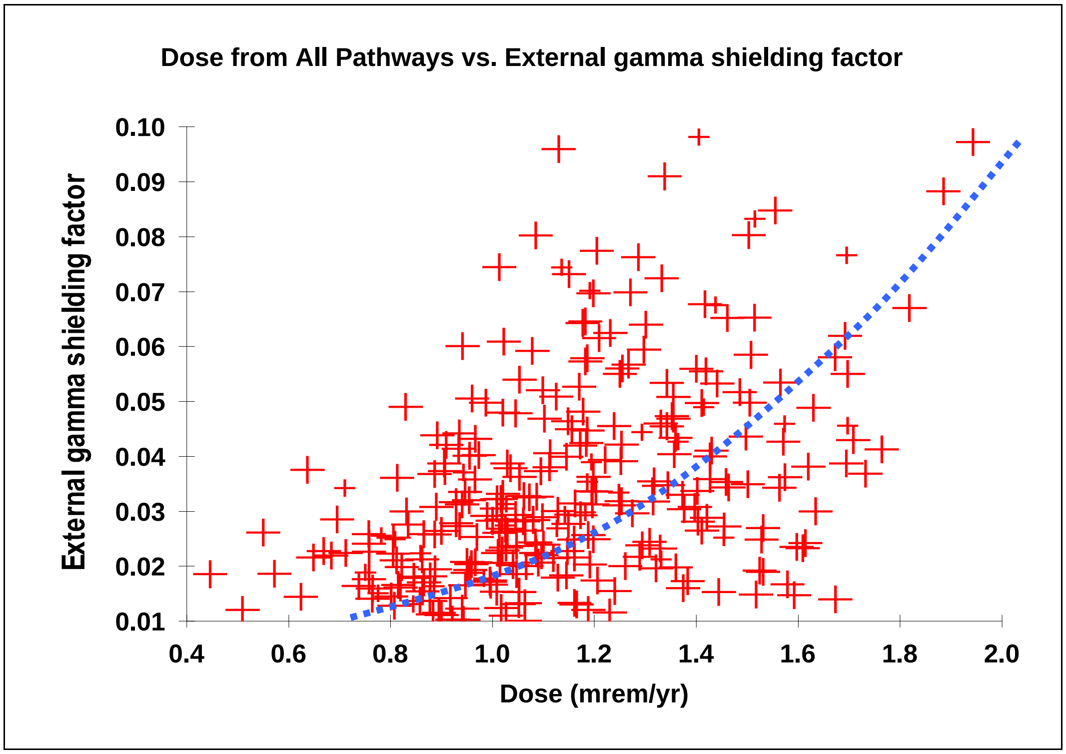


*Figure 5-12. Scatter Plot—External Gamma Shielding Factor*

The correlation between the external gamma shielding factor and the overall dose is stronger when the shielding factor is small. The external gamma shielding factor for this evaluation was derived using the MicroShield gamma transport modeling code (Grove 1996), (See Appendix B).

