Derivation of the Site-Specific Soil DCGLs

CE Windsor Site
2000 Day Hill Road
Windsor, Connecticut

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DERIVATION OF THE SITE-SPECIFIC SOIL DCGLS
CE WINDSOR SITE
WINDSOR, CONNECTICUT

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EXECUTIVE SUMMARY

This report presents Derived Concentration Guidance Levels (DCGLs) for the Combustion Engineering, Inc. (CE) Site located at 2000 Day Hill Road in Windsor, Connecticut[1]. 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 U.S. Nuclear Regulatory Commission (USNRC).

The Site was formerly used to perform design, engineering support, and manufacturing of uranium fuel components for both commercial and government reactors. Lesser functions supported at this Site included thermo-hydraulic testing of non-irradiated nuclear reactor plant components, radiographic assay and testing of materials, and servicing of radiologically contaminated reactor plant components. Because of these past activities, enriched uranium (principally) and reactor byproduct materials (minimally) may have been released to the soils at the site via incidental particle transport mechanisms and by approved discharges via industrial waste discharge lines. Byproduct materials are defined as materials generated through the nuclear fission process. They nominally include both activation products and fission products.

ABB manufactured nuclear (uranium) fuels for both commercial reactors and for government reactors. As a result, there is shared responsibility between ABB and the Federal government for the cleanup of environmental contaminants at the Site. The Federal government has assigned responsibility for the clean up of residual radioactivity at the Site as a result of government sponsored or contracted activities to the U.S. Army Corps of Engineers (USACE) under the Formerly Utilized Site Remedial Action Program (FUSRAP).

The objective of both ABB and USACE is to decontaminate and decommission the facilities and lands that supported these missions in accordance with applicable federal and state requirements and regulations such that the radioactive materials license held by ABB can be terminated.

ABB has entered the Site into the U.S. Environmental Protection Agency's (USEPA) Voluntary Corrective Action (VCA) program under the provisions of the Resource Conservation and Recovery Act (RCRA). Previous Site characterization activities indicate the presence of detectable quantities of hazardous or potentially hazardous materials residues, including uranium, polynuclear aromatic hydrocarbons (PAH), and heavy metals.

The USNRC regulates the residual radioactivity on the Site resulting from former commercial operations, while the residual radioactivity at the Site resulting from past

[1] The Site (or CE Windsor Site), as defined for the purpose of deriving the Site-specific clean-up standards, excludes the North Tract, which was previously shown to be non-impacted, and the parcel upon which the U.S. Navy's S1C facility was formerly Sited, which has already been decommissioned and released. There may, however, be residual byproduct radioactivity in soils outside the former S1C facility parcel (e.g., the site brook) as a result of S1C effluents.

Federal government operations are subject to the requirements of FUSRAP, which nominally follows the USEPA's Comprehensive Environmental Response, Compensation, and Liability Act (CERCLA) remediation and release process.

To release this property from regulatory control and terminate the Site's radioactive materials license, the risks to human health associated with potential exposure to radioactivity originating at the Site must be evaluated and demonstrated to be within acceptable limits. To comply with USNRC criteria for Site release, the residual radioactivity at the Site must not contribute an annual radiation dose in excess of the USNRC criteria and must be reduced to concentrations that are as low as reasonably achievable (ALARA) taking into account existing socio, political, and economic factors.

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. An assessment of chemical contamination, the RCRA Facility Investigation (RFI), was approved by the USEPA. Assessments of the human health and ecological risks associated with potential exposures to chemical substances at the Site have also been performed. Radiological contamination at the Site is being addressed following Multi-Agency Radiation Survey and Site Investigation Manual (MARSSIM) guidance through the preparation of a Historical Site Assessment and the preparation of the DCGLs presented in this document.

The USNRC has a promulgated a 25 mrem/y criterion for radiological release for unrestricted use while the State of Connecticut has determined that a potential future dose of 19 mrem/y is protective of human health and satisfies the requirements of its RSR regulatory framework. The DCGLs presented in this report are based on conservative assumptions and provide limits that are consistent with those required by both the USNRC and the State of Connecticut.

It is anticipated that future uses of the Site will be roughly consistent with its current use (commercial, light industrial uses). The current land use in surrounding area is a mixture of commercial, light industrial, warehousing, office park, residential, municipal landfill, and commercial farming. The land use is trending toward commercial and industrial uses.

Commercial farming of both consumable produce and cigar wrapping tobacco does occur in the near vicinity of the CE Windsor Site. Such commercial farms are characterized as large fields that are planted with a single commercially viable crop (such as tobacco, corn, cucumbers, etc.) and is harvested in bulk and trucked to a commercial wholesale buyer for subsequent distribution. These farms do not support residential habitation or subsistence. Locally, such farms are known as "truck" farms.

Future residential use of the land is considered unlikely given: 1) the current land-use trend; 2) the current community growth, planning, and development strategies of the local municipality; and 3) the economic value of the land for sustained commercial use.

Although unlikely, it is reasonable and credible to consider that the land might be used for locating residential dwellings in the future[2].

Subsistence (resident) farming was also considered as a future use scenario but is thought to be highly improbable. In addition to the factors that make a residential use unlikely, subsistence farming is improbable at this Site because: 1) the general population is moving away from subsistence farming; 2) the amount of land required to support subsistence farming is economically infeasible considering the value of the land; and 3) the population demographics are consistent with east coast urban/suburban uses. In spite of the evidence supporting the conclusion that subsistence farming is highly improbable as a reasonable future use at the site, a resident farming scenario has been included in this evaluation to meet Connecticut Department of Environmental Protection (CTDEP) requirements.

DCGLs were, therefore, calculated for six different potential future exposure scenarios:

- An occupational worker employed at a facility located at the Site;
- A commercial truck farmer;
- A construction worker participating in a construction or excavation project at the Site;
- A recreational visitor using open park-like space (jogging, biking, etc.) at the Site;
- A residential occupant in a suburban residential setting; and
- A residential occupant in a resident farm setting.

The DCGLs for the CE Windsor Site have been calculated using the RESRAD 6.0 modeling code. Each of the scenarios modeled results in a concentration corresponding to both the 19 mrem/y and 25 mrem/y dose limits. Considering the potential future land-use scenarios, the limiting scenario (the one that results in the smallest concentration yielding 19 mrem/y) is the Residential Farm scenario. Based on this scenario, the proposed uranium soil DCGL is 557 pCi/g total uranium and the proposed reactor byproduct DCGL is 5.0 pCi/g Co-60 in soil.

Conservatism has been built into the prospective dose modeling (and thus the proposed DCGL) by conscientiously selecting exposure factor values that err on the side of safety when confronted with uncertainty in the selection of input parameter values.

The DCGL proposed has been derived using appropriate techniques in accordance with governing guidance, standards, and regulations. In addition, stakeholders including the Town of Windsor, CTDEP, and USACE have all provided input into the parameter selection and scenario derivation. It is recommended that these soil concentration values be approved and adopted as the Site-specific permissible soil concentrations for the entire CE Windsor Site, as defined and as applicable.

[2] In qualitatively identifying the likelihood of occurrence of a future suburban residential land use, it is intended that the reader understand that there are more likely future uses. The term unlikely here does not indicate that the likelihood of occurrence is so small that the suburban residential land use setting is implausible or prohibitively unlikely.

1.0 INTRODUCTION

1.1 CE WINDSOR SITE

Between 1956 and 2001, the Combustion Engineering, Inc. (CE) Windsor Site was used (at various times) to conduct and support research and development as well as manufacturing of nuclear fuels. Such activities make the Site subject to regulatory requirements governing the use and termination of such use of radioactive materials.

The CE Windsor property is located in the Town of Windsor, eight miles north of Hartford, Connecticut (Figure 1–1). The entire property consists of approximately 600 acres and is located at 2000 Day Hill Rd. in Windsor, CT. The portion of the property under consideration for radiological site release and for which the soil (including sediment) derived concentration guideline levels (DCGLs) are designed consists of approximately 500-acres[3]. The portion of the property subject to the DCGLs derived in this report (hereafter referred to as the Site) is shown on Figure 1–2.

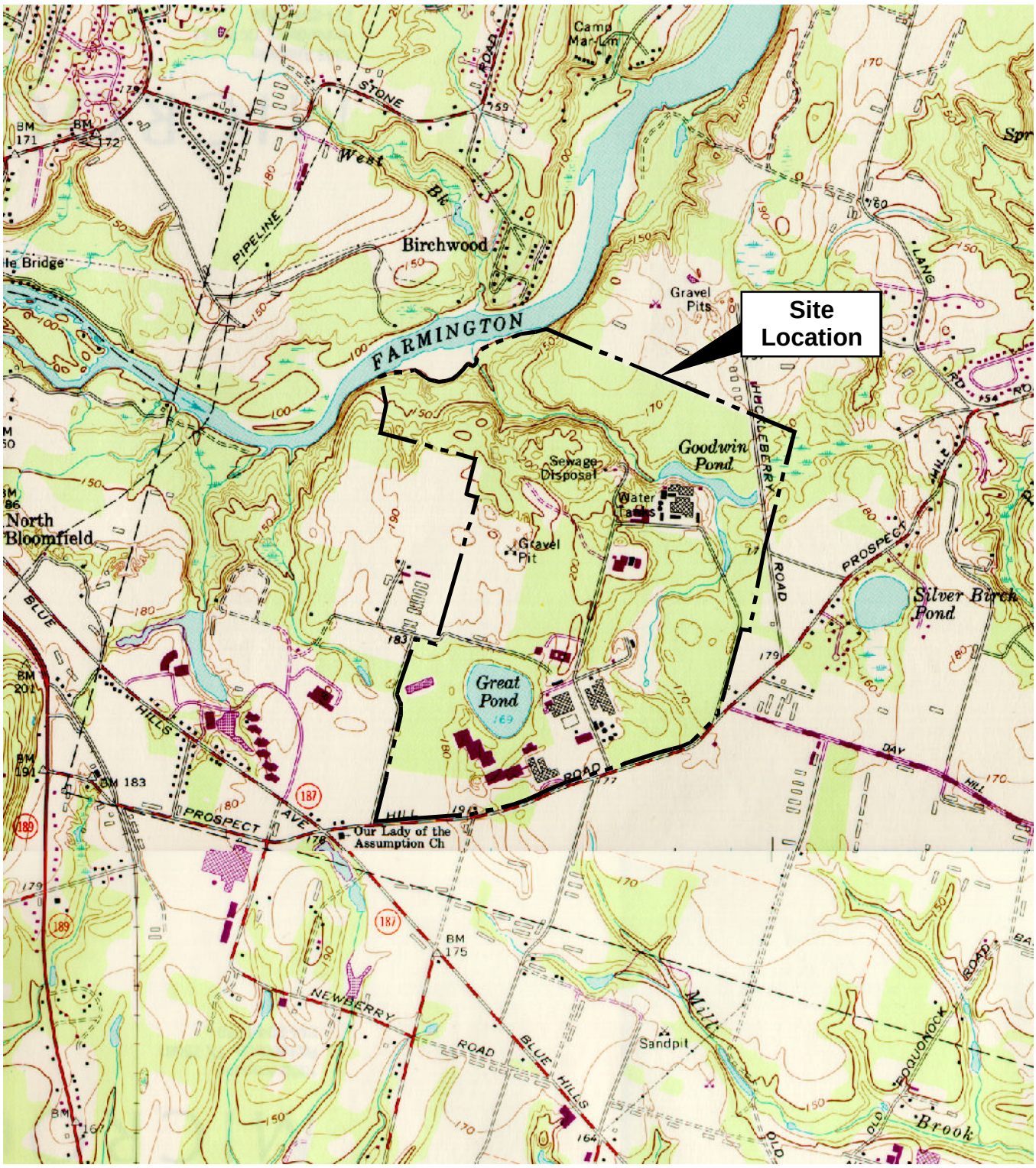
1.2 SITE DESCRIPTION

The Site is industrially zoned by the Town of Windsor, and is located in a Mixed Land Use area of Hartford County (Harding ESE, 2003). Nearby land uses are primarily commercial, commercial agricultural, industrial, and residential. Much of the northern and western portions of the property are wooded.

The CE property is bordered by Day Hill Road (formerly known as Prospect Hill Rd.) and agricultural and commercial land to the south; tobacco fields and a sand and gravel quarry to the west; the Windsor/Bloomfield Sanitary Landfill and Recycling Center (Landfill) to the north; and forested land as well as residential and commercial developments to the east. The northwest corner of the property is bordered by the Rainbow Reservoir portion of the Farmington River. The Site brook and northern shore of Goodwin Pond roughly mark the northern boundary of the portion of the property under consideration. Within the Site boundary (but excluded as part of the Site) is a 10.6-acre enclave known as S1C. This area is currently owned by the United States Government.

Surface water bodies are present on the Site and include: Great Pond, located on the southwestern end of the Site; Small Pond, located east of the Site buildings; Goodwin Pond, located on the northeast boundary of the Site; and the Site brook, located on the northern boundary of the Site. The Site brook flows to the northwest from Goodwin Pond into the Farmington River at the northwest boundary of the Site.

[3] The Site, as defined for the purpose of deriving the Site-specific clean-up standards (DCGLs), excludes the North Tract, which was previously shown to be non-impacted, and the parcel upon which the U.S. Navy's S1C facility was formerly Sited, which has already been decommissioned and released.



QuadrangleLocation

Map Source:USGSMap,WindsorLocks, Conn
Dated1964, Photorevised 1984.

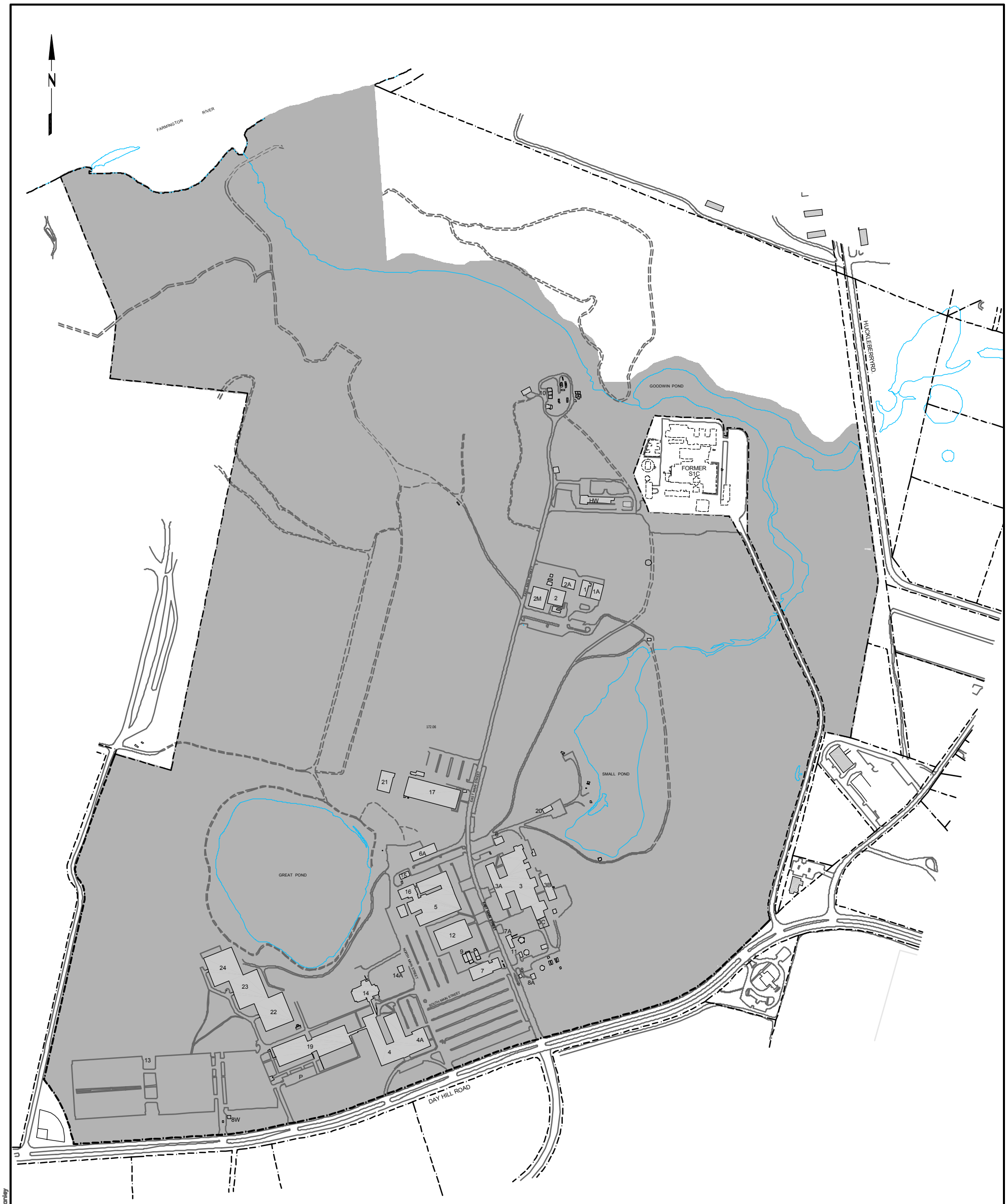
FIGURE 1-1
SITE LOCATION MAP
DERIVATION OF THE SITE-SPECIFIC SOIL DCGLs
CE WINDSOR SITE
WINDSOR, CONNECTICUT

Scale in Feet

0 2,000 4,000

MACTEC, Inc.

W2001012(c) 2



LEGEND

- PARCEL OF LAND INVESTIGATED
- EXISTING STRUCTURE
- FORMER STRUCTURE
- PROPERTY LINE
- WATER
- UNIMPROVED ROAD
- GROUND SURFACE CONTOUR (ELEVATION, FEET MSL)

NOTES:

1. BASE MAP PROVIDED BY METROPOLITAN DISTRICT COMMISSION.
2. CONNECTICUT STATE PLANE NAD 1983.

0 150 300 600 FEET

FIGURE 1-2
DEMARCATION OF SITE BOUNDARIES
DERIVATION OF THE SITE-SPECIFIC SOIL DCGLs
CE WINDSOR SITE
WINDSOR, CONNECTICUT

MACTEC, Inc.

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1.3 OBJECTIVE OF THIS REPORT

The objective of the CE Windsor Site owner (ABB) is to appropriately cleanup (remediate) both chemical and radiological residues that are present at the Site such that the property is available for beneficial reuse and redevelopment. The regulations governing the radiological constituents of concern require that residual radioactivity at the Site be reduced to concentrations that will be safe for future occupation and uses. To this end, and in accordance with the governing regulations, this report derives and documents the concentration(s) of residual radioactivity that correspond to safe public exposure levels. Non-radiological constituents of concern are addressed in other documents.

1.3.1 Property Disposition Options

Past use of the Site involved the use of hazardous and potentially hazardous materials, most notably the manufacturing of nuclear fuel components from enriched uranium. Other past site activities have included research and testing on fuel components fabricated from natural or depleted uranium and testing and repair of reactor plant components. Previous site characterization activities indicate the presence of detectable quantities of hazardous (or potentially hazardous) materials and residues, including uranium, reactor byproduct radionuclides, solvents, polynuclear aromatic hydrocarbons (PAHs), and heavy metals (Harding ESE, 2002). The Site is engaged in a Voluntary Corrective Action (VCA) for non-radiological hazardous constituents under the United States Environmental Protection Agency (USEPA's) Resource Conservation and Recovery Act (RCRA) regulations. The United States Nuclear Regulatory Commission (USNRC) regulates the residual radioactivity on the Site resulting from former operations involving licensed radioactive materials. The State of Connecticut has indicated that it has statutory authority to regulate residual radioactivity at the site under the State's Land Transfer Act. In addition, the USACE has been assigned responsibility under Formerly Used Sites Remedial Action Program (FUSRAP) for the cleanup and disposition of the materials in areas of the Site attributed to past activities conducted for the Federal government at the Site.

The purpose of this report is to derive the concentration guideline levels for residual radioactivity in soil (including sediment) at the Site. To obtain approval to release the Site from regulatory control (either under USNRC licensing authority or Connecticut Land Transfer Act provisions), the potential human health impacts associated with exposure to radioactive materials originating at the Site must be evaluated and demonstrated to be within acceptable limits.