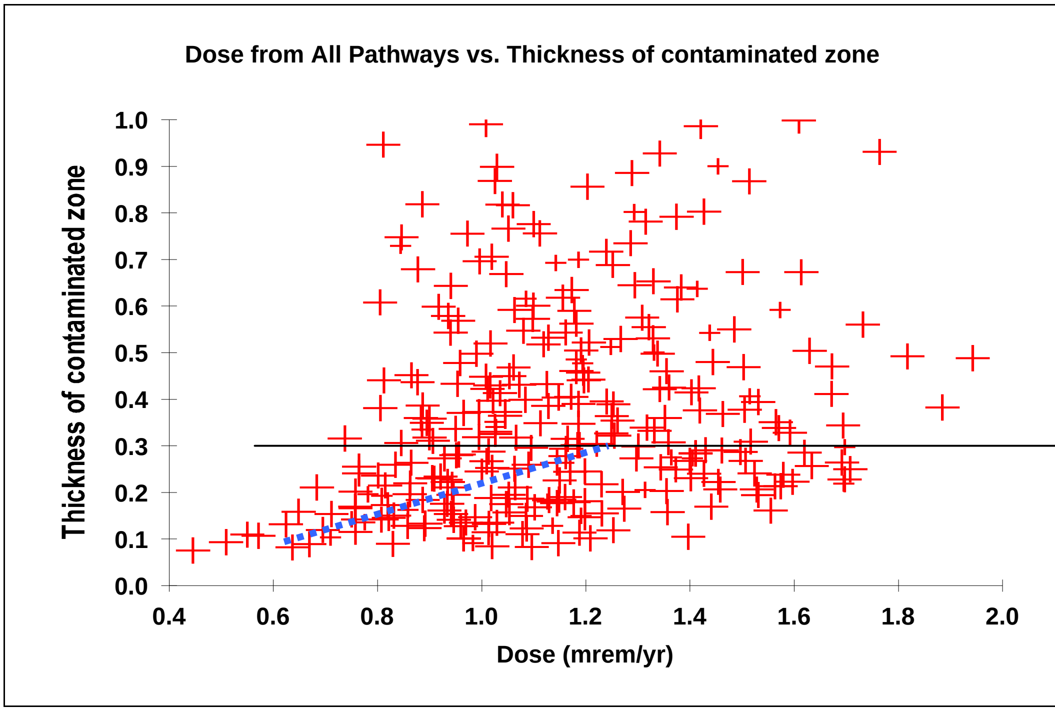


*Figure 5-13. Scatter Plot—Thickness of Contaminated Zone*

Figure 5-13 shows a strong dose dependency on the thickness of the contaminated zone, but only when the contaminated zone thickness is less than 0.3 meters. At thickness greater than 0.3 meters, a marked lack of correlation is exhibited. This is owning to the self-shielding effect of the soil matrix itself. Thicknesses greater than 0.3 meters simply do not contribute to greater dose or risk. An additional figure, (Figure 5-14) derived from the single parameter sensitivity analysis, provides an alternative view of this phenomenon.

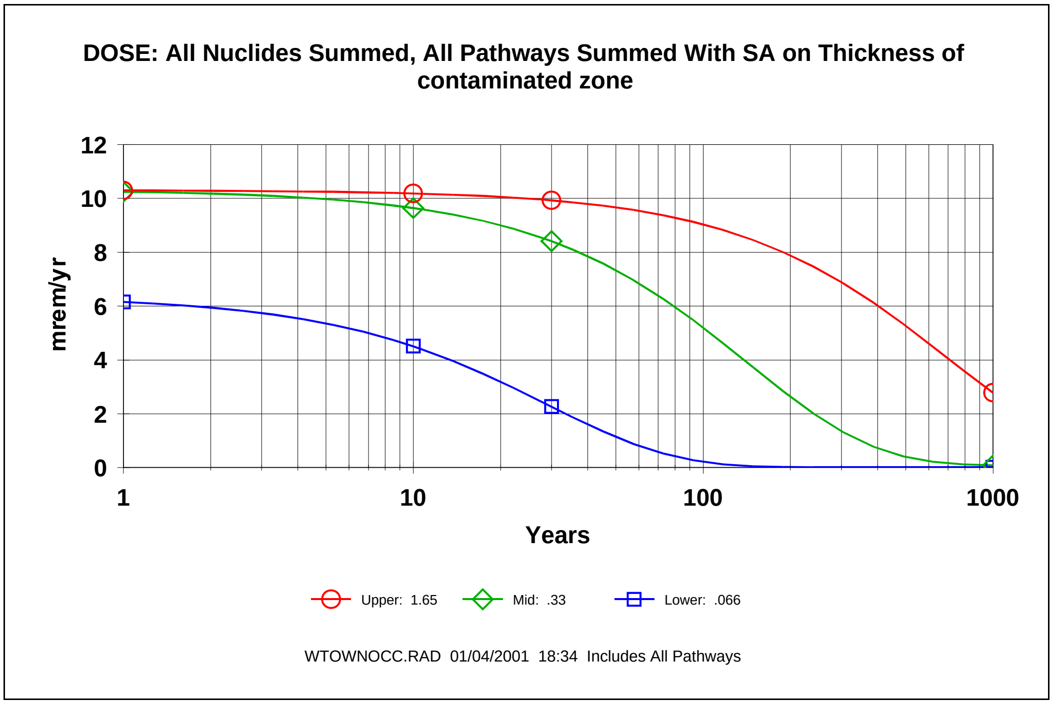


*Figure 5-14. Comparison of Various Contaminated Zone Thickness with Overall Dose vs. Time*