The evaluation of potential risks posed by substances present at the Site is being carried out on two parallel tracks. Chemical (non-radiological) contamination at the Site is being evaluated through a series of investigations under the RCRA VCA Program. A thorough assessment of the degree and extent of chemical impacts to the Site has been presented in the Site's RCRA Facility Investigation Report (RFI) (Harding ESE, 2003). The RFI report has been approved by the USEPA. In addition, assessments of human health and

ecological risks associated with potential exposures to chemical substances at the Site have been performed. Residual radioactivity at the Site is being addressed following the USNRC's decontamination and decommissioning protocol (with consideration for the State of Connecticut's criteria as published in the State's Remediation Standard Regulations [RSRs] [CTDEP, 2002]), which includes the preparation of a historical site assessment, the preparation of the DCGLs presented in this document, and demonstration of compliance with approved DCGLs using a statistically-based sampling and measurement regimen such as that described in Multi-Agency Radiation Survey and Site Investigation Manual (MARSSIM) guidance (USNRC, 2000a).

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 residual radioactivity at the Site.

- ***Remove 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 and might significantly impact soil erosion stability in the Farmington River watershed. Another disadvantage that should not be underestimated is the unnecessary generation of a substantial volume of excavated soil that would have to be handled and disposed of as radioactive waste.

- ***Derive and apply Site-specific soil concentration guidelines based on the health hazard (potential 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 could be left in place on the Site. A Site-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 (USNRC, 1999). The derivation of a site-specific concentration guideline is specifically called for by the State's RSRs in the case where the specific pollutant of concern is not listed (as is the case with radionuclides). Any Site-specific concentration guideline proposed is subject to review and approval by the USNRC and the State of Connecticut. Assuming that the actual average residual radioactivity concentration present in soil on the Site is below the approved Site-specific guideline(s), this option has the obvious advantages of directly satisfying all applicable regulations, avoiding significant soil excavation and the accompanying environmental damage, minimizing the amount of radioactive waste requiring special disposal, and potentially saving taxpayer costs (in the case of the FUSRAP areas of responsibility) compared with the preceding option.

The latter option is the chosen path for this Site.

1.4 STAKEHOLDER INPUT

ABB has taken a number of steps to ensure that stakeholders have had an opportunity to influence and comment upon the process for deriving a dose-based soil concentration guideline for the Site. Stakeholders who have been involved in the process at various times include the USACE, CTDEP, USEPA, and the Town of Windsor Department of Public Health.

A series of meetings were held to share information and to allow stakeholders to comment on the development of the dose-based soil concentration guidelines. Stakeholders provided input on the parameters and scenarios that would be used in the modeling. They also provided input on the maximum permissible annual public dose upon which the DCGL would be based. The goal of these meetings was to allow stakeholders an early influence in the process (ABB, 2001a; 2001b).

Subsequent to these meetings, stakeholders continued to provide comments and offer recommendations to the process. CTDEP continued to provide guidance and recommendations through a series of letters and meetings (CTDEP, 2003a; 2003b). USEPA provided guidance on requirements for combined radiological and chemical risk. The Town of Windsor continued to be helpful regarding assistance with the review of future town plans for the area of the Site.

These stakeholder inputs are considered key to the process of developing acceptable derived soil concentration guideline values for the Site.

1.5 REGULATORY FRAMEWORK FOR DEVELOPMENT OF THE DCGL

The USNRC has the regulatory licensing authority and federal responsibility to determine that the radiological criteria for release of this Site from USNRC licensing have been achieved. In this capacity, the USNRC will review and ultimately approve appropriate soil DCGLs for the Site.

While the State of Connecticut does not currently have a statute in place specifically addressing the decommissioning of a site that has operated under a nuclear materials license (or other authority as described in the Atomic Energy Act 1954, as amended by the Energy Reorganization Act 1974), CTDEP has communicated its intent to regulate sites having residual radioactive material to concentrations that would be protective of a total annual dose of 19 mrem (CTDEP, 2002). Additionally, the State's Attorney General's Office has determined that the provisions of the Connecticut Transfer Act (CTAG, 2003) together with the standards adopted by the State in regulation (CTDEP, 1996) provide a legally enforceable basis for the State's regulatory authority to approve DCGLs for residual radioactivity in soils following decommissioning.

1.5.1 U.S. Nuclear Regulatory Commission Regulations

The USNRC regulatory criteria for license termination and release of real property with residual radioactive material are contained in the U.S. Code of Federal Regulations (CFR), Title 10, "Energy," Parts 20, 30, 40, 50, 51, 70, and 72, *Radiological Criteria for License Termination* (USNRC, 1997a).

The applicable USNRC 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. In addition, the licensee must demonstrate that potential future doses arising from residual radioactivity at the site have been reduced to levels that are as low as reasonably achievable (ALARA).

1.5.2 State of Connecticut Regulations

CTDEP in conjunction with the Connecticut Department of Public Health (CTDPH) developed a radiological remediation standard for use in Connecticut that is consistent with other carcinogenic risks in Connecticut. CTDEP has adopted the radiological remediation standard of 19 millirem/year total effective dose equivalent to the average member of the critical group plus As Low As Reasonably Achievable (ALARA). This action is consistent with and authorized by Connecticut Remediation Standard Regulations (RSRs) and is necessary to ensure that the risk posed by sources of ionizing radiation does not exceed the cumulative excess lifetime cancer risk accepted by CTDPH. This radiological remediation standard is to be used at all sites in Connecticut when they undergo remediation or decommissioning activities. This new requirement is also applicable as a Connecticut radiological applicable or relevant and appropriate requirements (ARARs) for the Comprehensive Environmental Response, Compensation, and Liability Act (CERCLA) process.

1.5.3 FUSRAP Impacted Areas

Although the radioactive materials associated with the FUSRAP areas of responsibility are not technically licensed, USACE must consider USNRC regulations, requirements, and standards when remediating sites. A cooperative arrangement between the USNRC and the USACE is documented in an inter-agency memorandum of understanding (MOU) in which the USACE has committed to conduct radiological response actions and subsequent closeout of a FUSRAP Site to meet at least the (USNRC) standards required under 10 CFR 20.1402 (USNRC, 2001).

1.5.4 Approach to Deriving the Site-Specific Guideline

Figure 1–3 summarizes the overall approach used to establish the Site-specific soil (including sediment) DCGLs and determine whether the Site meets the radiological release criteria. For the Site, the first step to obtaining approval of a dose/risk-based limit is to establish the acceptable dose limits.

The USNRC 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. A number of federal agencies (in regulation) as well as nationally and internationally recognized bodies recommending safe levels for public exposure (International Commission on Radiological Protection [ICRP], 1990; National Counsel on Radiation Protection and Measurements [NCRP], 1993) specify a limit on annual public radiation dose contribution of 100 mrem/y. Since it is possible that public exposure will occur from more than one site (such as the CE Windsor Site), or from other contributors, only a fraction of the maximum allowable dose is typically allotted to any single site. Within the jurisdiction of the USNRC, the fraction allotted to a single site is specified in regulation. The compliance limit for unrestricted release and reuse[4] of the Site as specified by the USNRC is 25 mrem/y (USNRC, 1997a). As described previously, the State of Connecticut has established a compliance limit for the release of a site having residual concentrations of radioactivity at 19 mrem/y (CTAG, 2003). The more restrictive of the two applicable limits (19 mrem/y) is used to derive the site-specific soil DCGLs for the Site.

With this dose limit in hand, computer modeling codes are used to ***derive*** a concentration-based ***site-specific guideline*** that is protective of the established dose limit. A concentration-based guideline is critical to the license termination process since potential future dose (the performance criterion for obtaining release of the Site) is a projection of future exposures, 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 $DCGL_W$.

The process to derive the $DCGL_W$ involves the bulk of the subjectivity associated with the overall Site release decision process. Addressing the DCGLs first puts the approval process at the beginning rather than at the end of the project. With an approved $DCGL_W$, 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* (USNRC, 2000a) sampling strategy to develop a sampling and analysis plan (SAP) for final status survey. Part of the design strategy for the final status survey plan is the identification of the derived concentration guideline level for elevated measurement comparisons ($DCGL_{EMC}$). The $DCGL_{EMC}$ is derived as a multiple of the approved $DCGL_W$ and is calculated from the same dose modeling and exposure scenarios used to arrive at the $DCGL_W$. The $DCGL_{EMC}$ is not in and of itself a discrete limit to be achieved but a sentinel concentration that alerts to the potential presence of a locally significant anomaly.

[4] "Release for unrestricted use" is the term used by the USNRC to indicate that there are no conditions or restrictions (e.g., institutional controls prohibiting residential uses of the property in the future) that must be emplaced by the licensee to ensure that the future uses of the site are consistent with the uses that are determined to be safe for public exposure to residual radioactivity originating from the Site.

Retrospective analysis of the final status survey 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 ALARA analysis.

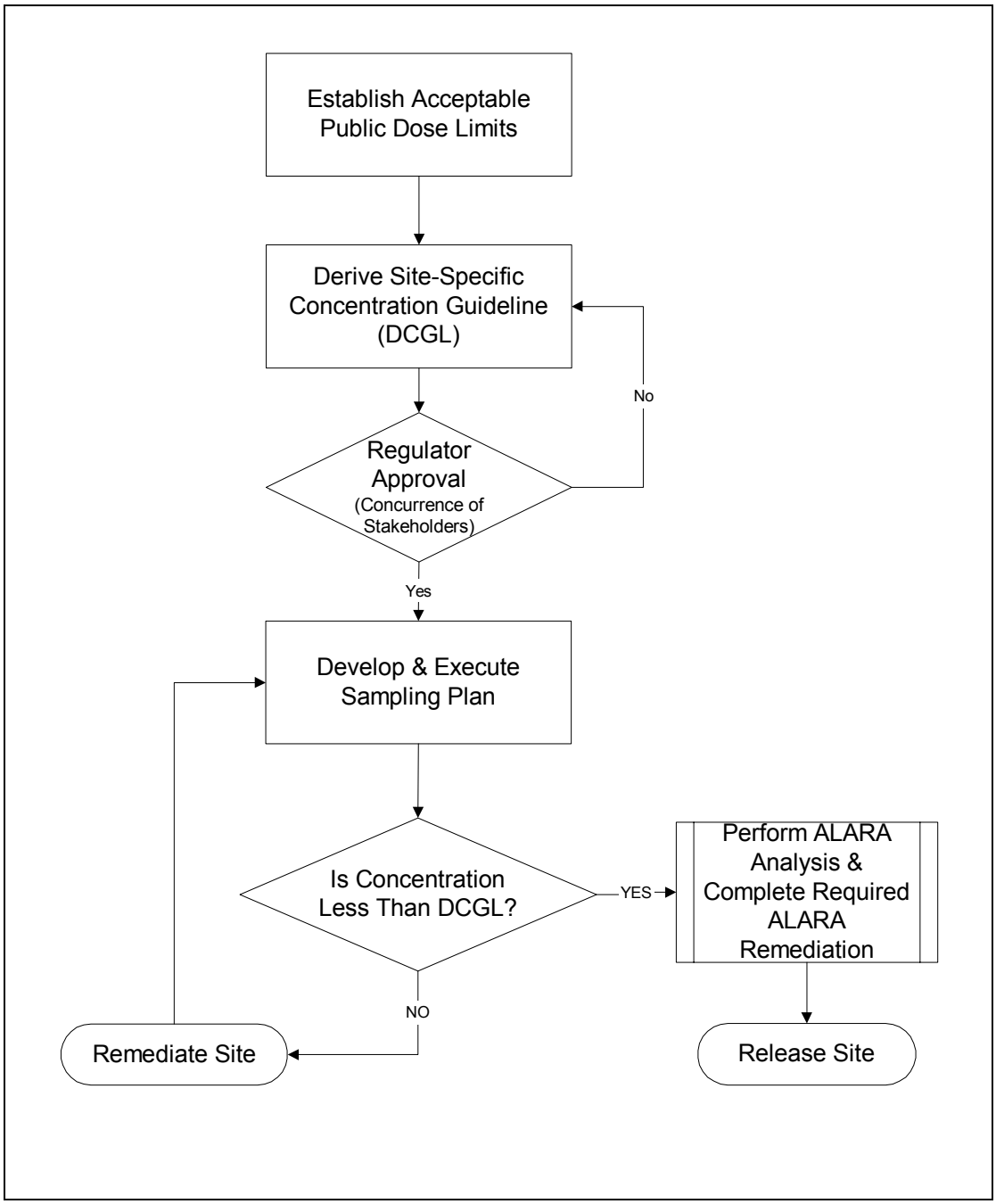


Figure 1–3. Approach to Deriving a DCGL and Releasing the CE Windsor Site

1.6 OBJECTIVE OF THE DERIVED CONCENTRATION GUIDELINE LEVEL

It is evident from the information available that the historical use of this property to perform nuclear fuel and reactor plant component design, research and development, and the manufacturing of nuclear fuels has resulted in residual radioactivity in the soil. 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 limits it is necessary to determine the residual radioactive concentration that can be left in place on this Site without exceeding these safe limits. In essence, the DCGL standard is the on-Site soil concentration below which the resulting radiological dose to a member of the public resulting from the future, unrestricted use of the Site would not exceed approved and allowable levels. The DCGL is the value upon which the subsequent final status survey and sampling plan for soils (including sediment) at the Site will be based. In addition to the requirement for conformance with accepted USNRC 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. Likewise, the collection of unnecessary amounts of data is costly and might slow the remediation process. Misdirection of monetary and time resources through the collection of excessive amounts of data ultimately results in a less effective remedy for the Site.

- 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(s) 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 environmental damage to sensitive wetlands and natural habitat.

- It is important to design a sampling plan to collect enough sample data such 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.

1.7 DOCUMENTATION IN THE SITE RELEASE PROCESS

The process outlined in Figure 1–3 for releasing the Site from radiological controls will be documented in four separate, though interrelated, reports described below:

- *Historical Site Assessment* (HSA) establishes the known history of the Site and its relevance to the objectives of establishing DCGLs and performing remediation needed to cleanup the Site and release it from radiological controls. It itemizes the radionuclides of concern, describes the operations and activities that have occurred at the Site, and identifies the areas of the Site that are potentially impacted by past radiological operations. The HSA also describes (in a conceptual way) the hydrology, geology, and contaminant deposition mechanisms specific to the Site. It serves as a basis for establishing the conceptual Site model that is used to derive the Site-specific DCGLs. It also serves to identify, with reasonable certainty, those areas of the Site that have never been used or impacted by radiological operations. A comprehensive historical assessment of the uses and activities involving radioactive materials at the Site has been written (Harding ESE, 2002) and many of the parameters used to describe the Site conceptual model for the derivation of the DCGLs are derived from it. In addition, a significant amount of characterization work has been done by both ABB and the USACE on the Site, providing a quite refined understanding of the nature or residual radioactivity present on the Site.

- *Development of the Derived Concentration Guideline Level* (this report) derives the Site-specific soil 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 and the acceptable annual public dose limits.[5] The ensuing work involves verifying that radionuclide concentrations in soil on the Site exceed, or do not exceed, the DCGLs.

- The *Final Status Survey Plan* (FSS) develops the DQOs including decision rules. It defines the criteria for evaluating existing data and prescribes the procedures for

[5] The context of the *Development of the Derived Concentration Guideline Level* report focuses exclusively on the derivation of the overall site average concentration in soil (termed the $DCGL_W$ in MARSSIM). This is not to say that locally elevated concentrations of significance are discounted or are viewed as an unimportant consideration. On the contrary, the significance of locally elevated concentrations can only rightly be determined once the $DCGL_W$ value is known (approved). The method recommended by MARSSIM is to arrive at a relationship between size and concentration of locally elevated concentrations of radioactivity in soil using the same site conceptual model and exposure scenarios used to arrive at the $DCGL_W$ value (resulting in values that are increments of the $DCGL_W$). A concentration with potentially significant impact in a localized anomaly is referred to (in MARSSIM terms) as the $DCGL_{EMC}$. The $DCGL_{EMC}$ is specified using the DQO process in the design of the sampling and analysis plans that are used to assess the residual radioactivity concentrations in soil.

conducting 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 or measurements needed to determine with statistical verity, whether the DCGLs are, or are not, exceeded. It also establishes the criteria for identifying and evaluating locally elevated concentrations of residual radioactivity in soil. The FSS also addresses quality control issues such as minimum detection limits, control of measurement error, and provides detailed procedures, as necessary for implementation of the survey.

- A *Final Status 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 estimates based on actual data collected from the Site, and a determination of whether residual radioactivity 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.

The overall process to achieve radiological release and termination of the Site's radioactive materials license is documented in the Site Decommissioning Plan.

2.0 SITE HISTORY AND DESCRIPTION

2.1 SITE HISTORY

ABB's activities at the Site started in 1955 with an Atomic Energy Commission (AEC) contract to begin research, development, and manufacturing of nuclear fuel for the United States Navy. Activities also included the construction, testing, and operation of the S1C facility, a U.S. Naval test reactor. Contracts with the AEC led to the construction of Buildings 1, 2, 3, 5, 6, and 6A in 1956 for the development, design, and fabrication of fuel element subassemblies for U.S. Navy submarine reactors. The sanitary wastewater treatment plant (WWTP), power plant, and support buildings were also constructed at that time to support AEC activities. AEC manufacturing and research and development activities for naval nuclear fuel were terminated by AEC by 1961.

ABB sold the S1C facility to the AEC in 1960. However, ABB continued to operate the S1C facility until 1970. After 1970, the S1C facility continued to operate under the management of Knolls Atomic Power Laboratory, Inc. (KAPL), now a Lockheed-Martin company, as a pressurized water naval nuclear propulsion plant for training, research, and development under the jurisdiction of the United States Department of Energy (USDOE). The S1C facility was shut down permanently in 1993. The S1C facility, currently owned by the United States Government, has been decommissioned.

From the early 1960s to 2000, the CE Windsor Site was involved in the research, development, engineering, production, and servicing of nuclear and fossil fuel systems. These activities were performed under both commercial and federal contracts. Projects included nuclear and combustion research for commercial use, as well as large-scale boiler test facilities and coal gasification. Nuclear fuel research and development was conducted in Buildings 2 and 5, and components were manufactured in Building 17. The large-scale fossil fuel boiler tests were conducted in Building 3.

In 2000, ABB's nuclear businesses were sold to Westinghouse and the fossil fuel businesses were sold to ALSTOM Power (ALSTOM). ABB retained ownership of the CE Windsor property.

Fossil fuel research was conducted in the Building 3 Complex from 1962 to 1995. After 1995, fossil fuel research operations continued in the high bay in the southern portion of Building 3, Building 3B, and recently in Building 3C. Additional test facilities are also located east of the buildings. ALSTOM continues to use these buildings.

Fossil fuel research was also performed between 1977 and the early 1980s by the U.S. DOE at the Process Development Unit (PDU), which is located west of the S1C property. The research at the PDU facility tested coal gasification processes in which gas was manufactured from coal. After PDU operations ceased, the main building was cleaned and renovated. This building is currently used for office and laboratory space.

Buildings 17 and 21 were built in 1967 and 1969, respectively. The buildings were used for nuclear fuel manufacturing (NFM) from 1968 to 1993. Operations were moved off-Site in 1993 and Building 21 was decommissioned and released from radiological controls. In 1998, Building 17 was substantially decontaminated and renovated for use by CE Nuclear Field Operations. CE's Nuclear Field Operations division (but not the property and structures) was later sold to Westinghouse Electric Company (Westinghouse), which subsequently occupied Building 17 for their nuclear support services business through August 2001. Westinghouse has since vacated and turned the building back over to ABB.

The historical processes at the Site generated both low-level radioactive wastes (LLRW) as well as RCRA hazardous chemical wastes. The most commonradioactive waste residues are non-soluble forms of uranium of various enrichments. A more detailed description of the Site history is presented in the Historical Site Assessment (Harding ESE, 2002) and the Historical Review Report (HRR) (ABB Environmental Services, Inc. [ABB-ES], 1998).

2.2 CURRENT USAGE

Some of the Site's buildings are currently occupied by two tenants: ALSTOM Power, which conducts fossil fuel research and engineering design; and Westinghouse, which conducts engineering operations.

Two environmental restoration projects are currently ongoing at the Site. Investigation of FUSRAP related materials on Site is currently being conducted by the USACE while ABB is pursuing remediation of facilities at the Site that are not associated with FUSRAP related materials. During the AEC operations that took place in the late 1950s, releases of residual amounts of enriched uranium (high-enriched uranium (HEU), low-enriched uranium (LEU), and natural uranium) occurred at some Site buildings and surrounding areas.

The Site was a permitted hazardous waste storage facility in the 1980s. Because it was permitted, it is subject to RCRA corrective action. In 1997, ABB entered into an agreement with the USEPA to perform a VCA at the Site. The VCA program is restricted to the investigation and remediation of chemical releases at the Site. This program is also ongoing.

Due to the sale of the Site businesses to Westinghouse and ALSTOM in 2000, the Site is also subject to the Connecticut Transfer Act with respect to Site investigation and cleanup. This program is being conducted concurrently with the VCA.

2.3 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; and
- Areal 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.

2.3.1 Historical Process Knowledge

As described in Section 2.0, the historical knowledge of the operations conducted and the materials handled at the Site are well known. The radiological constituents of concern are the uranium isotopes associated with uranium fuel research, testing, and fabrication and the mixture of byproduct radionuclides (fission and activation products) associated with the repair and testing of radiologically contaminated nuclear reactor plant components and with effluents from the S1C nuclear reactor plant.

Over the years, CE manufactured uranium fuels for both commercial and U.S. Naval reactors.

In the process of manufacturing uranium fuels for commercial reactors, CE received (from other, out-of-state facilities) low-enrichment uranium dioxide (UO_2) powder and pellets. The process to fabricate ceramic uranium fuels includes:

- Reconversion of enriched uranium hexafluoride to uranium dioxide powder;
- Pressing the uranium dioxide powder into configurations (e.g., pellets) required for the fuel assembly being manufactured;
- Fusing the granular powder particles together under high temperature and pressure to form a solid ceramic mass (sintering);
- Loading the sintered pellets into hermetically sealed cladding jackets (known as fuel pins or rods) under exacting quality conditions; and
- Assembling the cladded fuel rods into assemblies for shipment to clients' off-Site reactor facilities.

The production manufacturing process at the CE Windsor Site began with the receipt of UO_2 powder or pellets. Uranium dioxide fuel supplied to the CE Windsor Site was a ceramic compound that had been reduced to stoichiometric purity by hydrogen at temperatures of approximately 820 ºC. The physical and chemical properties of the UO_2 feed materials used at the Site make it highly insoluble and resistant to leaching in typical soil conditions encountered at the Site.

Fuel elements manufactured for U.S. Naval reactors employed highly enriched metallic uranium–zirconium alloy as opposed to a ceramic form. While the details of the manufacturing process and the exact metallic composition of the alloy of uranium are classified, a general understanding is sufficient to support the development of the soil DCGLs for the Site. The manufacturing process to fabricate metallic uranium fuels includes:

- Reconversion of enriched uranium hexafluoride to elemental uranium metal;
- Alloying of the uranium metal with other metals (zirconium) to achieve the desired physical and corrosion resistant properties required for the fuel assembly being manufactured;
- Casting the feed stock into ingots for transportation and safe storage;
- Recasting the feed stock ingots into fuel element geometries;
- Hermetically sealing the fuel matrix in cladding jackets under exacting quality conditions; and
- Assembling the cladded fuel elements into assemblies for shipment to off-Site naval reactor facilities.

Again, the production manufacturing process at the CE Windsor Site began with the receipt of cast ingots of uranium alloy feed stock that had already been enriched and alloyed in predecessor processes.

Like ceramic uranium dioxide, the uranium alloy used to fabricate metallic fuels possesses physical and chemical properties that make it highly insoluble and resistant to leaching in typical soil conditions encountered at the Site.

The deposition mechanisms for uranium likely include very small amounts of aerial dispersion of enriched uranium (EU) particles (both ceramic and metallic) from controlled and uncontrolled emission sources at uranium fuel fabrication facilities on Site. There is evidence that suggests both discrete and non-discrete spillage of EU materials in surface soils has occurred. There are identified localized areas on the Site where storage, incineration, and land disposal of equipment and debris contaminated with uranium materials has occurred. There is further evidence, supported by analytical testing and process knowledge, that the industrial waste lines and their effluent discharge pathways (principally the Site brook) are impacted with residual radioactivity in excess of background concentrations.

Deposition mechanisms for byproduct material might also include very small amounts of aerial dispersion from controlled emission sources at facilities where reactor plant component maintenance was performed. There is also evidence that the industrial waste lines and their effluent discharge pathways are impacted with byproduct radioactivity.

2.3.2 Previous Characterization and Remediation Activities

In addition to historical and process knowledge, a number of radiological assessment and characterization surveys have been undertaken at the Site over the years. The Oak Ridge Institute for Science and Engineering (ORISE) performed confirmation and designation surveys to characterize portions of the Site considered for inclusion in the FUSRAP (ORAU, 1985, and ORISE, 1994, 1996). Science Applications International Corporation (SAIC) completed additional surveys of the Site in 1999 and these surveys were recently expanded by ENSR, who completed a field program in December 2000 under contract to USACE. Building 3 was also characterized for radiological materials by SAIC in 1999.

In addition to the radiological characterization surveys, ABB is also currently performing a RCRA VCA Program under the USEPA. As part of the effort to identify chemical compounds of concern and areas on the Site where chemicals may have been released to the environment, a substantial and thorough characterization of the Site's geologic and hydrogeologic features has been conducted. (ABB-ES, 1998; Harding ESE, 2002). During field investigations, ABB screened many samples for radiological contamination providing valuable qualitative information regarding the extent and magnitude of residual radioactivity over a wide area of the Site.

In addition to the VCA program, several other chemical and radiological investigations have been completed to date. A complete listing of environmental (both radiological and chemical) sampling and survey reports is presented in the HSA, Appendix B (Harding ESE, 2002).

These efforts have yielded a reasonably well-defined understanding of many Site features that are used to derive the appropriate Site-specific DCGL.

Key features describing the extent of residual radioactivity at the Site are areal and depth dispersion. While the conceptual site model used to derive the soil DCGLs necessarily assumes that residual radioactivity is uniformly distributed over the entire footprint of the Site, characterization activities indicate that the true areal extent of known radioactive materials in soil is generally limited to relatively small impacted areas where either uranium or byproduct materials are known to have been introduced. For example, the corridor containing the Site brook, which received effluents containing radioactivity, is known to have elevated concentrations of both uranium and byproduct radioactivity, but the areal extent is limited relative to the entirety of the 500-acre site under consideration. The depth, or vertical extent, of radioactivity in soil does vary from one location to another depending on the mechanism(s) of introduction. Still, the depth of residual radioactivity is generally confined in the top 0.15 meters (6 inches) of the surface soil, with concentrations trending toward background as depth increases.

2.3.3 Site Geologic and Hydrogeologic Features

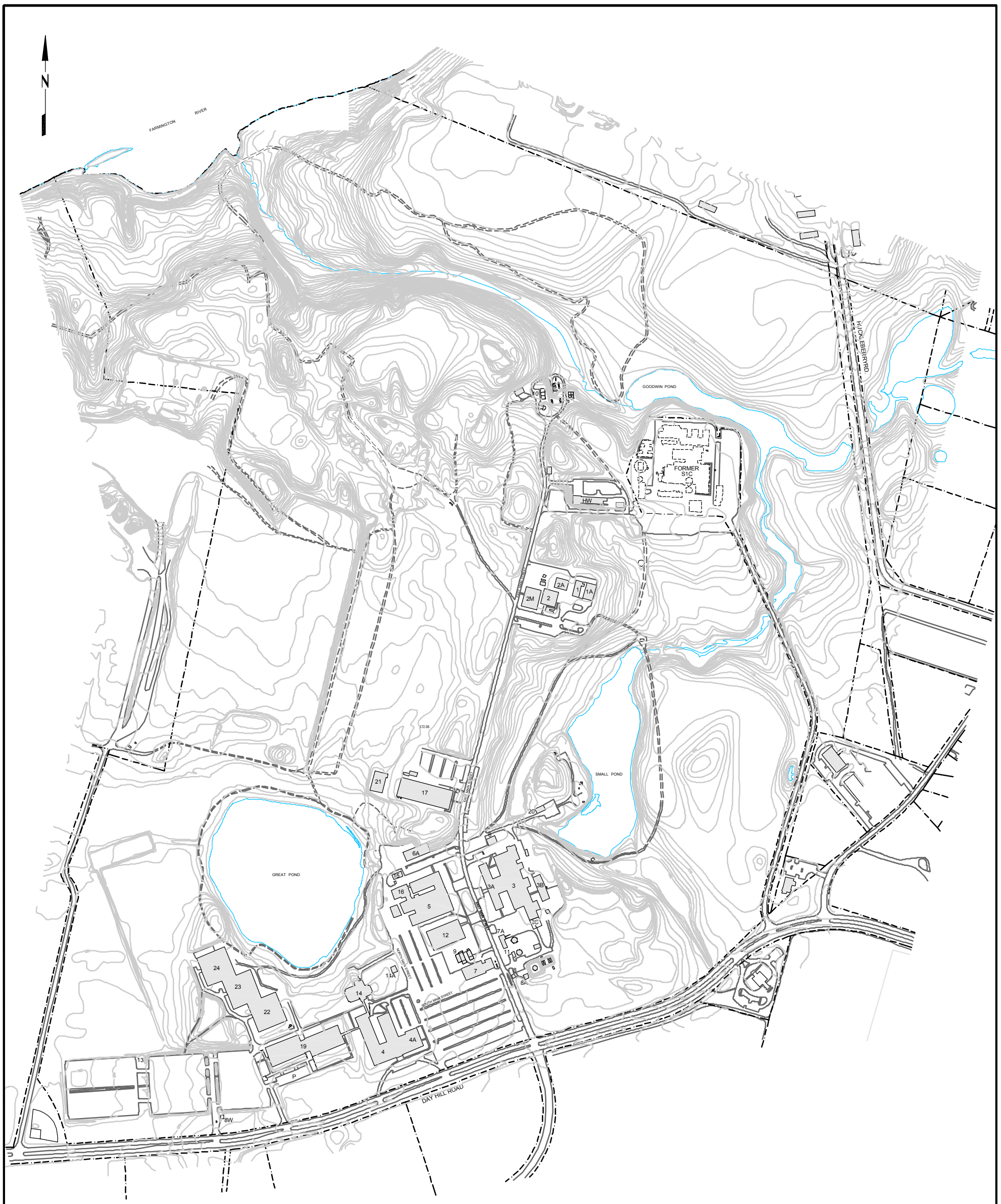
Generally, the southern, developed areas of the Site are paved or landscaped and relatively flat. The northeastern portion of the property is wooded and less disturbed by Site development and operations. The highest portion of the Site is approximately 210

feet above mean sea level (MSL) and drops to 98 feet above MSL along the banks of the Farmington River. Topographic contours are shown on Figure 2–1.

The regional geology in Windsor is mapped within the Central Valley landscape of the Newark Terrain. The underlying bedrock is mapped as Portland Arkose (or Portland Formation) (Schnabel, 1964). The Portland Arkose is sedimentary rock that is part of the Newark Supergroup of Mesozoic age. This formation is described as reddish-brown to maroon micaceous arkose and siltstone to red to black fissile silty shale (Rodgers, 1985). Regionally, the Portland Arkose is often referred to as "red rock" or "red beds" because it typically has a distinctive red/maroon color. The underlying Portland Arkose has been encountered at 27 and 37 meters below ground surface (bgs) at two locations on the Site.

Depth to bedrock is known at the former S1C reactor property and at isolated locations at the CE Windsor Site. The former S1C reactor was located on a 10-acre parcel of land that was originally part of the CE Windsor Site. Bedrock was encountered at approximately 39 meters (127 feet) bgs in several borings that were completed during decommissioning of the S1C reactor site. Till thickness on bedrock in this part of the Site varied from 10 to nearly 30 feet (KAPL, 2001).

At the CE Windsor Site, no explorations have penetrated the bedrock in order to characterize it. However, the same bedrock has been investigated at the Hamilton Sundstrand (formerly Hamilton-Standard) facility, located 2 miles northeast of the CE Windsor Site (D&M, 1992). This facility is located to the north of the Farmington River. At this site, a number of wells were drilled into the Portland Arkose and the upper 50 feet of the bedrock was characterized. Dames & Moore, (D&M, 1992) describes the uppermost part of the Portland Formation in this area as mudstone, siltstone, and sandstone. Depth to bedrock varied from 19 to 52 meters (64 to 170 feet) bgs. The bedrock at the Hamilton Sundstrand Site is fractured and is considered a pumpable aquifer. The average horizontal hydraulic conductivity measured in wells at this other location is reported to be 22 meters per year (0.2 ft/day). The major orientation of open fractures in the bedrock was found to be horizontal and essentially parallel with bedding-plane orientation (i.e., dipping gently towards the east). Flow direction at this site is southward towards the Farmington River at the location of the Rainbow Dam. This suggests that the flow at the boundaries of the shallow bedrock aquifer are similar to the overburden; that is the Farmington River acts as a regional discharge feature for flow from the overburden and shallow rock. Since the river along the northern CE Windsor Site boundary is dam-controlled, flow beneath the CE Windsor Site is interpreted to be towards the northeast (towards the lower reach of the Farmington River below the Rainbow Dam).



LEGEND

- EXISTING STRUCTURE
- FORMER STRUCTURE
- PROPERTY LINE
- WATER
- UNIMPROVED ROAD
- GROUND SURFACE CONTOUR (ELEVATION, FEET MSL)

NOTES:
1. BASE MAP PROVIDED BY METROPOLITAN DISTRICT COMMISSION.
2. CONNECTICUT STATE PLANE NAD 1983.

0 150 300 600 FEET

FIGURE 2-1
CE WINDSOR SITE TOPOGRAPHY
DERIVATION OF THE SITE-SPECIFIC SOIL DCGLs
CE WINDSOR SITE
WINDSOR, CONNECTICUT

MACTEC, Inc.

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The overburden consists of quaternary deposits. The most pronounced local geologic feature on the Site is a dense till ridge, or drumlin, that trends north-south and is located in the middle of the Site. West of the ridge, the overburden consists of stratified sands and silts. These deposits become finer with depth and have been investigated to depths of approximately 37 meters bgs without encountering till or bedrock. East of the ridge, the overburden consists of fine sands in silts to approximately 12 to 18 meters bgs. These deposits are underlain by ablation till that flanks the drumlin and pinches out to the east. In several borings, a coarse sand and gravel water-bearing zone was encountered at approximately 27 to 32 meters bgs. These coarse sands have been encountered within a soil unit that trends north-south and is located beneath Small Pond. This unit is not continuous to the east and west.

ABB has completed over 400 drilled subsurface explorations, associated with both the RCRA Voluntary Corrective Action (VCA) Program and various radiological characterization investigations. Soil explorations were designed to characterize the extent of impact (laterally and vertically) and often were terminated while still in the overburden soils once the limits of contamination were established. Monitoring wells were installed to fully characterize shallow groundwater conditions beneath all portions of the CE Windsor Site. Some deeper explorations were completed to determine lithology and groundwater quality throughout the saturated overburden. A network of deeper wells was established to monitor for chemical impacts in the deep overburden. These deep explorations were typically terminated once dense till was encountered. ABB's deep explorations confirm the lithology presented in the S1C logs described above (KAPL, 2001), specifically that the eastern portion of the CE Windsor Site is underlain by water-transmissive sandy to gravelly overburden soils that are up to 100 feet thick. Flow in the deeper portions of this surficial aquifer is towards the northeast.

Groundwater is encountered at approximately 4.5 to 6 meters bgs in the southern portions of the Site, and at approximately 14 meters bgs in the central, topographically high areas of the Site. As the ground surface slopes steeply to the Site brook in the northern portion of the Site, groundwater can be found at depths less than 2 meters bgs, but this groundwater is classified as "GB" (not suitable for use as a drinking water source) for reasons not associated with radiological considerations.

Based on the regional and Site geology, both surface and "near surface" groundwater is expected to flow generally toward the northwest and discharge to the Farmington River. Groundwater contours generated during the VCA in October 2000 are shown on Figure 2–2 (HLA, 2000).

Groundwater beneath the northern portion of the CE property was reclassified to "GB" in September 2000 (CTDEP, 2000). Groundwater beneath the southern portion of the Site remains classified as "GA" (groundwater that is protected as a potential source of drinking water) (Figure 2–3).

LEGEND

- EXISTING STRUCTURE
- FORMER STRUCTURE
- WELL PAIR LOCATION
- MONITORING WELL
- PROPERTY LINE
- WATER
- UNIMPROVED ROAD
- GROUND SURFACE CONTOUR (ELEVATION, FEET MSL)

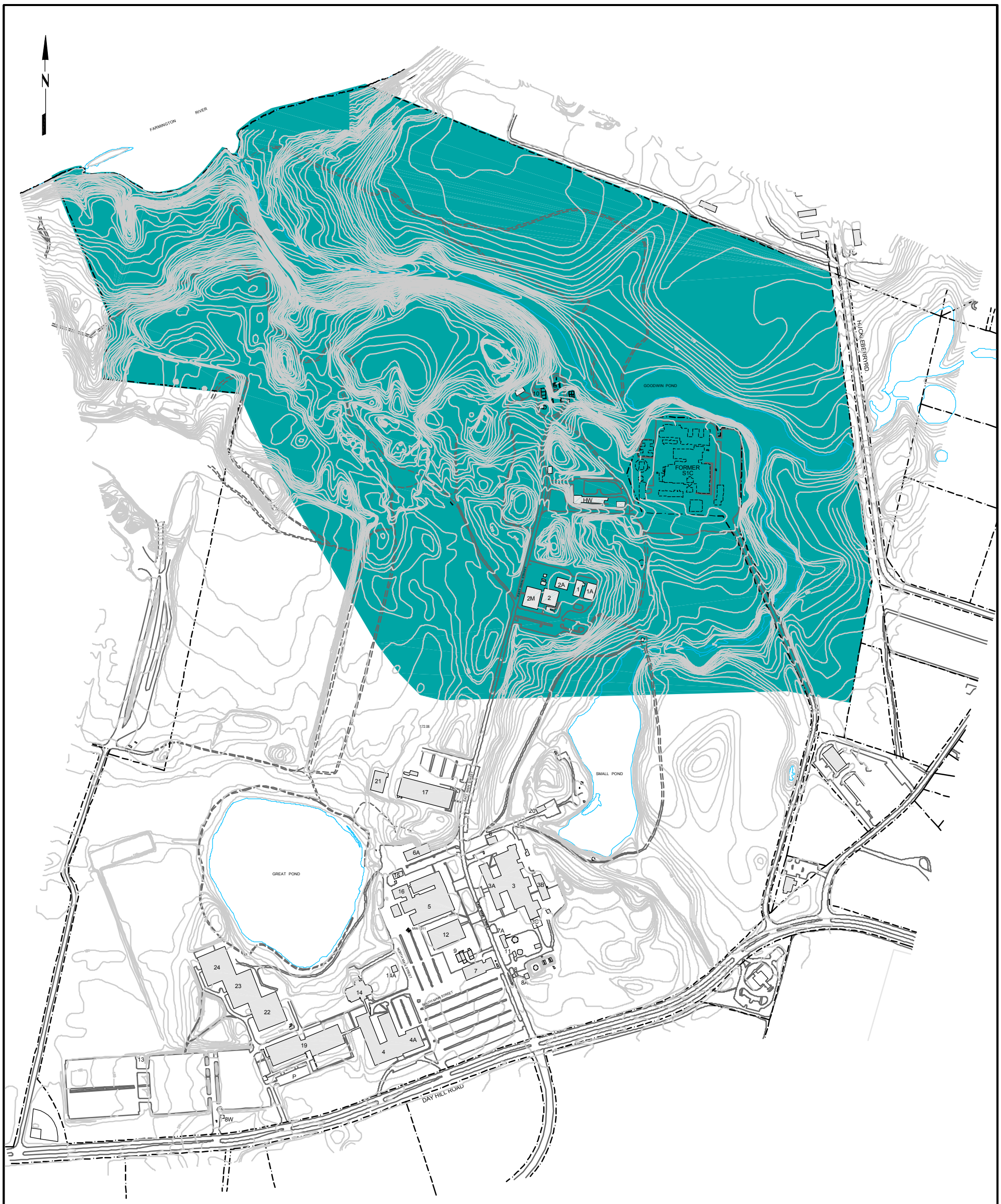
NOTES:

1. BASE MAP PROVIDED BY METROPOLITAN DISTRICT COMMISSION.
2. MONITORING WELL LOCATIONS SURVEYED BY ALFORD ASSOCIATES, AUGUST 1998 AND NOVEMBER 1999, MESSIER & ASSOCIATES, JUNE 1999, AND FUSS AND O'NEILL, JULY 1998 AND JANUARY 2000.
3. CONNECTICUT STATE PLANE NAD 1983.