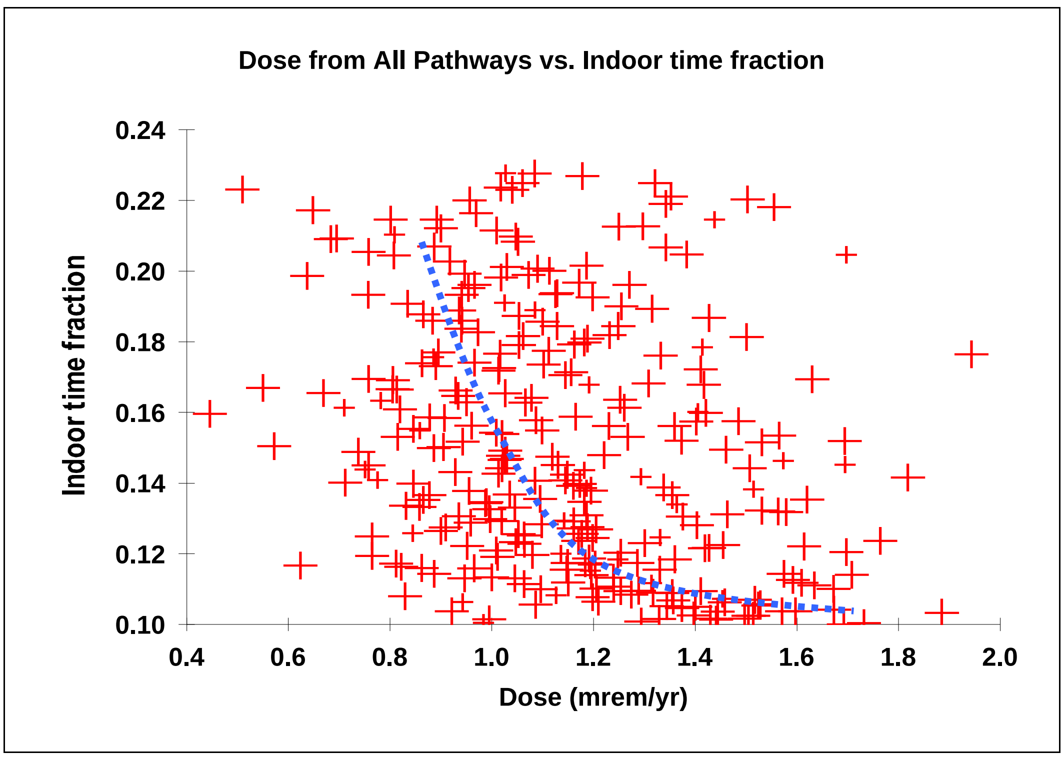


*Figure 5-15. Scatter Plot—Indoor Time Fraction*

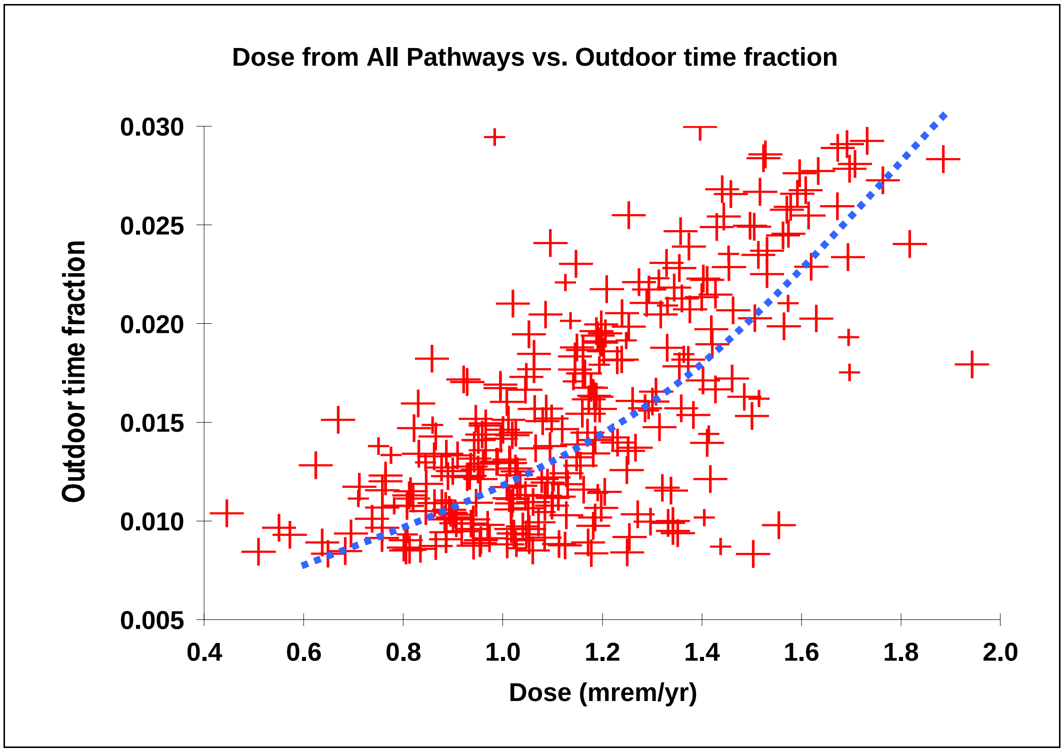


*Figure 5-16. Scatter Plot—Outdoor Time Fraction*

Figures 5-15 and 5-16 reveal an interesting and significant point about the uncertainty analysis. While the scatter plot for the Outdoor Time Fraction parameter shows a much stronger correlation to dose than does the plot for the Indoor Time Factor parameter, notice that the indoor time factor is inversely correlated with dose. This is due to the input rank correlation established between the indoor and outdoor time factors in the uncertainty module. Knowing that the true correlation stems from the external pathway, and that the external pathway is significantly more potent when a receptor is outdoors without the benefit of shielding provided by a structural foundation, it is easy to see why the overall annual dose is highly dependent upon the outdoor time fraction. However, the indoor and outdoor time fractions are dependent upon each other. If a receptor in the occupational worker scenario spends, on average, 8 hours per workday on site, that time must be divided between indoors and outdoors exposure time. To ensure that the Monte Carlo sampling did not randomly select high indoor and high outdoor time factors for the same calculation, the indoor and outdoor time factors were identified as inversely correlated with each other. This precluded unreasonably short exposure days and unreasonably long exposure days.

The next most significant parameter influencing the overall dose was determined to be the depth of the soil mixing layer. This parameter is used in calculating the depth factor for the dust inhalation and soil ingestion pathways (and for calculating foliar deposition for the dietary ingestion pathways when used). The depth factor is the fraction of resuspendable soil particles at the ground surface that are contaminated. It is calculated by assuming that mixing of the soil will occur within a layer of the specified thickness. Ironically, because no cover material was assumed to be present in any of the conceptual site models and scenarios, variation in the depth or thickness of the mixing layer introduced no uncertainty but did contribute significantly to the dose from the soil ingestion pathway. It's impact on the overall dose, however, is quite small. This is evidenced by the notable lack of trend or correspondence in the scatter plot in Figure 5-17.

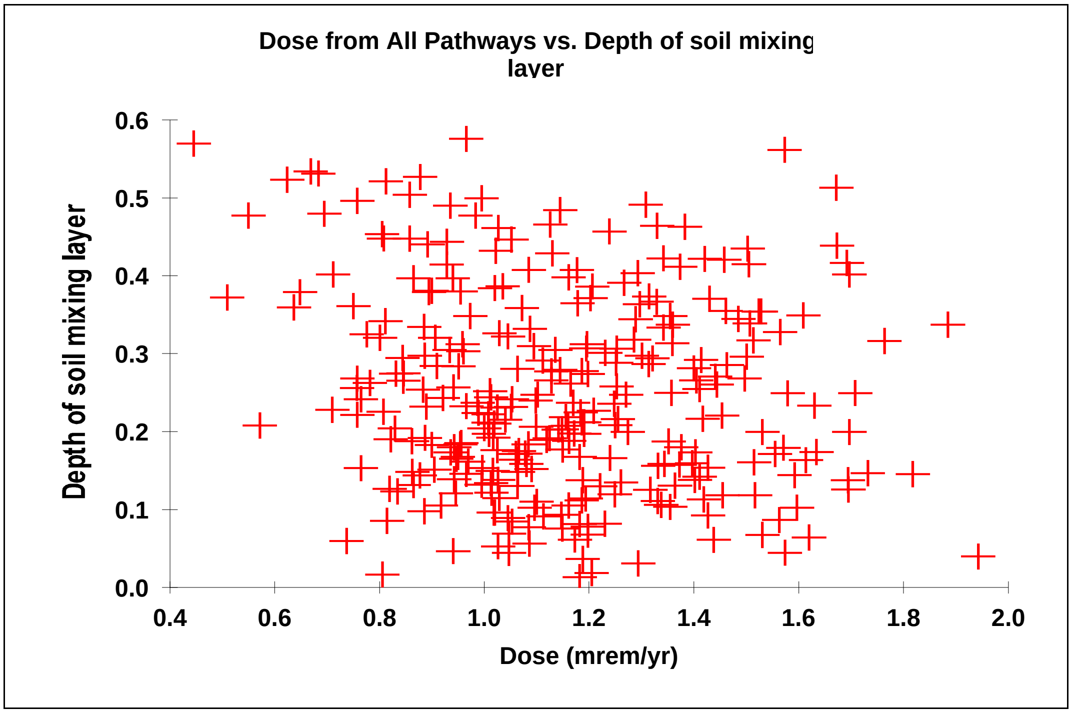


*Figure 5-17. Scatter Plot—Depth of Soil Mixing Layer*

None of the other individual parameter scatter plots are presented in this section because they exhibited even less dependency of dose on variation in the parameter's value.

One additional parameter–unique to the cumulative risk calculations–that is significant is exposure duration. This parameter does not show up as significant in the ranking of the correlation coefficients found in the computer generated uncertainty report in Appendix D because the focus in the report is the uncertainty on dose, which is normalized to an annual value. The variability in this parameter is responsible for the relative difference in the coefficients of variation for dose as compared to risk (See Table 5-2).

R-Square is called the "coefficient of determination" and can vary between 0 and 1. It provides a measure of the variation in the dependent variable (Dose or Risk) explained by regression on the independent variables with 0 indicating no identified dependency on the selected parameters and 1 indicating complete dependency. The high overall R-Squared value (0.83 to 0.95, depending upon the regression method used) is indication that the significant contributors to uncertainty have been identified in the analysis.

## 5.6 Qualitative Uncertainty

The foregoing summary description of the uncertainty in the dose/risk assessment focused on the aspects that could be quantified. There are however additional sources of uncertainty that are not easily measured in a quantitative sense. As is usually the case when these types of uncertainty arise, pessimistic assumptions in values used to describe the site conceptual model and exposure pathways in the deterministic calculations were used to force the uncertainty to the conservative side of the regulatory limit. The major bounding assumptions responsible for producing this additional conservative bias are identified in Table 5–3 with a qualitative remark indicating the affect on receptor dose and risk estimates.

*Table 5–3. Additional Sources of Uncertainty in Computer Modeling*

| Source of Uncertainty | Remark |
|---|---|
| The site conceptual model assumes that the entire site is contaminated at the concentration input in the computer model (340 pCi/g Total uranium). | Investigation data collected to date and reported in the HSA indicates that the majority of the site (particularly the southern half) is not contaminated to any significant degree. Many measurements made in this area were below detectable levels or comparable to the regional background concentration. Concentrations on the site that are divergent from background are, in fact, isolated to relatively localized areas and few measurements have exceeded the concentrations modeled; most notable among these is the burn area. This means that the source concentrations (amount of radioactivity) used in the model are likely to be substantially higher than existing average concentrations. An overestimated source concentration will overstate receptor doses and risk from all pathways. |
| The site conceptual model assumes that no cover material overlies the existing contaminated layer during future use scenarios. | The shallow depth of the nearest groundwater at the site and the prevalence of marshy low lying areas makes the site unsuitable for construction of substantial structures such as would be required to support a recreation center or urban housing. In order to create ball fields or parking lots, site grading along with the import of fill materials to facilitate drainage would be required. Further, such uses would necessitate the addition of gravel, concrete, or asphalt in the case of parking facilities or topsoil, clay, and sod for ball fields. Any community gardening scenario would require the import of 1 to 2 feet of loamy topsoil suitable for gardening. A layer of material covering over the contaminated zone would represent a significant attenuation in the dose to any receptor from all pathways. This conservatism alone causes the overstatement of dose and risk by perhaps as much as an order of magnitude. |

## 5.7 Conclusion

The uncertainty analysis performed for the dose and risk calculations used to derive a DCGL for the GSA site indicates that the key factors and parameter values affecting receptor dose and risk estimates (source strength, pathway migration, and receptor exposure characteristics) have been overstated such that a strong conservative bias is evident. It further shows that major sources of uncertainty in the modeling have been identified and either quantified or intentionally set to yield a conservative bias. Risk management decisions based upon the results of these modeling estimates will reflect this conservative bias and likely err on the side of safety.