0 150 300 600 FEET

FIGURE 2-2
INTERPRETIVE GROUNDWATER CONTOUR PLAN
CE WINDSOR SITE
WINDSOR, CONNECTICUT

MACTEC, Inc.



LEGEND

- AREA RECLASIFIED TO GB
- EXISTING STRUCTURE
- FORMER STRUCTURE
- PROPERTY LINE
- WATER
- UNIMPROVED ROAD
- 180 GROUND SURFACE CONTOUR (ELEVATION, FEET MSL)

NOTES:

1. BASE MAP PROVIDED BY METROPOLITAN DISTRICT COMMISSION.
2. CONNECTICUT STATE PLANE NAD 1983.

0 150 300 600 FEET

FIGURE 2-3
SITE GROUNDWATER CLASSIFICATION

CE WINDSOR SITE
WINDSOR, CONNECTICUT

MACTEC, Inc.

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ABB currently conducts quarterly radiological groundwater sampling in more than 70 monitoring wells located throughout the CE Windsor Site. These wells were selected to monitor the most likely areas were contaminants could enter groundwater (potential source areas). Areas downgradient of the most likely contaminant source areas were also monitored. This extensive monitoring program helps to ensure that even if a contaminant was not detected at the source, it would be detected downgradient.

Measurable radioactivity has only been observed in water samples from two unique settings where shallow monitoring wells are installed directly in near-surface contaminant sources (monitoring well MW-1201 and wellpoint WP-1403). Each is uniquely situated in shallow water-saturated uranium-impacted soils. ABB believes the radiological impact observed in groundwater results at each of these two locations is limited to the immediate vicinity of the monitoring wells (or wellpoint) with no reasonable likelihood of transport through the thick soil column to the underlying bedrock. Additionally, even these 'measurable' results are near the lower limits of detectability and therefore do not indicate the likelihood of transport at detectable levels.

MW-1201 is installed alongside former industrial waste lines that carried radioactively-impacted liquid waste from Building 5 laboratories to dilution tanks in Building 6A and Building 6. Solvents and other chemical contaminants are also present in groundwater at MW-1201 in relatively high concentrations. The residual source of these chemical and radiological impacts is believed to be sediment within the adjacent lines and in the fill bedding immediately surrounding these lines. Despite the potential age of the release (ca. 1960) there has been no significant lateral transport of water-soluble chemical contaminants. Surrounding downgradient monitoring wells have trace or low levels of solvents that are several orders of magnitude lower than levels observed at MW-1201. No uranium has been detected in these downgradient wells.

In addition MW-1201 is located in a thin saturated layer of fill soils founded on dense till. It is dense and does not conduct water like the permeable sands detected at the Site. It is likely that the till has acted as a confining layer and the contamination detected, chemical or radiological, is confined to the fill around the sewer line. When the contaminated fill is removed, it is likely that the contamination detected in MW-1201 will be removed as well.

Wellpoint WP-1403 is located in the upper reach of Site brook (between Goodwin Pond and the Farmington River). This monitoring point consists of two PVC wellpoints that are hand-driven into the uranium-contaminated sediments of the streambed. A shallow wellpoint (WP-1403S) was driven to a depth of 2 feet and a slightly deeper wellpoint (WP-1403D) was driven to a depth of 5 feet. Because of their shallow nature and limited screened intervals (one foot each), these wellpoints cannot sustain the recharge needed to obtain samples by low-flow methods. The wellpoints are sampled using a bailer and the samples are not filtered to remove fines. The elevated radiological results are interpreted to be principally caused by particles of impacted sediment that are included in the samples.

Additionally, seeps are reportedly present along the banks of upper reaches of Site brook near where these wellpoints are located. The presence of these seeps and measured upward gradients between WP-1403S and WP-1403D support the interpretation that this reach of the brook receives groundwater recharge. Since groundwater discharges to the brook, there is no mechanism to transport impact downward through underlying till to the bedrock.

ABB has historically pumped large quantities of water from two production wells located to the south of Small Pond. These wells draw water from the lower portion of the surficial aquifer at depths between 23 and 27 meters (75 and 90 feet). The wells are located in a highly conductive sand and gravel layer that is present just above dense till, which is generally found at depths of 27 to 38 meters (90 to 125 feet) in areas east of the north-south trending drumlin. Decades of monitoring from the two high-capacity production wells has revealed no impact to groundwater.

The wells are located downgradient of the developed southern portion of the Site including the principal FUSRAP-era nuclear fuel manufacturing and laboratory complexes (i.e., Building 3 and 5 Complexes). If radiological impact was migrating from shallow soils sources (including the industrial waste lines at MW-1201), it is likely that these wells would have identified such impact. The absence of observed impact helps confirm that no significant vertical transport has occurred.

Monitoring wells have been established in the area known as the former waste storage pad (FUSRAP name) or Woods Area (RCRA VCA Area of Concern 1 (AOC 1)) which has broad delineated radiological impacts to surficial soils. Several monitoring wells have been established within the area of known surficial impact. Lithology is permeable fine sand above dense till. The permeable sand increases in thickness towards the north and west (i.e., as the western flank of the till drumlin drops deeper below ground surface). Depth to water in wells established at the area is generally 12 meters (40 feet) bgs. Wells such as E-1, MW-0105, MW-0106, MW-0118, and MW-0145, all established within the known boundaries of surficial radiological impact, exhibit no elevated radioactivity (see results reported in Table 4-5 of the Decommissioning Plan).

It should be noted that wells in this area exhibit chemical impact from dissolved-phase perchloroethylene (PCE). A dissolved phase plume of PCE has been tracked through the Woods Area. It has been delineated both vertically and horizontally and has not been detected deep enough in the surficial aquifer to impact bedrock. The vertical delineation of the plume was performed through the installation of monitoring wells at various depths in the aquifer and through multi-level groundwater sample collection. This sampling confirmed the Site conceptual model, which indicates that the plume of PCE is discharging to the Site brook and is not impacting bedrock.

The chemical characteristics of PCE make it much more likely to impact bedrock than other chemical contaminants such as uranium. It is heavier than water, and even a dissolved phase plume has a slightly higher specific gravity than water, making bedrock

impacts from PCE more likely than from other chemicals. Given that it has been determined that the PCE plume is confined to the uppermost aquifer, and the plume is discharging to the Site brook, it can be assumed that even if a plume of soluble radioactive species were possible in this area, it would even be less likely that it might migrate vertically resulting in impacts the underlying bedrock.

Because of the reasons listed above, the Site conceptual model does not support contaminant transport into bedrock at the CE Windsor site. The primary Site lithology, which consists of sand over dense till, does not support transport of contaminants into bedrock. In addition, the presence of the Site brook (locally) and Farmington River (Regionally) as significant discharge sources for the groundwater at the CE Windsor site does not support a model that includes a potential contaminant pathway to bedrock.

2.4 RADIOLOGICAL CHARACTERISTICS OF SITE MATERIALS

2.4.1 Radiological Characteristics of Enriched Uranium

The suite of radionuclides found in EU is fixed by the physical and chemical processes used to produce the EU and by the laws of physics describing radioactive decay. The same physical laws govern the relative concentrations of these radionuclides, making their proportions at a given U-235 mass enrichment known with a high degree of certainty. Isotopically, EU does not vary substantially by batch for a given percent enrichment, assuming that the EU was produced using the same enrichment (isotope separation) process. The EU fuel stock used at the Site is known to have come from gaseous diffusion enrichment processes. There is no indication that EU fuel stock derived from other enrichment processes (e.g., centrifuge, laser) was ever used at the Site.

The uranium enrichment percentage does impact the relative concentrations of the uranium isotopes in the fuel mixture. In gaseous diffusion, the smaller U-234 atoms are more readily enriched than either U-235 or U-238 atoms. Likewise, U-235 atoms are more readily enriched than U-238 atoms. Uranium 234 having a radioactive half-life more than three orders of magnitude shorter than U-235, dominates the total uranium radioactivity for enrichments greater than naturally occurring abundances. The relationship between the uranium isotopes for enriched nuclear fuels created by gaseous diffusion can be described by Equation 2–1 (USNRC, 1974) and is illustrated for a wide array of enrichments in Figure 2–4 (USDOE, 2000).

$$SA = \left(0.4 + 0.38E + 0.0034E^2\right)10^{-6}$$

(Equation 2-1)

Where: *SA = total uranium specific activity in Ci/g*
E = % U-235 by weight (% enrichment)

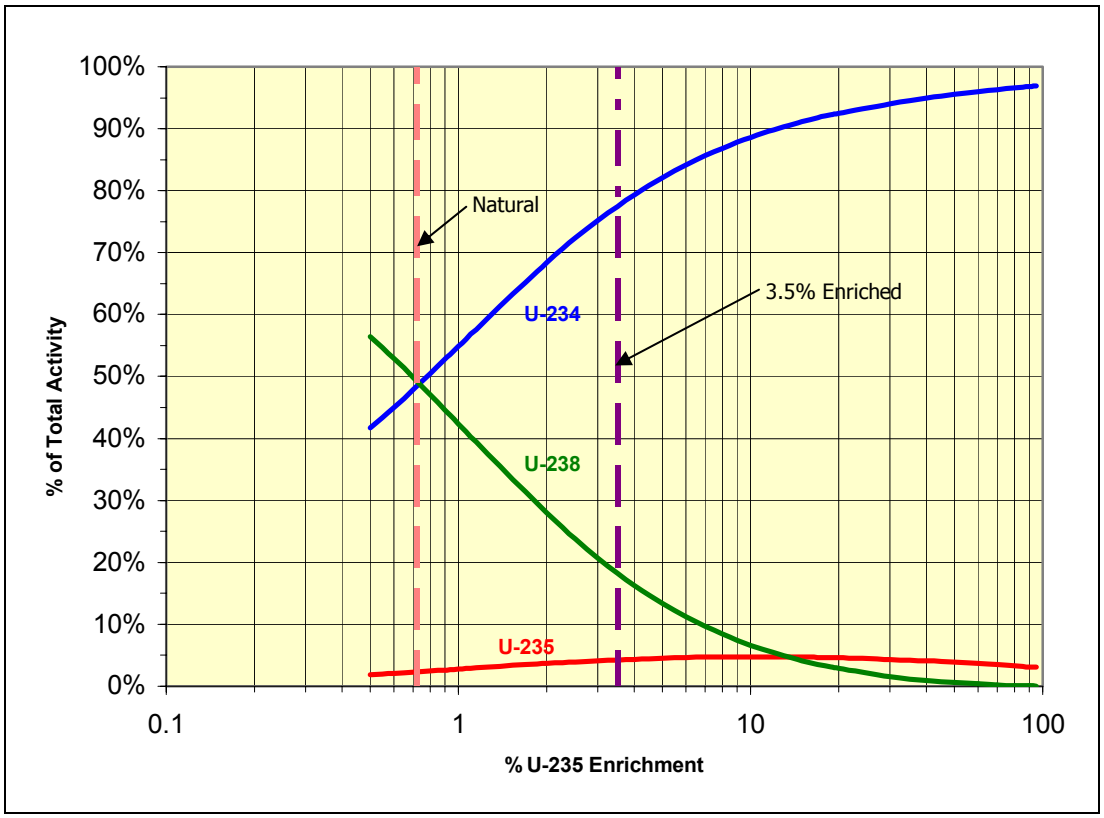

Figure 2–4. Isotopic Contributions to Total Uranium Activity vs. Percent Enrichment

The HSA (Harding ESE, 2002) indicates that some depleted and natural uranium materials were present and used for research and development on Site. However, quantities of these materials used on Site are overwhelmed by the amount of EU used. Typical commercial grade, LEU fuel stock was supplied to CE at about 3.5% enrichment. HEU with enrichments greater than 90% was used to manufacture special nuclear fuels for the Federal government. Thus, a range of potential uranium isotopic ratios might occur on the Site, and could vary from one location to another depending upon the deposition source.

To determine the consequence of various enrichments upon the soil DCGL, a series of RESRAD calculations were performed. The source term was adjusted iteratively with uranium isotopic ratios associated with enrichments from 0.1% to 95%. The total uranium activity was held constant. The result, graphically presented in Figure 2–5, shows that for a constant total uranium activity in soil, the lower enrichments produce nearly equivalent but slightly greater dose than higher enrichments.

Uranium enrichments ranging from 3.5% to 95% produce a virtually flat (<15% variance) dose response allows for the use of a single uranium in soil DCGL without regard to the enrichment. To ensure that the uranium in soil DCGL will be derived to be protective of the annual dose limits without regard to enrichment, ABB has chosen to derive the DCGL conservatively assuming that the uranium isotopes are present in ratios associated with 3.5% EU. The isotope ratios used to derive the uranium soil DCGL are, themselves,

derived using Equation 2–1 and assuming 3.5% enrichment and are presented in Figure 2–6.

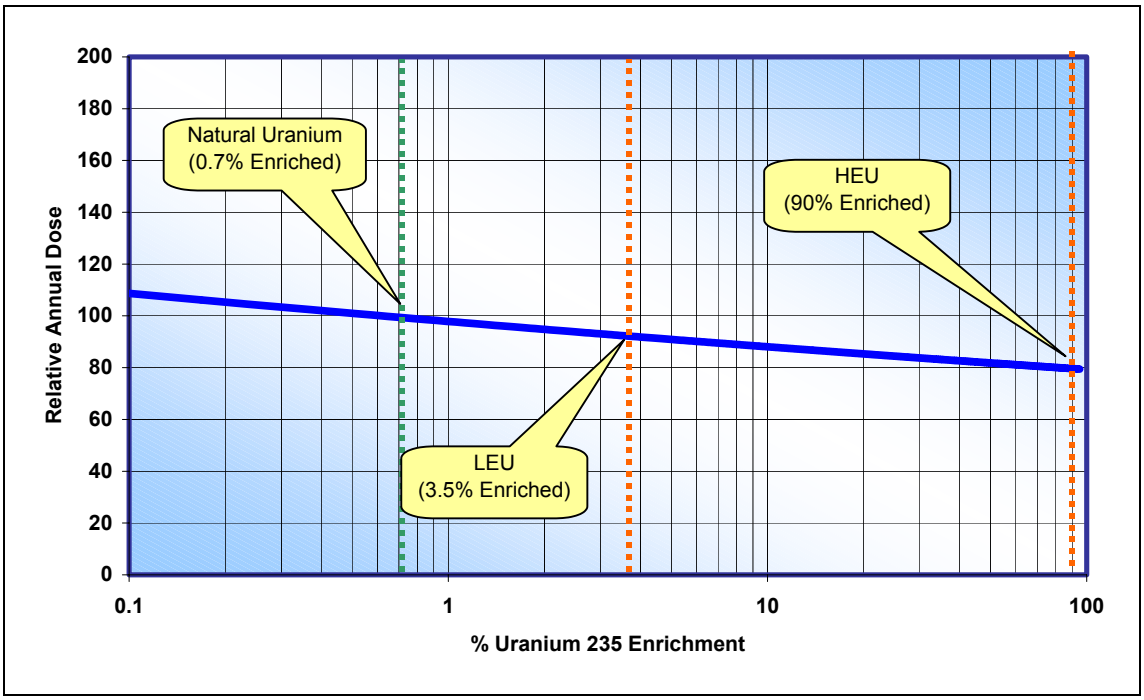

Figure 2–5 Effect of Uranium Enrichment on Projected Future Dose

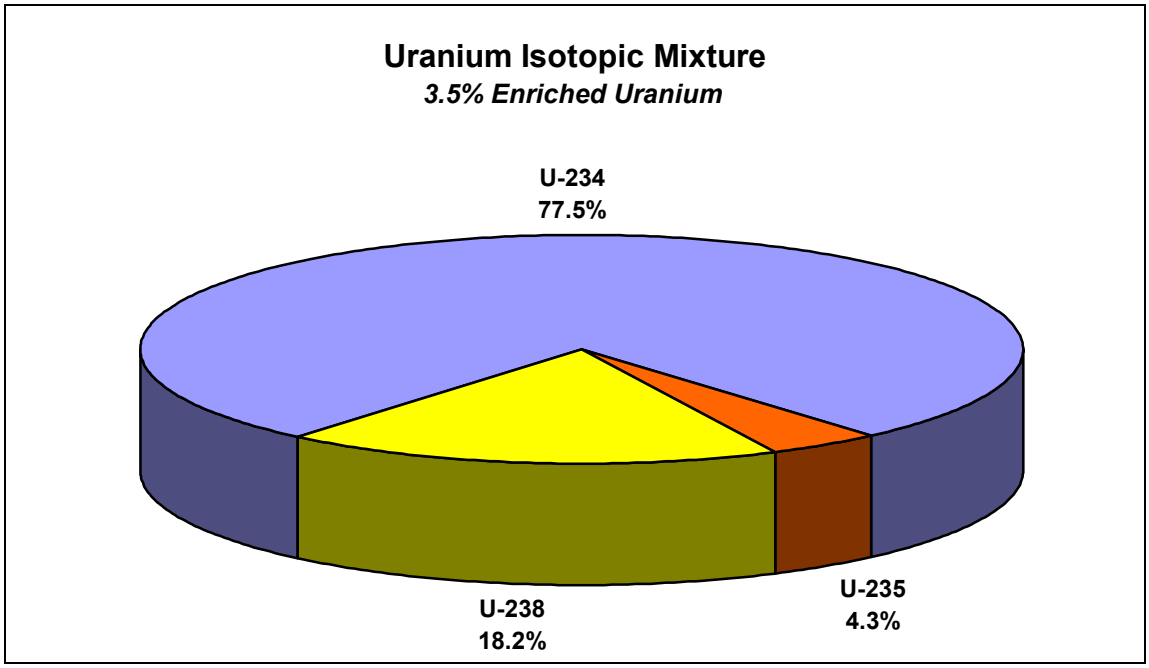

Figure 2–6 Uranium Isotope Activity Fraction Used to Derive the Uranium Soil DCGL

It should be noted that this assessment is based upon an analysis normalized to specific uranium radioactivity in soil. The relatively shorter half-lives of both U-234 and U-235, which dominate in EU, causes an equal mass of 90% HEU to be approximately 100 times more radioactive than natural uranium and 40 times more radioactive than LEU (3%). The relationship between radioactivity of uranium in soil at a given total uranium soil concentration (e.g., 100 mg/kg) vs. percent enrichment is depicted in Figure 2–7.

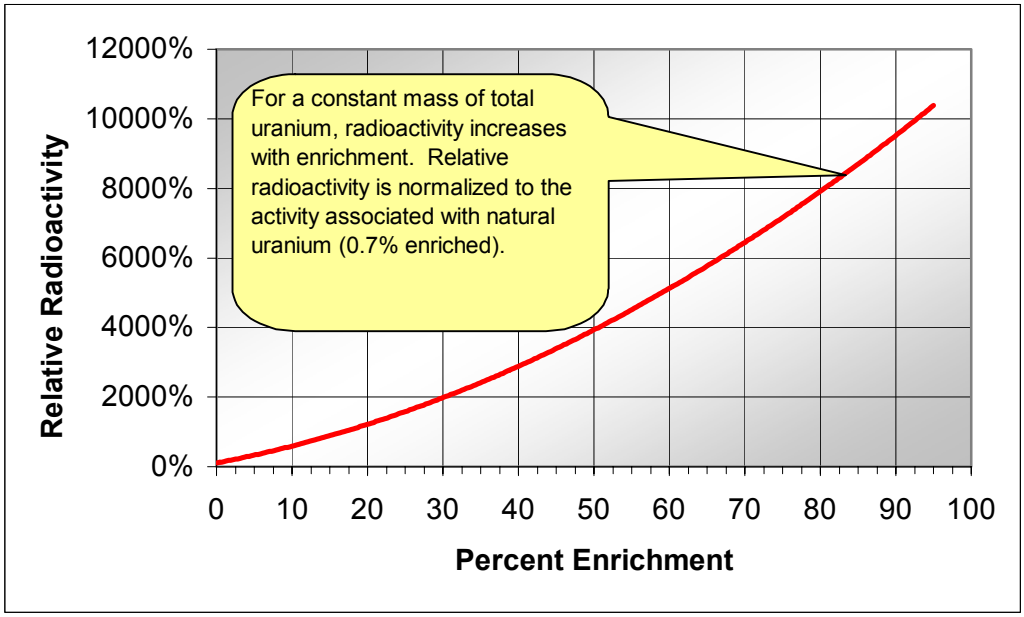

Figure 2–7 Relative Total Uranium Activity in Soil vs. Percent Enrichment

2.4.2 Radiological Characteristics of Byproduct Materials

Radionuclides produced in the operation of a nuclear reactor are classified as byproduct materials, as they are the "byproduct" of a nuclear reaction. There are two subcategories of isotopes collectively classed as byproduct materials. They are described by their production mechanisms: 1) fission products, and 2) activation products. The nuclear fuel services work performed by CE and later by Westinghouse at the Site involved the repair, maintenance, and testing of reactor plant components. Since nuclear fuel itself is clad, or jacketed, to prevent a significant release of fission products, the principle radionuclides associated with plant components handled at the Site and effluent discharges from the S1C reactor are activation products. For purposes of derivation of the DCGL, it is unimportant to further distinguish between these, but it does serve to understand the byproduct material isotopic mixture.