Based on the conservative bias identified in the quantitative uncertainty calculations and supported by the additional conservative bias described in section 5.6 above, risk-managers may legitimately determine to permit higher soil concentrations than are indicated by the deterministic method calculations alone.

# 6.0 Summary and Recommendations

## 6.1 Proposed Site Specific DCGL Values

The dose/risk evaluation described in this report provides the risk managers and decision makers with the substantive basis necessary to set and approve a site specific permissible concentration standard, the DCGL, derived from the applicable regulatory limits for public dose and risk. When approved, the proposed DCGL will become the permissible concentration limit for unrestricted release of the Watertown GSA site from radiological controls (by NRC and MADPH) and from consideration (due to the presence of residual radioactivity) under the MCP.

The evaluation establishes a constrained public dose limit of 10 mrem/y[11] and an excess lifetime cancer risk limit on the order of 1 x 10-5 from which the DCGLs are derived. Constraining the allowable dose to 10 mrem/y provides the risk managers and decision makers with a built-in margin to safety, acknowledging that the basic public dose limit is nominally set at 100 mrem/y. Additionally, the proposed DCGLs have been derived with a level of conservatism commensurate with the extent of the hazard and uncertainty in the estimation tools. Therefore, the use of a constrained dose limit coupled with the use of conservative techniques in deriving the DCGL(s) provide the risk managers with a very conservatively derived permissible depleted uranium-in-soil concentration that ensures protection of human health. Table 6–1 identifies the possible candidate DCGLs derived from the foregoing analysis.

[11] The basic public dose limit is 100 mrem/y considering all sources and all pathways. The NRC's decommissioning standard establishes a constrained site-specific value of 25 mrem/y to provide reasonable assurance that public exposure to sources other than those that might be present at a single site, such as the GSA site, will not produced a combined dose to a member of the public in excess of the basic public dose limit. In this evaluation, the Commonwealth of Massachusetts has further constrained the site-specific dose limit by requiring that a member of the critical exposure group be exposed to no more than 10 mrem/y on the average.

*Table 6–1. Candidate DCGLs*

| Exposure Scenario [c] | DCGL [a, b] | Remark |
|---|---|---|
| ***Construction Worker*** – Contact intensive exposure from handling, excavating, and grading site soils as a first step to constructing future facilities at the site. | 560 pCi/g | Relates to an annual dose of 10 mrem/y TEDE to an earth worker on a major construction excavation site. |
| ***Occupational Worker*** – Exposure to a worker who spends their entire secular work year on the site. The worker is assumed to perform a range of duties both indoors and outdoors on the site. | 340 pCi/g | Relates to a $1 \times 10^{-5}$ ELCR to the full time, career recreation facility worker. |
| ***Recreational Visitor/User*** – Exposure to a member of the public who uses the developed facilities at the site year-round. | 725 pCi/g | Relates to a $1 \times 10^{-5}$ ELCR to the person who lives nearby and uses the facilities periodically every week, year-round. |
| ***Community Gardener*** – Exposure to a member of the public who uses a small plot of public land at the site that has been set-aside for community gardening and consumes vegetation grown there. | 635 pCi/g | Relates to a $1 \times 10^{-5}$ ELCR to the urban resident who lives nearby and uses a community gardening facility periodically every week during the growing season for 30 years and consumes the vegetation grown there. |

a. All DCGL values are average total uranium radioactivity.
b. All DCGL values presented in this table were derived using the deterministic dose/risk assessment method. As presented in Section 6.0, the deterministic method likely overstates the potential dose and risk corresponding to these candidate DCGL concentrations. Considering this, the concentrations presented as candidate DCGLs more closely correspond to the maximum likely dose/risk (See Section 6.0 and Appendix D) to a member of the critical exposure group rather than to the average dose or risk to this group.
c. The Urban Residential scenario is not included here because it is not considered to be a likely future use for the site. The evaluation performed for that scenario is not intended to be used to derive a site-specific DCGL.