Isotopes found in byproduct materials are generally characterized by short half-lives and beta decay mechanisms. The shortest-lived isotopes rapidly decay away and are essentially gone before components can be removed from a reactor plant for service. After one year (by the time any soil cleanup will begin, no new byproduct radioactive materials will have been introduced at the Site for more than one year), only a small number of the longest-lived radionuclides remain in potentially significant quantities.

The presence of byproduct radioactivity in soils at the Site is limited to a few discrete locations having very low activity concentrations. In fact, concentrations detected to date are low enough to challenge the detection capabilities of reasonable measurement technologies. As a result, it is virtually impossible to adequately characterize the byproduct source term isotopic mixture by analyzing soil samples from the site. To address the need to understand the mixture of isotopes associated with the byproduct source term, and to arrive at the byproduct source term isotopic profile used in modeling the potential future dose at the site, three data sources were evaluated (See Appendix G).

The first, and arguably the most representative, data source evaluated derives from the waste characterization data generated during recent decontamination work in buildings on the site in which reactor plant services work had been performed. From among the many characterization samples collected and analyzed, those with results indicating the presence of Co-60 and Cs-137 (the signature radionuclides associated with the byproduct source term) were isolated. These samples were analyzed with gamma spectroscopy techniques and thus report only those isotopes in the byproduct mixture that emit a measurable gamma radiation signal. This data set indicates that among the isotopes detected, only three contribute as much as 1% of the total activity with Co-60 contributing 89.9%, Cs-137 contributing 2.9%, and Mn-54 contributing 6.7%. The remainder is made up of trace quantities of other gamma emitters.

The second data source considered was derived from samples collected explicitly to evaluate the potential for the presence of quantities of "hard-to-detect" radionuclides. Hard-to-detect radionuclides include those that are typically present in only trace quantities relative to the principal isotopic constituents and those that have only very weak radiation emission signatures and require more specialized radiochemical analyses in order to assay. Among these are the low-energy beta emitters (Fe-55, Ni-63, H-3, Tc-99, and Sr-90) and trace quantity alpha- and beta-emitting actinides. Because these radionuclides are either very difficult to detect or present in only trace quantities, samples were collected from locations likely to yield the highest concentrations—sediments from the now unused evaporator and industrial waste lines. These sediment samples were subjected to a series of special radio-analytical tests designed specifically to detect and quantify the presence of the hard-to-detect isotopes. Predictably, the isotopes detected and identified were typically present in only minor activity concentrations (pCi/g) relative to the activity concentrations of either uranium or Co-60.

The third data source considered was the waste stream characterization data used by the reactor services contractor on site to complete the Connecticut Annual Low-Level Radioactive Waste Reports supplied each year to the CTDEP. The annual reports for the years 1999 and 2000 (Westinghouse, 2000; Westinghouse, 2001) were selected as they were from the last two years during which a significant volume of reactor services operations (involving byproduct source term) were conducted. The waste stream profile data contained in the reports is logically derived from analytical measurements of samples derived from the associated waste stream. The reported presence of some shorter-lived radionuclides in the annual low-level waste reports, while those same

radionuclides were either undetected or reported at significantly lower concentrations in more contemporary sampling, indicates that this data is associated with the byproduct mixture earlier in its decay process. The annual reports summarize the radioactive wastes shipped off site with the annual aggregate isotopic composition identified for each applicable waste stream. The waste stream profile reports from 1999 and 2000 identify five isotopes that contribute 1% or more to the total byproduct activity (Table 2-1).

Table 2-1 Byproduct Material Isotopic Profile (>1%)

Isotope	% of Total Activity
Co-60	73.2%
Cs-137	1.1%
Fe-55	2.9%
Mn-54	2.7%
Sb-125	5.0%

Cobalt 60 clearly dominates the relative contribution to total activity in each of the three data sources evaluated. This dominance is amplified by the fact that Co-60 is by far the most potent dose producer among the byproduct nuclides present. To gauge the sensitivity of the potential future dose to a receptor with respect to variability in the isotopic ratios that might be reasonably expected in byproduct material, a sensitivity analysis was performed (Appendix G).

The sensitivity analysis reveals that contribution to potential future dose (at the time of peak mean annual dose) is almost entirely attributed to Co-60.[6] Potential future dose is very insensitive to variation in the relative contributions of the other isotopes compared with Co-60. Among the isotopes reported present in each of the three data sources evaluated, none produced even 10% of the annual TEDE produced by Co-60 at the time of peak mean annual dose.

An additional feature key to understanding the relative significance of the various isotopes in the byproduct mixture on the Site is that no isotope other than Co-60 contributes a dose approaching even 1 mrem/yr at any time in the 1000-year outlook. After approximately 10 years, the potential dose contribution from byproduct materials has been reduced to only a few millirem per year primarily through radioactive decay of cobalt.

Guidance contained in the USNRC's *NMSS Decommissioning Standard Review Plan*, NUREG-1727 (USNRC, 2000b) for development of the site-specific DCGLs, acknowledges that a number of radionuclides might be present in the source term found at a site, yet "almost all of the dose would come from just one or two of the nuclides."

[6] Because the radioactive decay half-life of Co-60 is almost six times shorter than that of Cs-137, over time the dose from Cs-137 overtakes that of Co-60. Still, the annual TEDE contributed from Cs-137 continues to diminish over time, approaching zero by the end of the 1000-year projection period. The relative dose producing potential of all significant isotopes in the byproduct source term is most sensitive at time zero.

This is clearly the case with the reactor plant derived byproduct source term encountered at the CE Windsor Site as evidenced by the results of the sensitivity analysis. The USNRC's decommissioning guidance (USNRC, 2000b) suggests that in such cases, "the presence of nuclides that likely contribute less than 10% of the total effective dose equivalent may be ignored."

Considering that the sensitivity analysis confirms that only Co-60 is capable of producing as much as 10% of the total effective dose equivalent, the isotope mixture used to derive the site-specific soil DCGL corresponding to the byproduct source term includes only Co-60.

2.5 OTHER THAN RADIOLOGICAL HAZARDS

The Site HSA (Harding ESE, 2002) indicates the presence of a number of non-radiological (chemical) constituents of concern at the Site. These constituents are addressed and evaluated in other project documentation such as the RCRA Facility Investigation Report (Harding ESE, 2003), the Project Management Plan (MACTEC, 2001a) the Building Demolition and Excavation Plan (MACTEC, 2001b), and task specific asbestos abatement plans.

The scope of this document pertains only to the derivation of the radiological DCGLs for soil, but is logically consistent with the concepts and assumptions used to assess the risk from non-radiological hazards at the Site.

3.0 DEVELOPMENT OF THE DERIVED CONCENTRATION GUIDELINE LEVEL

3.1 SELECTION OF THE ANNUAL PUBLIC DOSE LIMIT

The USNRC 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). The state of Connecticut has determined that it has authority to regulate residual radioactivity at the Site, and has established an acceptable annual public dose limit at 19 mrem/y (CTAG, 2003). These limits require that all regulated 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 into the selection of the 25 mrem/y post decommissioning annual dose limit specified by the USNRC. 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 per year over many consecutive years (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 and adds a margin to safety. Additionally, the 19 mrem/y annual dose limit specified by the State of Connecticut, which is even slightly more conservative than the USNRC promulgated standard, is (according to the State's technical basis documentation [CTAG, 2003]) equivalent to and therefore protective of human health risk of 10^{-5} associated with excess lifetime cancer induction.

On the weight of this relevant public, an annual public dose limit of 19 mrem Total Effective Dose Equivalent (TEDE) was adopted as the dose basis for the DCGL.

3.2 DOSE–CONCENTRATION RELATIONSHIP

The process to correlate a radioactivity concentration to dose can proceed after the annual public dose limit 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).

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

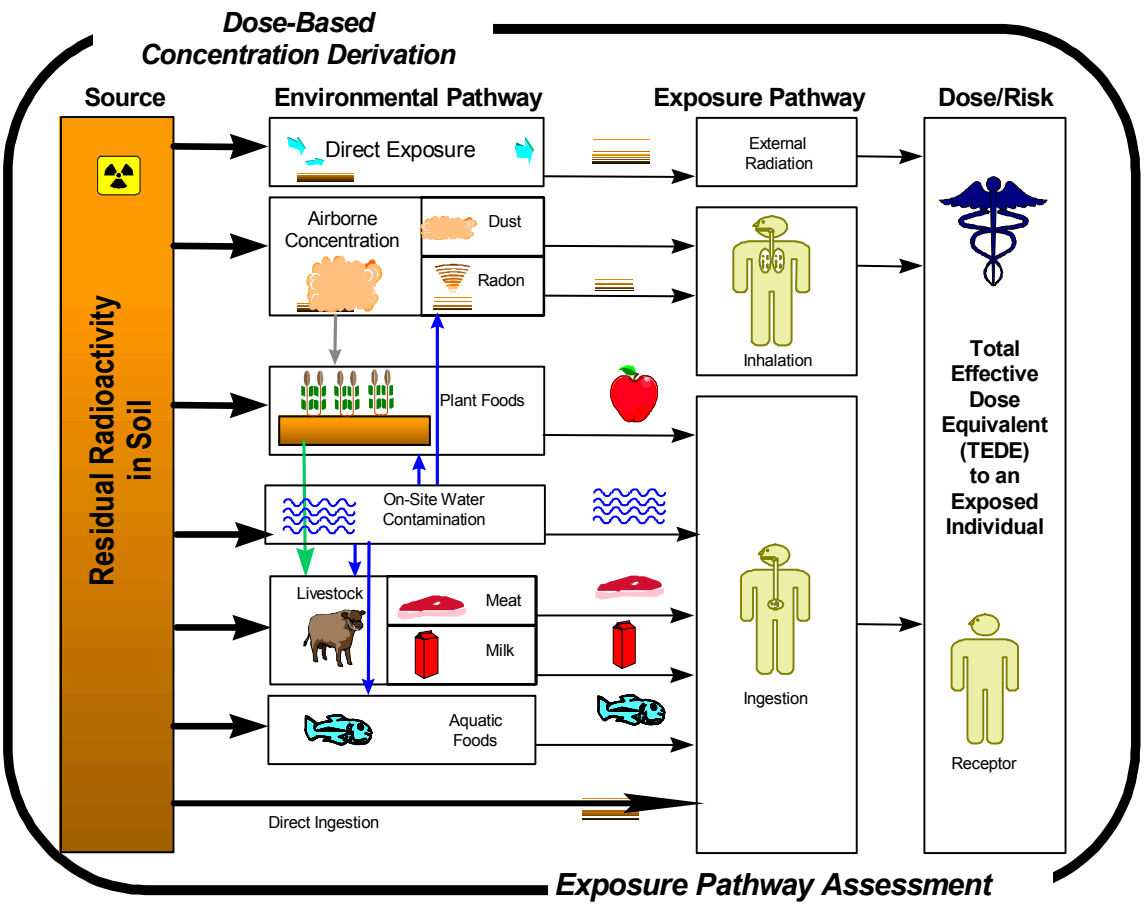

Figure 3–1 Conceptual Human Exposure Assessment Model

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 other factors 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 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 includes all conceivable pathways for human exposure to residual radioactivity associated with the 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 project stakeholders. They represent a range of potential future uses of the Site and thus serve to gauge the range of potential human exposures that may result from residual radioactivity in soil at the Site.

3.3 POTENTIAL FUTURE EXPOSURE SCENARIOS

A number of potential future use scenarios were proposed by ABB and discussed with stakeholders. Future use scenarios considered ranged from the conservative rural subsistence family farm, to commercial agricultural site uses, suburban residential uses, recreational use of open public space, and continued use as a commercial and light industrial type office park into the foreseeable future. It was acknowledged among stakeholders that the most likely potential future use of the Site was continued use as a commercial and light industrial type office park. The land is currently zoned for commercial/industrial uses and the Town of Windsor has indicated that their long-term planning and growth strategy identifies this and surrounding property as designated for commercial and light industrial uses.

Future residential use of the land is considered unlikely given: 1) the current land-use trend; 2) the current community growth, planning, and development strategies of the local municipality; and 3) the economic value of the land for sustained commercial use. Although unlikely, it is reasonable and credible to consider that the land might be used for locating residential dwellings in the future.

ABB considers the future use of the Site for subsistence farming to be highly improbable. In addition to the factors that make a residential land use unlikely, the likelihood that subsistence farming might occur at this Site is thought to be even more remote because: 1) the general population is moving away from subsistence farming; 2) the amount of land required to support subsistence farming is economically infeasible considering the value of the land; and 3) the population demographics in the Windsor area are consistent with east coast urban/suburban uses and trending away from farm/agricultural uses. In spite of the evidence supporting the conclusion that subsistence farmin is highly improbable as a reasonable future use at the Site, a resident farming scenario has been included in this evaluation to meet CTDEP requirements.

From among the many scenarios and variants considered, a suite of six separate future use scenarios has emerged as candidates to be considered in the development of the site-specific soil DCGLs. The future use scenarios evaluated include:

- Workers exposed while working occupationally at the Site's facilities
- Construction Activities
- Users of Publicly Accessible Lands designated for recreational uses
- Commercial Crop "Truck" Farming

- Suburban Residential
- Resident Farming

The current condition of the Site is ideally suited for its current and projected future uses as a commercial office/light industrial complex. A number of non-impacted buildings specifically designed to house office, research and development, and warehousing operations are already built and are currently in use. Thus, the scenario for use of the Site in its current condition is consistent with the most likely credible future use of the Site.

Many of the support structures on Site have never been used in connection with operations and activities involving radioactivity. Some others have already been shown to have no measurable concentrations of residual radioactivity. Structures that have been impacted by past operations involving radioactive materials are slated to be remediated and ultimately demolished. Therefore, the buildings and structures themselves do not represent a source of potential future exposure. However, future earthwork on the Site, such as backfilling, utility and foundation installations, and grading warrants consideration of a potential future exposure scenario for a construction worker. A construction scenario was developed and evaluated to gauge the exposure potential to construction workers engaged in Site excavation and grading operations that would likely be involved in preparing the Site for many of these other future uses. A single scenario evaluates the potential future exposure to Site construction workers.

Each of the six scenarios is evaluated to arrive at a single, site-specific, residual radioactivity concentration in soil that will be protective of human health in accordance with the guidelines. Figure 3–2 illustrates the six scenarios evaluated and depicts the overall conceptual approach to deriving a DCGL that will satisfy the annual public dose limits for the population potentially exposed in each of the scenarios.

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

3.3.1 Dose Assessment Methodology

The objective, or endpoint, for this portion of the project is to arrive at a residual radioactivity concentration (the DCGL) in soil, which, if left in place, will be adequately protective of human health in reasonably foreseeable future uses of the Site.

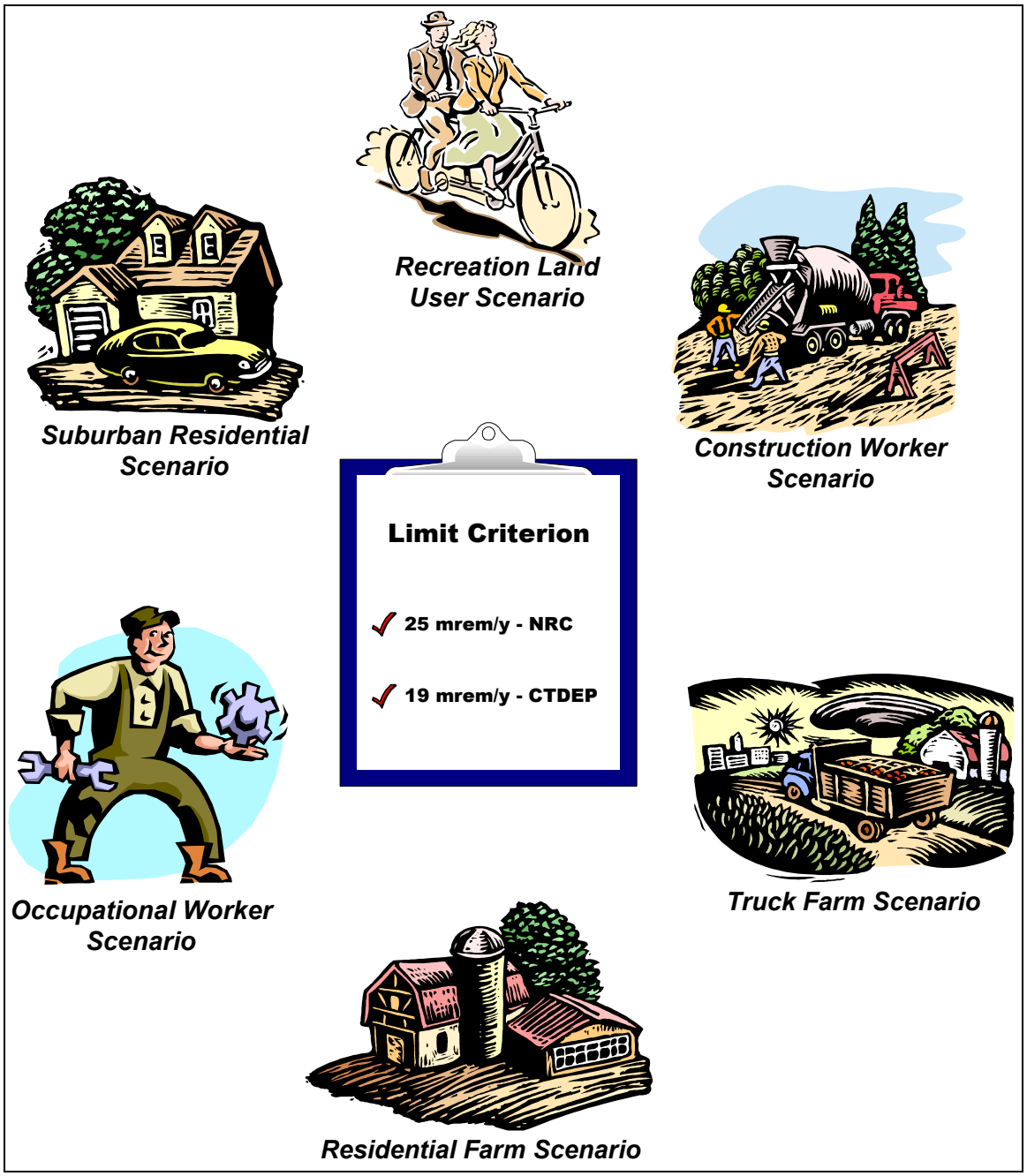

Figure 3–2 Potential Future Land Use Exposure Scenarios Evaluated

Fundamentally, there are two types of risk assessment methods: deterministic and probabilistic. Most are familiar with the deterministic approach as it has been, until recently, the most widely used of the two. The deterministic health risk assessment method is designed to capture the reasonable maximum exposure (RME) condition for a receptor using single point estimates of parameter values used to calculate dose. Such a calculation provides the risk manager with a single point estimate of dose that could

result from a given concentration of radioactivity. Few parameters used to calculate future dose potential are so well known that they could be described by a single value. In recognition of this limitation, deterministic risk assessments typically use overly conservative values for parameters in an attempt to bound the inherent uncertainty.

By contrast, the probabilistic methodology specified by the USNRC addresses extreme case exposure potential through what is essentially an uncertainty analysis taking the range and distribution of individual parameters into consideration. The probabilistic method provides a substantially clearer picture of the potential future dose corresponding to a residual radioactivity concentration for the risk manager to evaluate.