Each of the scenarios modeled (except urban resident scenario) is credible and foreseeable and each result in a concentration corresponding to the either the 10 mrem/y TEDE dose limit or the ELCR limit on the order of $1 \times 10^{-5}$. Considering the potential future land-use scenarios, the limiting scenario (the one that results in the smallest concentration yielding 10 mrem/y or ELCR on the order of $1 \times 10^{-5}$) is the Occupational Worker scenario. Therefore, the proposed $DCGL_W$ (340 pCi/g total uranium) is the one associated with the Occupational Worker scenario.

If the land use does evolve to the point where the conditions described by the Occupational Worker scenario are possible, the conditions described in the Recreational Visitor/User will also have been established, and the Construction Worker scenario will have already occurred. However, in selecting the Occupational Worker scenario as a basis for establishing the DCGL(s), the more conservative and protective concentration limits will have been chosen. Thus, ensuring that the site is safe for a future full-time, career occupational worker at a recreational facility also ensures that the site is safe for workers involved in construction work at the site, for visitors to and users of the proposed recreation facilities at the site, and for nearby residents who may use portions of the site set aside for community gardening.

## 6.2 Summary of the Uncertainty and Conservatism in the Proposed DCGL

The proposed DCGL values have been derived with industry standard modeling tools specifically designed to assess exposures to residual radioactivity. The RESRAD modeling code is recognized as an industry standard, and is accepted for use by the NRC, DOE, and EPA for modeling dose and risk to individuals exposed to radioactivity originating in soils.

Conservatism has been built into the modeling by conscientiously selecting exposure factor values that err on the side of safety when confronted with uncertainty in the selection of input parameters. In order to provide the risk managers and decision makers with insight as to the degree of conservatism associated with the proposed DCGLs, a quantitative uncertainty analysis addressing the key variables and their effect on the relationship between dose and concentration was performed (See Section 6.0 and Appendix D). The uncertainty analysis shows that the deterministic point estimates used to derive the DCGL are very conservative[12]. In fact, this analysis indicates that the candidate DCGL for the most limiting scenario, the Occupational Worker, is unlikely to produce a dose greater than 2 mrem/y (the 99$^{th}$ percentile value emerges as 1.88 mrem/y) or risk greater than 1 x $10^{-5}$.

The uncertainty analysis focused on the limiting scenario, *Occupational Worker Scenario*, recognizing that the key exposure parameters are comparable in each of the scenarios. Considering the magnitude and range of candidate DCGLs that emerged from the individual scenarios in comparison with the 340 pCi/g DCGL identified for the occupational worker scenario, it is evident that there is considerable additional conservatism for these other exposure scenarios. Risk managers can expect at least the same magnitude of conservatism and safety in their derivation.

This degree of conservatism in the proposed DCGL accommodates the remote possibility that uranium tailings might have been deposited in a small area at the north end of the site (Harding ESE, 2000). To assess the impact that tailings might have on the dose and risk potential at the site, a separate analysis was performed. The source term concentrations for Ra-226 and Th-230 (isotopes prevalent in tailings but virtual non-existent in depleted uranium) were modified for the Occupational Worker scenario to include 5 pCi/g of each isotope. The 5 pCi/g radium concentration corresponds to the EPA promulgated surface soil standard for soils contaminated with uranium mill tailings (40 CFR 192). All other source concentrations and exposure parameters were unchanged. The analysis shows that the site would still be in compliance with the regulatory limits with the added residual radioactivity associated with tailings. The most likely annual dose a member of the critical exposure group with 5 pCi/g of tailings added to the 340 pCi/g of total uranium associated with depleted uranium is 2.17 mrem/y and the most likely ELCR is on the order of 1 x 10-5. The suite of reports

[12] Readers are reminded that a conservative DCGL is one that establishes a low concentration correlation with the allowable dose limit. Thus, the smaller the probabilistic estimate of dose (or risk) for the concentration presented, the greater assurance the risk manager has that 10 mrem/y (or ELCR on the order of 1 x $10^{-5}$) limit will not be exceeded.

detailing the assessment of dose and risk with tailings residue is contained in Appendix F.

## 6.3 Recommendation

The DCGL proposed has been derived using appropriate techniques in accordance with governing guidance, standards, and regulations in concert with the input of a panel of experts and stakeholders assembled into a steering group and representing the interests of the stakeholders, the CENAE, the U.S. Army, and State and federal regulators. The recommended $DCGL_W$ value for the Watertown GSA site is 340 pCi/g total uranium. It is recommended that this value be approved and adopted as the site-specific permissible concentration.