Rather than using the RME from among the entire population (as is the case in the typical deterministic method risk decisions) the probabilistic method allows the risk manager to focus on what is termed the "critical exposure group." The critical exposure group is the sub-population expected to be the most exposed among those who may receive exposures at the Site. The USNRC establishes the decision criterion based upon the use of a probabilistic assessment method and the resulting mean or "most likely" exposure to an exposed member of the critical exposure group (USNRC, 1997; 2000b). Table 3–1 summarizes the principal differences that exist between the deterministic and probabilistic methods.

The RESRAD dose modeling code is capable of calculating both deterministic and probabilistic risk estimates from a data set defining a specific set of parameters. For the derivation of the Site-specific DCGL, a probabilistic analysis will be presented using the range and distribution of values for parameters expected for the Site-specific exposure scenarios and conditions considered.

Table 3-1. Comparison of Methodologies

	Probabilistic	***Deterministic***
Measure of Human Health Detriment	Annual Radiation Dose measured in millirems per year	Annual Radiation Dose measured in millirems per year
Parameter Value Basis	Mean value for average member of a defined critical exposure group in a specific exposure scenario	Reasonable Maximum Value picked from accepted default values
Calculation Method	Computer Modeling Code	Algebraic summation using Spreadsheet (or older computer codes without Monte Carlo sampling algorithms).
Time Integration	Yes. Integration intervals vary to allow for radioactivity in growth, decay and transport.	No. Point estimate, considering discrete point in time and Site conditions

3.3.1.1 Understanding the RESRAD Computer Modeling Code

Among the advantages that RESRAD brings to a radiological dose or risk assessment is its ability to derive values for exposure parameters based on built-in fate and transport computations using well-defined site-specific data. It is also able to integrate dose and

risk projections over time taking into account transient conditions over that period. It is widely accepted as an industry standard tool for performing radiological dose assessments and specifically for deriving concentration guideline values. A few of the key points that should be recognized about the RESRAD modeling code and the algorithms it uses are:

- Default Dose Conversion Factors (DCFs) used in RESRAD 6.0 are taken from Federal Guidance Report (FGR) #11 (USEPA, 1988) and FGR #12 (USEPA, 1993), and are derived using the ICRP 30 dosimetry model. The bio-kinetic dosimetry model accounts for particle fractioning that might occur following exposure. For example, the DCFs for particle inhalation account for the dose to the GI tract from the fraction of respired particles that are ingested. As a result, there is no need to independently account for biological fractioning in the dose calculations.
- Short-lived (<180 days) radioactive progeny isotopes are accounted for using the "parent+D" DCFs.
- RESRAD integrates and normalizes exposure factors based on the fraction of time a receptor is exposed over the exposure period. For example, a soil ingestion rate of 100 mg/d for a receptor who is exposed on Site for only 50% of one day would result in an ingestion intake of 50 mg.
- RESRAD requires that the risk assessor input single point estimates for values of every parameter required to evaluate complete pathways in the deterministic module of the code. RESRAD uses the single point deterministic value for a specific parameter to calculate dose or risk unless the risk assessor specifies that the value be evaluated with a range of possible values selected from a specified distribution. It is not necessary to evaluate the uncertainty in every parameter, as variability (perhaps stemming from uncertainty) in many parameters does not contribute significantly to variability or uncertainty in the resulting dose.

3.3.2 Site-specific Geophysical Model

The basic site-specific geophysical conditions at the site are essentially independent of the predicted future land uses and the metabolic and behavioral parameters associated with human exposure at the site. The key parameters describing the conceptual geophysical model used in all of the future use scenarios evaluated are those describing the depth and areal deposition of the residual radioactivity in soil, the physical and hydraulic properties of the underlying unsaturated layer(s), as well as the physical and hydraulic properties of the underlying saturated layer from which water might be drawn.

3.3.2.1 Surface Soil (Contaminated) Layer

Generally, residual radioactivity in soils at the site is confined to a thin, surface soil veneer. Historically available evidence, coupled with contemporary screening level analysis indicates that elevated radioactivity in soils, where it can be found at all, is typically confined to the top 3" of soil (7.5 cm) with few screening results indicating the presence of detectable radioactivity at depths of 6" bgs (15 cm). The thickness of the

contaminated layer used in the RESRAD model is described as a triangular distribution ranging in thickness from zero to 12 inches (0 to 30 cm) with a mode of 3 inches (7.5 cm). The areal extent of the contaminated layer is assumed, for modeling purposes, to cover the entire 500-acre parcel described earlier. In reality, several smaller areas of land surface located within the 500-acre parcel are potentially impacted by radiological operations.

The hydraulic conductivity, hydraulic field capacity, porosity, and density are all described with the deterministic RESRAD default values.

The contaminant soil/water partitioning coefficient (K_d) is a key hydrogeologic parameter used in the derivation of the soil DCGLs. The RESRAD defaults are used for deriving the soil DCGL for the byproduct source term (Co-60). Data from the two reports that have evaluated site-specific K_d values for the CE Windsor Site (ENSR, 2001 and Wang, 1996) were evaluated to arrive at the RESRAD input values for uranium K_d in soils. In the study performed by Wang, eight surface soil samples from various locations were tested for desorption K_d (transfer of radioactivity from soil to water). The results ranged from 1,760 to 22,800 ml/g with an average of 8,591 ml/g. In the study performed by ENSR, three soil samples were tested for desorption K_d. The desorption K_d samples were from different locations across the CE Windsor Site and the results ranged from 1,700 to 20,000 ml/g with an average of 8,922 ml/g. A map summarizing K_d sample locations and values for both reports is shown in Figure 3–3.

Comparing the two studies reveals that the desorption K_d values are comparable since the range and mean for both sets are essentially identical and therefore can be considered one population. This provides data from 11 locations and can be considered a reasonable approximation for the CE Windsor Site. The desorption K_d values are summarized in Table 3–2 and are applicable for the contaminated layer in RESRAD. The Site-specific desorption K_d values were used to create a lognormal-N distribution in the probabilistic module in RESRAD for the contaminated layer as shown in Figure 3–4. K_d for the contaminated layer has a central tendency of 8,700 ml/g with a range of approximately 1,700 to 40,000 ml/g.

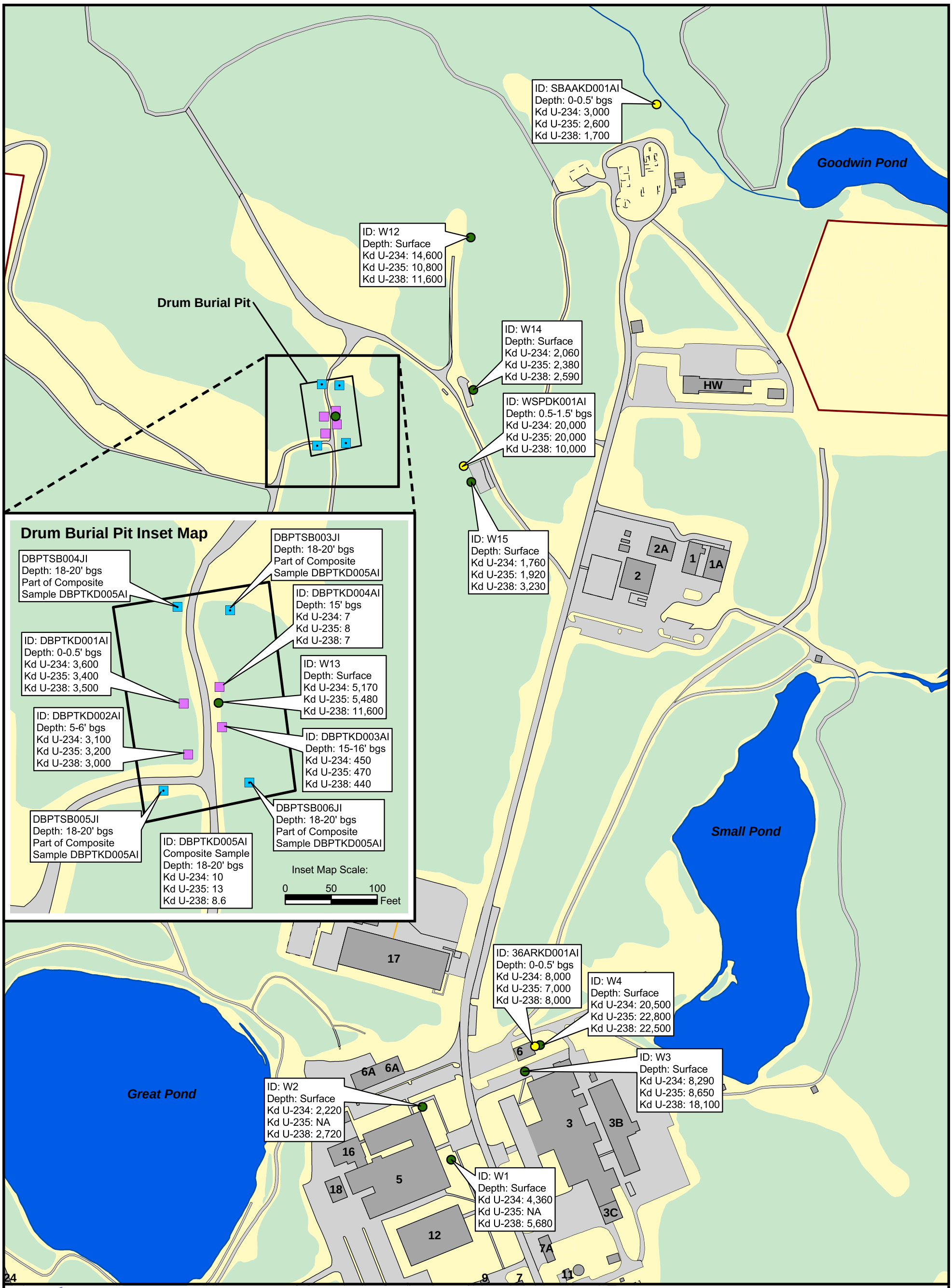

Figure 3-3
Kd Sample Locations

CE Windsor Site
Windsor, Connecticut
MACTEC, Inc.

Document: P:\Projects\ABBWIN\GIS-Av8\MapDocuments\Under_Development\Kd_Samples.mxd PDF: P:\Projects\ABBWIN\GIS-Av8\Figures\KdSamples\KdSamples_Figure3-3.pdf 09/24/2003 3:39 PM brpeters

Table 3-2 Desorption K_d Values for Surface Soils of the CE Windsor Site

Source	Uranium Distribution Coefficient (K_d), ml/g		
	U-234	U-235	U-238
ENSR 2001	20000	20000	10000
ENSR 2001	8000	7000	8000
ENSR 2001	3000	2600	1700
Wang 1996	4360	*	5680
Wang 1996	2220	*	2720
Wang 1996	8290	8650	18100
Wang 1996	20500	22800	22500
Wang 1996	14600	10800	11600
Wang 1996	5170	5480	11600
Wang 1996	2060	2380	2590
Wang 1996	1760	1920	3230
Minimum	1,700 ml/g		
Average	8,687 ml/g		
Maximum	22,800 ml/g		

Note: * indicates not analyzed

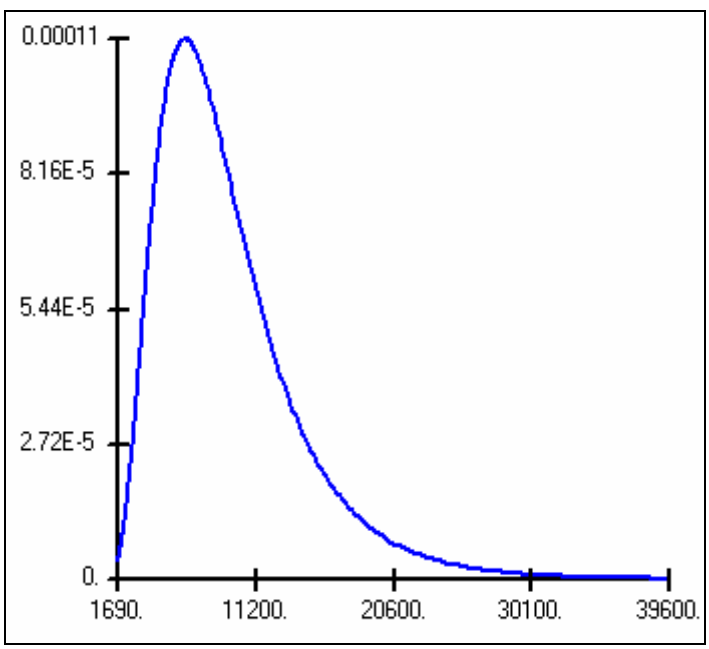

Figure 3–4 Uranium K_d (ml/g), Contaminated Layer

3.3.2.2 Unsaturated Layer #1

The site-specific K_d studies suggest the need to use two distinct values for K_d in the underlying unsaturated soils depending upon the depth of the soil below the ground surface. This is because measured K_d values for uranium isotopes in near surface soils are markedly different from those measured in deeper subsurface soils. The demarcation point below which the uranium K_d appears to change markedly is approximately 2 meters below ground surface (bgs). Consequently, the underlying unsaturated layer at the site has been subdivided into two unsaturated layers. The uranium K_d for the uppermost layer (unsaturated layer #1) is derived from adsorption K_d measurements made on samples collected from 0 to 2 meters bgs. Uranium adsorption K_d measurements made on samples collected from deeper than 2 meters are used to derive the probabilistic K_d distribution used for unsaturated layer #2.

The adsorption K_d values (transfer of radioactivity from water to soil) were only evaluated in the ENSR study (ENSR, 2001). Table 3–3 contains measured adsorption K_d values from soils between 0 and 6 ft. (0 to 2 meters) bgs. Based on the Site-specific data available, uranium K_d values in unsaturated zone #1 have been described in RESRAD with a lognormal-N distribution having a central tendency of 3,300 ml/g and a range of approximately 3,000 to 3,600 as shown in Figure 3–5.

The thickness of Unsaturated Layer #1 is described with a lognormal-N probabilistic distribution having a central tendency value corresponding to 2 meters thickness and a range of 1 to 4 meters thick. The hydraulic conductivity, hydraulic field capacity, porosity, and density are all described with the deterministic RESRAD default values.

Table 3-3 Adsorption K_d Values, Unsaturated Layer #1

Depth (ft)	Uranium Distribution Coefficient (K_d), ml/g		
	U-234	U-235	U-238
0 - 0.5	3600	3400	3500
5 - 6	3100	3200	3000
Minimum	3,000 ml/g		
Average	3,300 ml/g		
Maximum	3,600 ml/g		

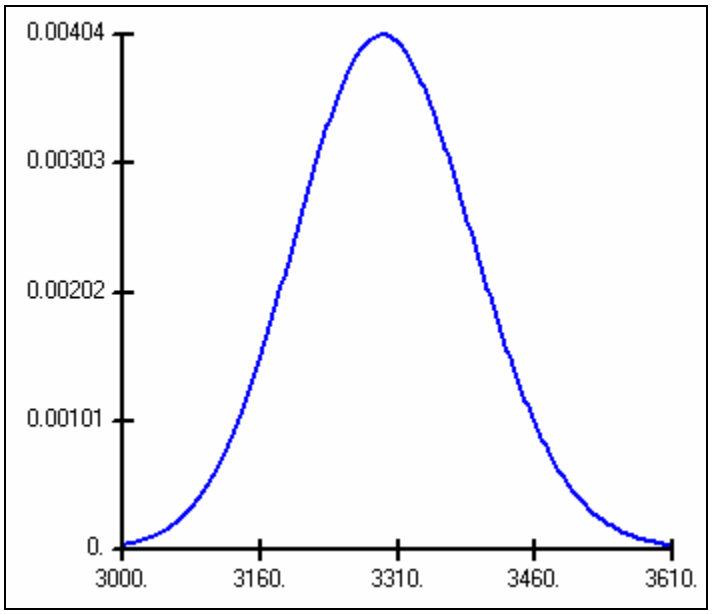

Figure 3–5 Uranium K_d (ml/g), Unsaturated Layer #1

3.3.2.3 Unsaturated Layer #2

The thickness of Unsaturated Layer #2 is described with a lognormal-N probabilistic distribution having a central tendency value corresponding to 4 meters thickness and a range of 2 to 17 meters thick. The hydraulic conductivity, hydraulic field capacity, porosity, and density are all described with the deterministic RESRAD default values.

Table 3–4 contains measured adsorption K_d values from soil samples collected from depths 10 ft. (3 meters) and greater bgs.

Table 3-4 Adsorption K_d Values, Unsaturated Layer #2

Depth (ft.)	Uranium Distribution Coefficient (K_d), ml/g		
	U-234	U-235	U-238
10	7	8	7
15 - 16	450	470	440
18 - 20	10	13	8.6
Minimum	7 ml/g		
Average	157 ml/g		
Maximum	470 ml/g		

Based on the Site-specific data available, the uranium K_d value in Unsaturated zone #2 has been described in RESRAD with a lognormal-N distribution having a central tendency of 125 ml/g (the RESRAD default) and a range of approximately 6 to 2,500 ml/g as shown in Figure 3–6.

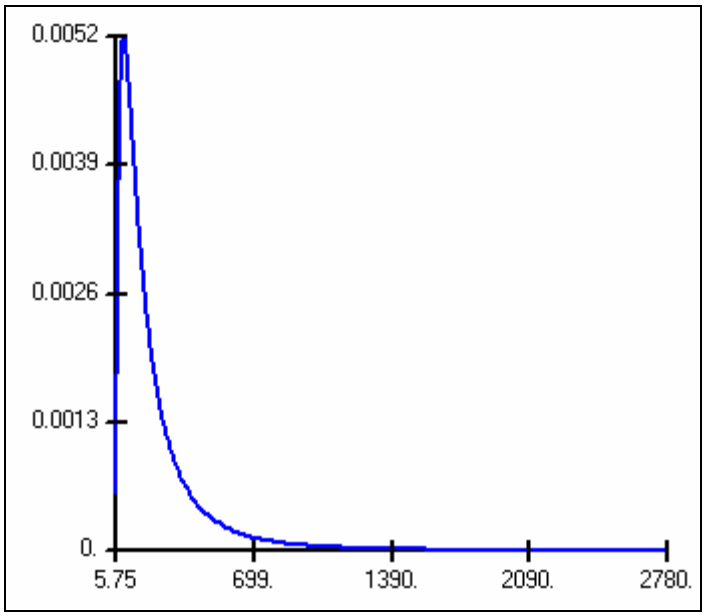

Figure 3–6 Uranium K_d (ml/g), Unsaturated Layer #2

3.3.2.4 Saturated Layer

The saturated soil layer is described, essentially, with RESRAD deterministic default parameters. The one exception is the parameter description for the uranium K_d in the Saturated Layer. In that case, the same RESRAD default probabilistic distribution (lognormal-N) used to describe the uranium K_d for Unsaturated layer #2 is used to describe the uranium K_d in the Saturated Layer. It is conservatively assumed that the near surface, water-bearing zone produces a sufficient quantity of drinking quality water to support all water demands that might be placed upon it and that the water would be extracted thru onsite wells placed at the down gradient edge of the source term.

3.3.3 Occupational Worker Exposure Scenario

Among the scenarios evaluated, the occupational worker scenario is estimated to be the most likely given the expected future use of the Site. From a probabilistic perspective, this scenario would yield the most likely correlation between concentration of residual radioactivity and potential future dose. It is presented first in this report in acknowledgement of this qualitative assessment. Other scenarios are presented in successive order using this same logic.

3.3.3.1 Conceptual Site Model for the Occupational Worker Scenario

In describing the exposure scenario, it is first necessary to establish the conceptual site model, which defines the physical and geological conditions at the Site[7]. Figure 3–7 illustrates the conceptual description of the site's physical conditions expected with the occupational worker scenario.