# 7.0 References

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# 8.0 Glossary of Terms, Acronyms, and Abbreviations

ABB-ES ........ ABB Environmental Services
Ac-228........... actinium 228
AEC............... Atomic Energy Commission
ALARA......... As Low as Reasonably Achievable
AMMRC ....... Army Materials and Mechanics Research Center
AMTL ........... Army Materials Technology Laboratory
ANL .............. Argonne National Laboratory
ARL-WT....... Army Research Laboratory
AST............... Above-ground Storage Tank
ATF............... Bureau of Alcohol, Tobacco, and Firearms
AUL .............. Activity Use Limitation

Bgs ................ below ground surface

CENAE ......... US Army Corps of Engineers, New England District
CFR............... Code of Federal Regulations
CMR.............. Code of Massachusetts Regulations
CNSI............. Chem-Nuclear Services Inc.
cpm................ counts per minute
Cs-137........... cesium 137

DCF............... Dose Conversion Factor
DCGL............ derived concentration guideline level
$DCGL_W$ ......... derived concentration guideline level, survey unit average (median) concentration corresponding to the permissible limit
DEA .............. Drug Enforcement Administration
DOE .............. Department of Energy
dpm................ disintegration per minute
DQO.............. Data Quality Objective
DU................. depleted uranium

ELCR ............ Excess Lifetime Cancer Risk
EPA............... (United States) Environmental Protection Agency (See USEPA)

FBI ................ Federal Bureau of Investigation
FGR............... Federal Guidance Report
FR.................. Federal Register
FUDS ............ Formerly Utilized Defense Site
FUSRAP........ Formerly Utilized Site Remedial Action Program

$g/cm^3$ ............. grams per cubic centimeter
GM ................ Geiger-Mueller detector
GSA............... General Services Administration

HLA .............. Harding Lawson Associates
HPGe............. high purity germanium
HSA............... Historical Site Assessment

ICRP.............. International Commission on Radiological Protection
ISGS.............. in-situ gamma spectrometry
IRS ................ Internal Revenue Service

K-40 .............. potassium 40
kg/y................ kilo-grams per year

$m^2$ .................. meters squared
$m^3/y$ ............... cubic meters per year
MADEP......... Massachusetts Department of Environmental Protection
MADPH ........ Massachusetts Department of Public Health
MAMDC ....... Massachusetts Metropolitan District Commission
MARSSIM .... Multi-Agency Radiation Survey and Site Investigation Manual
MCP .............. Massachusetts Contingency Plan
MDA ............. minimum detectable activity
MDC.............. minimum detectable concentration
MED.............. Manhattan Engineer District
MK/SEG........ Morrison Knudsen and Scientific Ecology Group, Inc.
μg/g ............... micro-grams per gram
$\mu g/m^3$............. micro-grams per cubic meter
μR/h............... micro-Roentgens per hour
mg/d .............. milli-grams per day
mph................ miles per hour
mrem ............. milli-Roentgen equivalent man
mrem/y .......... mrem per year (See mrem)
MSL .............. Mean Sea Level
MTL .............. (Army) Materials Technology Laboratory (See AMTL)

NCRP ............ National Council on Radiation Protection and Measurements
NED .............. (Army Corps of Engineers,) New England Division
NRC .............. (United States) Nuclear Regulatory Commission (See USNRC)

PAL ............... Public Archaeology Laboratory Inc.
pCi/g.............. pico-Curies per gram
PDF ............... Probability Density Function
ppb................. Parts per Billion
ppm................ Parts per Million
PRA............... Probabilistic Risk Assessment

Ra-226........... radium 226
RME.............. Reasonable Maximum Exposure

SAP ............... Sampling and Analysis Plan

TEDE ............ Total Effective Dose Equivalent
Th-230........... thorium 230
Th-234........... thorium 234
TOR............... Top of Riser

U+d................ uranium plus daughters
U-233 ............ uranium 233
U-234 ............ uranium 234
U-235 ............ uranium 235
U-236 ............ uranium 236
U-238 ............ uranium 238
USEPA.......... United States Environmental Protection Agency
USNRC ......... United States Nuclear Regulatory Commission
UST ............... Underground Storage Tank