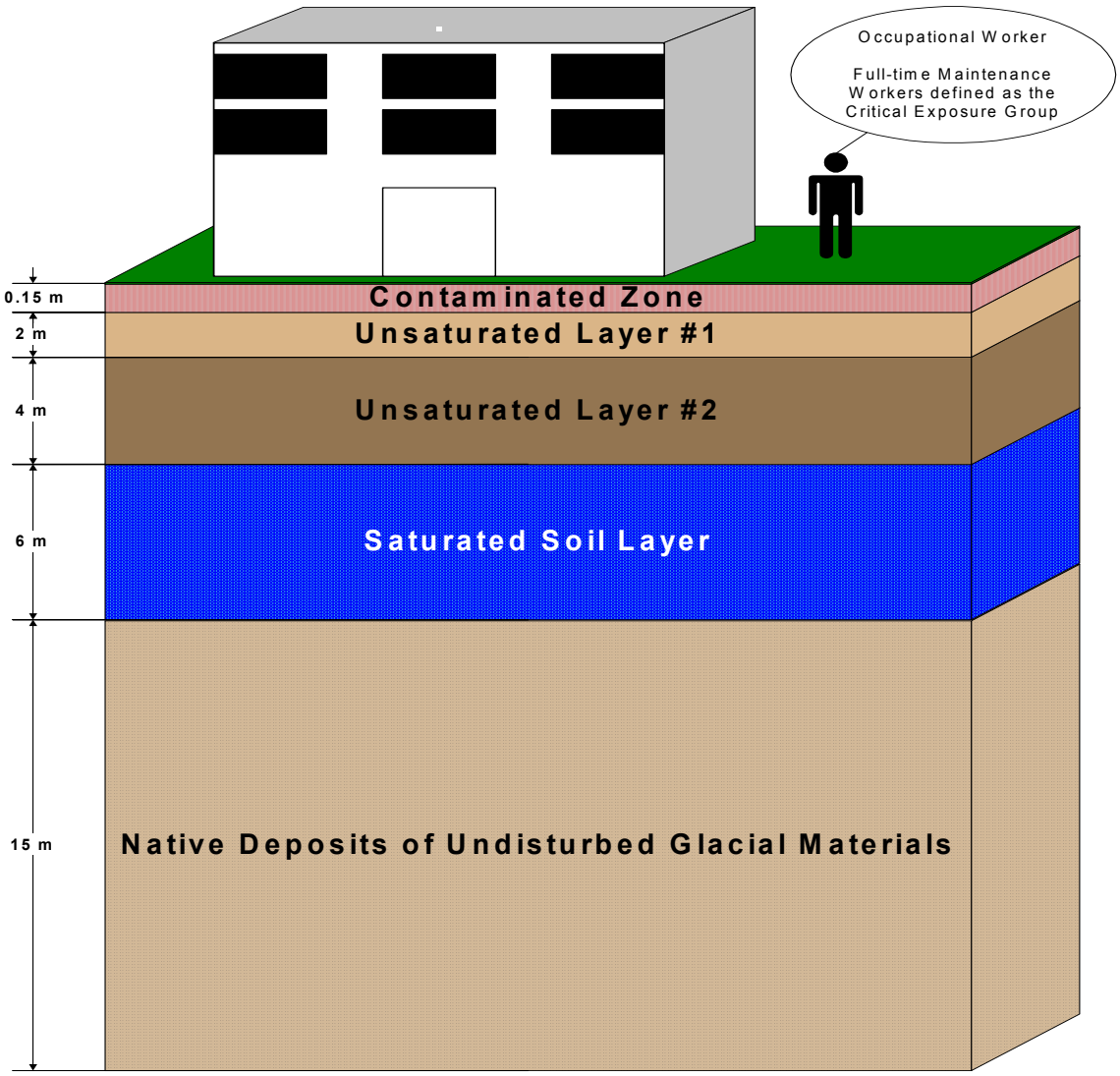

Figure 3–7. Conceptual Site Model Describing the Occupational Worker Scenario

[7] RESRAD is not a comprehensive groundwater and surface water fate and transport code. It does, however, model the vertical migration of radiological contaminants from surface or near surface soils to groundwater sources of drinking water and surface water bodies for the purpose of calculating the dose potential to human receptors who use such water as a drinking water or irrigation water source. As such, detailed hydrogeologic depictions of the Site are not necessary for RESRAD to model the pertinent radiological parameters.

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 potential dose.
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 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	A municipal potable drinking water supply system is already available and in use on the Site. By far, the most probable source for drinking water to a facility constructed at this Site is the local municipal water system making this pathway incomplete.
Meat Ingestion	No	Occupational workers are not expected to raise animals on the Site for food consumption. 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 occupational workers would graze milk cows on this Site.
Aquatic Foods Ingestion	No	Occupational workers are not expected to spend time fishing the surface water bodies on the Site. Therefore, the aquatic foods pathway is considered incomplete for this scenario.
Direct Ingestion	Yes	Occupational workers on the Site may ingest relatively small amounts of soil through incidental oral contact with their hands.

3.3.3.3 Critical Exposure Group

There is a vast array of crafts and skills that might be employed at a commercial facility engaged in research and development, light industry, or warehousing such as has been proposed. Those employed would include classes of workers who spend a vast majority of their workday indoors (e.g., office workers) but might also include workers spending a larger fraction of their workday, on average, outdoors. Longer outdoor exposure durations and more soil contact-intensive activities while at work are the keys to identifying the critical exposure group in this scenario. The workers having the potential for the longest outdoor exposure durations and the greatest contact with potentially contaminated soils for this occupational setting are the ones that work full-time at a large

light industrial 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 lawn care or building and systems repair. These factors make the full-time facility maintenance workers the *critical exposure group* for the occupational worker exposure scenario.

3.3.3.4 Exposure Factor Parameters

The occupational worker scenario involves typical workdays and 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. An exhaustive list of input parameters used in the RESRAD modeling code to evaluate the occupational worker scenario can be found in Appendix A.

Table 3-6 Key Parameters—Occupational Worker Scenario

Parameter			Central Tendency Value	Description of Parameter Distribution		Remark
Description	Code	Unit		Distribution	Range & Fit	
Receptor Exposure Factors						
Exposure Frequency (Total)	EF	Days per year	250	EF and ET are not input parameters used by RESRAD. They are presented here to disclose the calculation used to arrive at the parameters RESRAD uses to account for exposure frequency, FIND & FOTD.		Assumes full-time year around employment period (50 weeks) with two weeks allowance for sickness and vacation.
Exposure Frequency (Outdoors)	EF	Days per year	125			Assumes outdoor exposures do not occur during inclement weather
Exposure Time	ET	Hours per Day	8			Assumes 8-hour workday. Exposure time is divided between time spent indoors (8 hours/day during winter months, 4 hours/day during summer months) and time spent outdoors (4 hrs/day during summer months).
Indoor Time Fraction	FIND	0 to 1	0.171	Triangular	Range: 0.057 to 0.228	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 1500 hrs indoors on Site divided by 8760 hours.
Outdoor Time Fraction	FOTD	0 to 1	0.057	Triangular	Range: 0 to 0.114	The fraction of a total year (8760 hr) that is spent outdoors on Site. Equals 500 hrs outdoors on Site divided by 8760 hours.
Shielding Factor, External Gamma	SHF1	unit less	0.27	Bounded Lognormal-N	μ Normal: -1.3 σ Normal: 0.59 min: 0.044 max: 1.0	The structure itself provides an attenuating effect during indoor exposure periods. RESRAD default probabilistic distribution is used.
Inhalation Rate	INHALR	m^3/yr	8400	Triangular	Range: 4380 to 13100	RESRAD default probabilistic distribution is used. The RESRAD default is conservative for the critical exposure group evaluated in this scenario. Studies of worker inhalation rates suggest that an appropriate annual inhalation rate for long-term exposure to adult males (geometric mean) is 5548 m^3/yr (USEPA, 1997).

Table 3-6 Key Parameters—Occupational Worker Scenario

Parameter			Central Tendency Value	Description of Parameter Distribution		Remark
Description	Code	Unit		Distribution	Range & Fit	
Shielding Factor, Inhalation	SHF3	unitless	0.4	Single point (deterministic) estimate used.		RESRAD deterministic default value used. The RESRAD default is conservative for the critical exposure group evaluated in this scenario. A study designed to investigate the fraction of indoor dust relative to outdoor dust reported a range of values (0.2-0.3) less than the RESRAD default. (Rutz, 1994)
Mass Loading for Inhalation	MLINH	g/m^3	0.00003	Continuous Linear	0.0 0.0000 0.000008 0.0151 0.000016 0.1365 0.00003 0.8119 0.00004 0.9495 0.00006 0.9937 0.000076 0.9983 0.0001 1.0000	Mass loading in air describes the airborne dust loading conditions on the Site. RESRAD default probabilistic distribution is used. The RESRAD default is conservative for the critical exposure group evaluated in this scenario. This is evident given that the arithmetic mean of the annual average PM10 concentrations reported among measurement stations in E. Hartford, Hartford, and Enfield, CT indicate that the regional dust loading in air in the vicinity of the site is approximately a factor of three lower than the RESRAD default (CTDEP, 1998).
Soil Ingestion Rate	SOIL	g/y	18.3	Triangular	Range: 0 to 36.5	RESRAD default probabilistic distribution is used. The RESRAD value used is consistent with the USEPA default value for adults engaged in non-contact intensive activities (50 mg/day). (Yu, 2000; USEPA, 1994).
Calculation Times	T(n)	Yrs.	0, 1, 10, 30, 100, 300, & 1000	NA		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 (USNRC 1997, 2000).
Site Parameters						
Area of Contaminated Zone	AREA	m^2	2,023,000	Parameter uncertainty not evaluated since the area of the potentially impacted Site is known with high degree of certainty.		Area selected conservatively corresponds to the entire Site (~500 acres).

Table 3-6 Key Parameters—Occupational Worker Scenario

Parameter			Central Tendency Value	Description of Parameter Distribution		Remark
Description	Code	Unit		Distribution	Range & Fit	
Cover Depth (thickness)	COVER0	m	0	NA		The DCGL has been conservatively derived assuming no advantage that would be associated with the attenuating nature of cover material overlying the source layer.
Thickness of Contaminated Zone	THICK0	m	0.075	Triangular	Range: 0 to 0.3	Site characterization data indicates that the residual radioactivity in soil on the Site is confined to the top 0-3 inches of surface soil on average. The source term thickness has been conservatively defined to be as thick as 1' (0.3m) thick to account for localized variability. Deeper deposits are covered with clean overburden, effectively attenuating radiation from these deep sources. Areas where the source thickness is greater than six inches are rare and typically associated with higher surface soil activity concentrations that warrant localized soil removal.
Contaminated Zone Density	DENSCZ	g/cm^3	1.5	Single point (deterministic) estimate used.		RESRAD deterministic default
Contaminated Zone Erosion Rate	VCZ	m/yr	0.001	Single point (deterministic) estimate used.		RESRAD deterministic default
Average Annual Wind Speed	WIND	m/sec	3.16	Truncated Lognormal-N	μ Normal: 1.15 σ Normal: 0.10 Quantile, min: 0.05 Quantile, max: 0.95	Site-specific annual average value, equal to 7.2 mph. (NOAA)
Precipitation Rate	PRECIP	m/year	1.12	Single point (deterministic) Site-specific value used		Annual average in Windsor (Hartford) area. Equals 44.1 inches per year. (NOAA)
Runoff Coefficient	RUNOFF	unitless	0.45	Uniform	Range: 0.1 to 0.8	The fraction of total annual precipitation that sheds off the surface and drains to the watershed drainage without percolating through the soil. The RESRAD default probabilistic distribution is used.
Evapo-transpiration Coefficient	EVAPTR	unitless	0.5	Single point (deterministic) estimate used.		RESRAD deterministic default. The RESRAD default is conservative compared to typical values in New England (approximately 0.7).
Depth of Soil Mixing Layer	DM	m	0.15	Triangular	Range: 0 to 0.6	RESRAD probabilistic default distribution used.

Table 3-6 Key Parameters—Occupational Worker Scenario

Parameter			Central Tendency Value	Description of Parameter Distribution		Remark
Description	Code	Unit		Distribution	Range & Fit	
K_d (Uranium)	DCACTC	cm^3/g	8700	Lognormal-N	μ Normal: 9.07 σ Normal: 0.53	Contaminated Layer: Site-specific, uranium desorption Kd derived from two Kd studies done at the CE Windsor Site (WANG, 1996; ENSR, 2001).
	DCACTU1	cm^3/g	3300	Lognormal-N	μ Normal: 8.1 σ Normal: 0.03	Unsaturated Layer #1: Site-specific uranium adsorption Kd derived from Kd study done at the CE Windsor Site (ENSR, 2001).
	DCACTU2	cm^3/g	125	Lognormal-N	μ Normal: 4.84 σ Normal: 1.0	Unsaturated Layer #2: RESRAD probabilistic default distribution used with the standard deviation adjusted such that the distribution approximates the Site-specific uranium adsorption Kd measured in deep subsurface soils at the CE Windsor Site (ENSR, 2001).
	DCACTS	cm^3/g	125	Lognormal-N	μ Normal: 4.84 σ Normal: 1.0	Saturated Layer: RESRAD probabilistic default distribution used with the standard deviation adjusted such that the distribution approximates the Site-specific uranium adsorption Kd measured in deep subsurface soils at the CE Windsor Site (ENSR, 2001).
K_d (Cobalt)	DCACT(n)	cm^3/g	235	Lognormal-N	μ Normal: 5.46 σ Normal: 2.53	All Layers: RESRAD probabilistic default distribution used.
Source Term Factors						
Dose Conversion Factors	DCFX(n)	mrem/pCi	All DCFs used are RESRAD defaults			RESRAD defaults from FGR #11 (USEPA, 1988) and FGR #12 (USEPA, 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			Uranium Source Term (% of total activity)			This isotopic mix is derived from Site-specific data and is consistent with the mixture expected for 3.5% enriched uranium. All percentages calculated as the fraction of total uranium activity in the mixture.
U-234	S1(6)	pCi/g	77.49%			
U-235	S1(7)	pCi/g	4.27%			
U-238	S1(8)	pCi/g	18.25%			

Table 3-6 Key Parameters—Occupational Worker Scenario

Parameter			Central Tendency Value	Description of Parameter Distribution		Remark
Description	Code	Unit		Distribution	Range & Fit	
Source Isotopes			Byproduct Source Term			
Co-60	S1(1)	pCi/g	100%			This byproduct source term is derived from three Site-specific sources: 1) Waste characterization data collected during the remediation of Buildings 2, 5, and 17; 2) sampling performed on site specifically designed to analyze "hard-to-detect" nuclides; and 3) waste stream profile data associated with reactor plant component maintenance activities with which the byproduct radioactivity on Site is associated. The source term accounts for the reactor plant byproduct isotopes with contributions of greater than 10.0% to the total annual effective dose equivalent. (See Appendix G for details on byproduct source term derivation).

3.3.4 Construction Worker Exposure Scenario

3.3.4.1 Conceptual Site Model for the Construction Worker Scenario

The geologic and hydraulic parameters of the conceptual Site model used in describing the construction worker exposure scenario are identical to those described for the occupational worker scenario. The major difference is that the construction worker scenario assumes that all activities take place outdoors. Thus, no structures or buildings are included. The conceptual Site model of the Site conditions evaluated for the construction worker is illustrated in Figure 3–8.

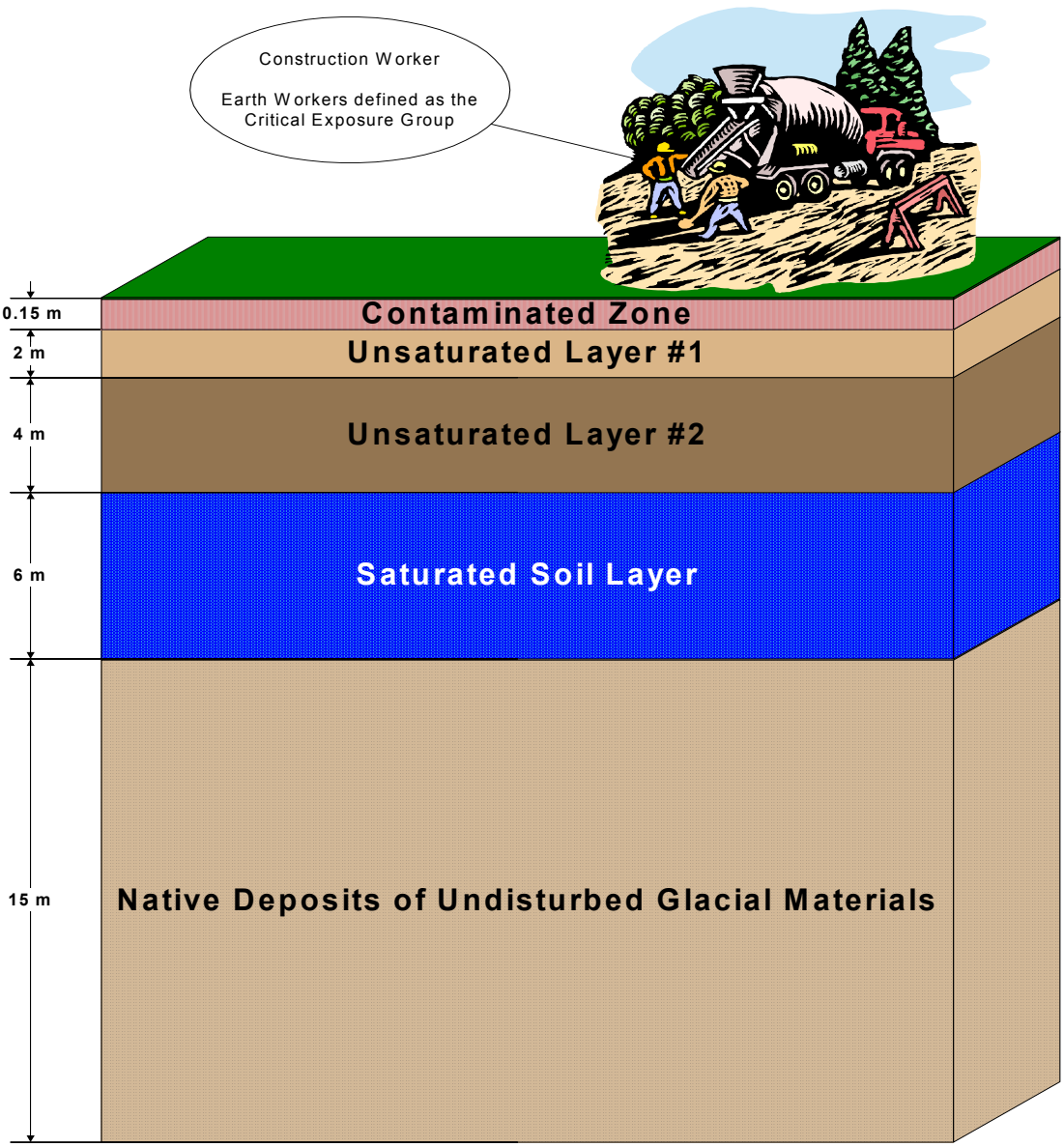

Figure 3–8 Conceptual Site Model Describing the Construction Worker Scenario

3.3.4.2 Pathways Included in the Construction Worker 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 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.
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 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. Potable drinking water is immediately available on Site from existing municipal water supply sources. 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. 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	Construction workers are not expected to spend time fishing the surface water bodies on the Site. Therefore, the aquatic foods pathway is considered incomplete for this scenario.
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.

3.3.4.3 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, the earth workers 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 3–8 along with specific remarks explaining the values selection, which shows the RESRAD input.

Table 3-8 Key Parameters—Construction Worker Scenario

(Earth Workers Defined as the Critical Exposure Group)

Parameter			Central Tendency Value	Description of Parameter Distribution		Remark
Description	Code	Unit		Distribution	Range & Fit	
Receptor Exposure Factors						
Exposure Frequency (Total)	EF	Days per year	125	EF and ET are not input parameters used by RESRAD. They are presented here to disclose the calculation used to arrive at the parameters RESRAD uses to account for exposure frequency, FIND & FOTD.		Assumes earthwork occurs for a six-month period (25 weeks) with no allowance for weather, sickness, vacation, or Site condition interruptions. Value is consistent with USEPA (and USEPA, Region I) guidance for evaluation of high-intensity, short-term exposures to excavation workers. The value selected is typical for exposure frequencies experienced by construction workers engaged in year-around activities at a given location.
Exposure Frequency (Outdoors)	EF	Days per year	125			
Exposure Time	ET	Hours per Day	8			Assumes 8-hour outdoor workday (USEPA, 1994). Exposure time is assumed to occur outdoors only.
Indoor Time Fraction	FIND	0 to 1	0.0	NA	NA	No credit is taken for time that a construction worker might spend indoors on Site (e.g., inside a construction trailer).
Outdoor Time Fraction	FOTD	0 to 1	0.114	Triangular	Range: 0 to 0.114	The fraction of a total year (8760 hr) that is spent outdoors on Site. Equals 1000 hrs outdoors on Site divided by 8760 hours.
Inhalation Rate	INHALR	m^3/yr	8400	Triangular	Range: 4380 to 13100	RESRAD default probabilistic distribution is used
Mass Loading for Inhalation	MLINH	g/m^3	0.00003	Continuous Linear	0.0 0.0000 0.000008 0.0151 0.000016 0.1365 0.00003 0.8119 0.00004 0.9495 0.00006 0.9937 0.000076 0.9983 0.0001 1.0000	Mass loading in air describes the airborne dust loading conditions on the Site. RESRAD default probabilistic distribution is used.
Soil Ingestion Rate	SOIL	g/y	18.3	Triangular	Range: 0 to 36.5	RESRAD default probabilistic distribution is used.

Table 3-8 Key Parameters—Construction Worker Scenario

(Earth Workers Defined as the Critical Exposure Group)

Parameter			Central Tendency Value	Description of Parameter Distribution		Remark
Description	Code	Unit		Distribution	Range & Fit	
Calculation Times	T(n)	Yrs.	0 1 10 30 100 300 1000	NA		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 (USNRC 1997, 2000).
Site Parameters						
Area of Contaminated Zone	AREA	m^2	2,023,000	Parameter uncertainty not evaluated since the area of the potentially impacted Site is known with high degree of certainty.		Area selected corresponds to the entire impacted portion of the Site (500 acres). Because the area selected in larger than the RESRAD default value (10,000 m^2) the area factor used in RESRAD to account for small source sizes is 1 indicating that while on Site, a receptor is continuously exposed over the contaminated area.
Cover Depth (thickness)	COVER0	m	0	NA		The DCGL has been conservatively derived assuming no advantage that would be associated with the attenuating nature of cover material overlying the source layer.
Thickness of Contaminated Zone	THICK0	m	0.075	Triangular	Range: 0 to 0.3	Site characterization data indicates that the residual radioactivity in soil on the Site is confined to the top 0-3 inches of surface soil on average. The source term thickness has been conservatively defined to be as thick as 1' (0.3m) thick to account for localized variability. Deeper deposits are covered with clean overburden, effectively attenuating radiation from these deep sources. Areas where the source thickness is greater than six inches are rare and typically associated with higher surface soil activity concentrations that warrant localized soil removal.
Contaminated Zone Density	DENS (zone)	g/cm^3	1.5	Single point (deterministic) estimate used.		RESRAD deterministic default
Contaminated Zone Erosion Rate	VCZ	m/yr	0.001	Single point (deterministic) estimate used.		RESRAD deterministic default

Table 3-8 Key Parameters—Construction Worker Scenario

(Earth Workers Defined as the Critical Exposure Group)

Parameter			Central Tendency Value	Description of Parameter Distribution		Remark
Description	Code	Unit		Distribution	Range & Fit	
Depth of Soil Mixing Layer	DM	m	0.15	Triangular	Range: 0 to 0.6	RESRAD probabilistic default distribution used.
Average Annual Wind Speed	WIND	m/sec	3.16	Truncated Lognormal-N	μ Normal: 1.15 σ Normal: 0.10 Quantile, min: 0.05 Quantile, max: 0.95	Site-specific annual average value, equal to 7.2 mph. (NOAA)
Precipitation Rate	PRECIP	m/year	1.12	Single point (deterministic) Site-specific value used		Annual average in Windsor (Hartford) area. Equals 44.1 inches per year. (NOAA)
Runoff Coefficient	RUNOFF	unitless	0.45	Uniform	Range: 0.1 to 0.8	The fraction of total annual precipitation that sheds off the surface and drains to the watershed drainage without percolating through the soil. The RESRAD default probabilistic distribution is used.
Evapo-transpiration Coefficient	EVAPTR	unitless	0.5	Single point (deterministic) estimate used		RESRAD deterministic default. The RESRAD default is conservative compared to typical values in New England (approximately 0.7).
Hydraulic Conductivity	HCCZ	m/yr	10	Single point (deterministic) estimate used		Contaminated Layer: RESRAD default
	HCUZ(1)		10			Unsaturated Layer #1: RESRAD default
	HCUZ(2)		10			Unsaturated Layer #2: RESRAD default
	HCSZ		100			Saturated Layer: RESRAD default
K_d (Uranium)	DCACTC	cm^3/g	8700	Lognormal-N	μ Normal: 9.07 σ Normal: 0.53	Contaminated Layer: Site-specific, uranium desorption Kd derived from two Kd studies done at the CE Windsor Site (WANG, 1996; ENSR, 2001).
	DCACTU1	cm^3/g	3300	Lognormal-N	μ Normal: 8.1 σ Normal: 0.03	Unsaturated Layer #1: Site-specific uranium adsorption Kd derived from Kd study done at the CE Windsor Site (ENSR, 2001).
	DCACTU2	cm^3/g	125	Lognormal-N	μ Normal: 4.84 σ Normal: 1.0	Unsaturated Layer #2: RESRAD probabilistic default distribution used with the standard deviation adjusted such that the distribution approximates the Site-specific uranium adsorption Kd measured in deep subsurface soils at the CE Windsor Site (ENSR, 2001).

Table 3-8 Key Parameters—Construction Worker Scenario

(Earth Workers Defined as the Critical Exposure Group)

Parameter			Central Tendency Value	Description of Parameter Distribution		Remark
Description	Code	Unit		Distribution	Range & Fit	
	DCACTS	cm^3/g	125	Lognormal-N	μ Normal: 4.84 σ Normal: 1.0	Saturated Layer: RESRAD probabilistic default distribution used with the standard deviation adjusted such that the distribution approximates the Site-specific uranium adsorption Kd measured in deep subsurface soils at the CE Windsor Site (ENSR, 2001).
K_d (Cobalt)	DCACT(n)	cm^3/g	235	Lognormal-N	μ Normal: 5.46 σ Normal: 2.53	All Layers: RESRAD probabilistic default distribution used.
Source Term Factors						
Dose Conversion Factors	DCFX(n)	mrem/pCi	All DCFs used are RESRAD defaults			RESRAD defaults from FGR #11 (USEPA, 1988) and FGR #12 (USEPA, 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			Uranium Isotopic Mix (% of total activity)			This isotopic mix is derived from Site-specific data and is consistent with the mixture expected for 3.5% enriched uranium. All percentages calculated as the fraction of total uranium activity in the mixture.
U-234	S1(6)	pCi/g	77.49%			
U-235	S1(7)	pCi/g	4.27%			
U-238	S1(8)	pCi/g	18.25%			
Source Isotopes			Byproduct Source Term			This byproduct source term is derived from three Site-specific sources: 1) Waste characterization data collected during the remediation of Buildings 2, 5, and 17; 2) sampling performed on site specifically designed to analyze "hard-to-detect" nuclides; and 3) waste stream profile data associated with reactor plant component maintenance activities with which the byproduct radioactivity on Site is associated. The source term accounts for the reactor plant byproduct isotopes with contributions of greater than 10.0% to the total annual effective dose equivalent. (See Appendix G for details on byproduct source term derivation).
Co-60	S1(1)	pCi/g	100%			

3.3.5 Recreational Visitor Exposure Scenario

3.3.5.1 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 construction worker scenario (Figure 3–9). No soil cover (e.g., asphalt or concrete in parking areas or on trails, no topsoil, clay and sod on playing fields) is considered even though it would be likely in at least some areas in such a scenario. The differences in this scenario are found, not in the hydrogeologic and geologic features of the Site conceptual model, but in the exposure factors related to the receptors and their activities.

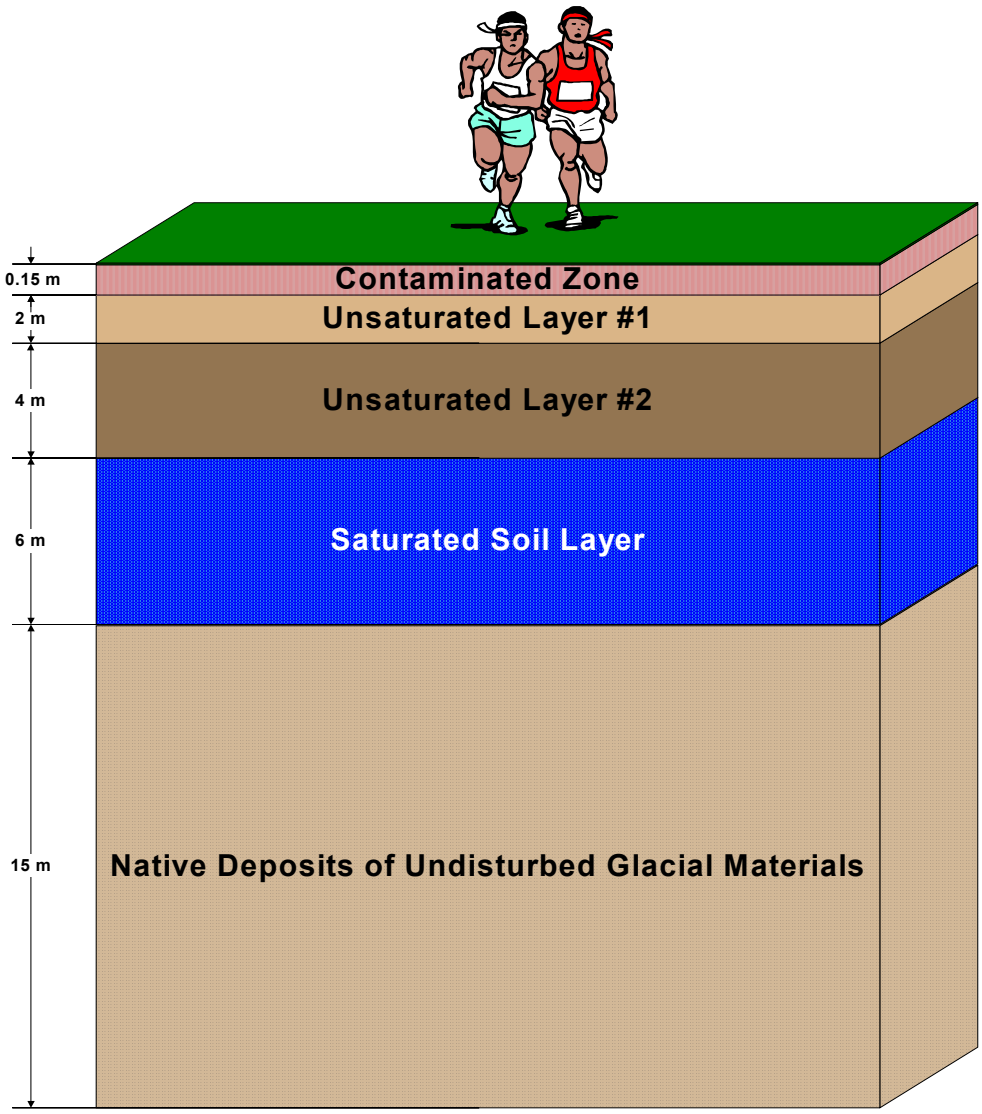

Figure 3–9 Conceptual Site Model Describing the Recreational Visitor/User Scenario

3.3.5.2 Pathways Included in the Recreational Visitor 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 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.
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 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	A municipal potable drinking water supply system is available both on Site and in the immediate vicinity of the Site. The most probable source for drinking water to a recreational use facility constructed at this suburban Site is the local municipal water system. It is prohibitively unlikely that drinking water might be drawn from potentially impacted surface or ground water, and so this pathway is considered incomplete.
Meat Ingestion	No	The fact that this Site is located in a populated suburban 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	Yes	This pathway is potentially complete for this scenario since there is a credible potential for aquatic foods (fish) to be available in the surface water bodies on the 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 walking/biking trails are placed present the possibility for contact with soils and incidental ingestion.

3.3.5.3 Exposure Factor Parameters

There is likely to be a great variety in the uses and frequency of visits to such a Site for recreational uses as envisioned and considered herein. Possible uses range from passive activities such as walks, reading, and picnicking 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 more passive activities that might be anticipated at the Site (e.g., walks, picnics, bike riding). Such activities involve light or non-intensive contact with soils having concentrations of residual radioactivity. Young children (under 6 years old) may also be present at the Site as a recreational user or visitor. Activities of very young children will inevitably involve more intensive soil contact, but are not expected to occur with a high frequency. The activities of the older adult and very young child receptor groups are characterized by seasonal availability, are typically engaged in less frequently than routine or scheduled activities such as regular jogging or league play on ball fields.

Older children (6 years and older) and young adults are more likely to be engaged in organized sporting activities that might occur at a park built on the Site such as little league baseball games or soccer matches. Some adults could make use of such a facility for regular jogging, roller blading, or biking are potentially the most exposed sub-population among those who may receive exposures while engaged in recreational activities at the Site. The possibility that a person may engage in relatively frequent, routine, or scheduled activities at the Site make the adult/adolescent who frequently participates in active outdoor recreational activities the *critical exposure group* for the recreational visitor exposure scenario.

The recreational visitor scenario involves high usage and non-intensive soil contact 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 along with specific remarks explaining the values selection.

Table 3-10 Key Parameters—Recreational User / Visitor Scenario

(Year Around Adult Users Defined as the Critical Exposure Group)

Parameter			Central Tendency Value	Description of Parameter Distribution		Remark
Description	Code	Unit		Distribution	Range & Fit	
Receptor Exposure Factors						
Exposure Frequency (Total)	EF	Days per year	91	EF and ET are not input parameters used by RESRAD. They are presented here to disclose the calculation used to arrive at the parameters RESRAD uses to account for exposure frequency, FIND & FOTD.		Assumes person visits facility three-times per week during spring, summer, and fall (April through October).
Exposure Frequency (Outdoors)	EF	Days per year	91			Assumes all exposures occur outdoors. Exposure during inclement weather is not likely to occur. (USEPA, 1994)
Exposure Time	ET	Hours per Day	2			Assumes 2-hours per visit, based on a typical duration of a field sporting event. This duration is longer than durations for most other events and activities that might occur (e.g., jogging).
Indoor Time Fraction	FIND	0 to 1	0	NA		It is conservatively assumed that all exposures occur outdoors.
Outdoor Time Fraction	FOTD	0 to 1	0.0208	Triangular	Range: 0 to 0.034	The fraction of a total year (8760 hr) that is spent outdoors on Site. Mode equals time spent outdoors on days when outdoor exposures are assumed to occur (91 days @ 2 hours/day). Equals 181 hrs on Site divided by 8760 hours. Value is allowed to range as high as 300 hrs per year.
Inhalation Rate	INHALR	m^3/yr	8400	Triangular	Range: 4380 to 13100	RESRAD default probabilistic distribution is used

Table 3-10 Key Parameters—Recreational User / Visitor Scenario

(Year Around Adult Users Defined as the Critical Exposure Group)

Parameter			Central Tendency Value	Description of Parameter Distribution		Remark
Description	Code	Unit		Distribution	Range & Fit	
Mass Loading for Inhalation	MLINH	g/m^3	0.00003	Continuous Linear	0.0 0.0000 0.000008 0.0151 0.000016 0.1365 0.00003 0.8119 0.00004 0.9495 0.00006 0.9937 0.000076 0.9983 0.0001 1.0000	Mass loading in air describes the airborne dust loading conditions on the Site. RESRAD default probabilistic distribution is used. The RESRAD default is conservative for the critical exposure group evaluated in this scenario. This is evident given that the arithmetic mean of the annual average PM10 concentrations reported among measurement stations in E. Hartford, Hartford, and Enfield, CT indicate that the regional dust loading in air in the vicinity of the site is approximately a factor of three lower than the RESRAD default (CTDEP, 2000b).
Soil Ingestion Rate	SOIL	g/y	18.3	Triangular	Range: 0 to 36.5	RESRAD default probabilistic distribution is used.
Drinking Water Well Intake Depth	DWIBWT	m	10	Triangular	Range: 6 to 30	While the drinking water pathway for the Recreational User Scenario is incomplete, allowance is made for the potential that a recreational user of the site might engage in fishing the ponds on the site.
Fish Consumption	DIET(5)	kg/y	5.4	Single point (deterministic) estimate used		RESRAD deterministic default value used. The RESRAD default is very conservative for the critical exposure group evaluated in this scenario as it includes the annual average fish consumption including both freshwater and saltwater species and does not differentiate between the amount of recreationally-caught fish and that provided commercially (USEPA, 1997).
Contaminated Fraction of Aquatic Food	FR9	0 to 1	0.39	Triangular	Range: 0 to 1.0	RESRAD default probabilistic distribution is used

Table 3-10 Key Parameters—Recreational User / Visitor Scenario

(Year Around Adult Users Defined as the Critical Exposure Group)

Parameter			Central Tendency Value	Description of Parameter Distribution		Remark
Description	Code	Unit		Distribution	Range & Fit	
Calculation Times	T(n)	Yrs.	0 1 10 30 100 300 1000	NA		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 (USNRC 1997, 2000).
Site Parameters						
Area of Contaminated Zone	AREA	m^2	2,023,000	Parameter uncertainty not evaluated since the area of the potentially impacted Site is known with high degree of certainty.		Area selected corresponds to the entire impacted portion of the Site (500 acres). Because the area selected in larger than the RESRAD default value (10,000 m^2) the area factor used in RESRAD to account for small source sizes is 1 indicating that while on Site, a receptor is continuously exposed over the contaminated area.
Cover Depth (thickness)	COVER0	m	0	NA		The DCGL has been conservatively derived assuming no advantage that would be associated with the attenuating nature of cover material overlying the source layer.
Thickness of Contaminated Zone	THICK0	m	0.075	Triangular	Range: 0 to 0.3	Site characterization data indicates that the residual radioactivity in soil on the Site is confined to the top 0-3 inches of surface soil on average. The source term thickness has been conservatively defined to be as thick as 1' (0.3m) thick to account for localized variability. Deeper deposits are covered with clean overburden, effectively attenuating radiation from these deep sources. Areas where the source thickness is greater than six inches are rare and typically associated with higher surface soil activity concentrations that warrant localized soil removal.

Table 3-10 Key Parameters—Recreational User / Visitor Scenario

(Year Around Adult Users Defined as the Critical Exposure Group)

Parameter			Central Tendency Value	Description of Parameter Distribution		Remark
Description	Code	Unit		Distribution	Range & Fit	
Thickness of Unsaturated Zone #1	H(1)	m	2	Bounded Lognormal-N	μ Normal: .693 σ Normal: 0.25 min: 1.0 max: 4.0	Site characterization data indicates that the combined thickness of unsaturated strata underlying the contaminated zone at the Site is, on average, approximately 20 feet (6 meters) thick. The unsaturated zone is segmented into two strata such that they may be assigned separate uranium K_d values.
Thickness of Unsaturated Zone #2	H(2)	m	4	Bounded Lognormal-N	μ Normal: 1.386 σ Normal: 0.6 min: 2.0 max: 17.0	
Contaminated Zone Density	DENSCZ	g/cm^3	1.5	Single point (deterministic) estimate used		RESRAD deterministic default
Contaminated Zone Erosion Rate	VCZ	m/yr	0.001	Single point (deterministic) estimate used		RESRAD deterministic default
Average Annual Wind Speed	WIND	m/sec	3.16	Truncated Lognormal-N	μ Normal: 1.15 σ Normal: 0.10 Quantile, min: 0.05 Quantile, max: 0.95	Site-specific annual average value, equal to 7.2 mph. (NOAA)
Precipitation Rate	PRECIP	m/year	1.12	Site-specific single point (deterministic) value used		Annual average in Windsor (Hartford) area. Equals 44.1 inches per year. (NOAA)
Runoff Coefficient	RUNOFF	unitless	0.45	Uniform	Range: 0.1 to 0.8	The fraction of total annual precipitation that sheds off the surface and drains to the watershed drainage without percolating through the soil. The RESRAD default probabilistic distribution is used.
Evapo-transpiration Coefficient	EVAPTR	unitless	0.5	Single point (deterministic) estimate used		RESRAD deterministic default. The RESRAD default is conservative compared to typical values in New England (approximately 0.7).
Hydraulic Conductivity	HCCZ	m/yr	10	Single point (deterministic) estimate used		Contaminated Layer: RESRAD default
	HCUZ(1)		10			Unsaturated Layer #1: RESRAD default
	HCUZ(2)		10			Unsaturated Layer #2: RESRAD default

Table 3-10 Key Parameters—Recreational User / Visitor Scenario

(Year Around Adult Users Defined as the Critical Exposure Group)

Parameter			Central Tendency Value	Description of Parameter Distribution		Remark
Description	Code	Unit		Distribution	Range & Fit	
	HCSZ		100			Saturated Layer: RESRAD default
Depth of Soil Mixing Layer	DM	m	0.15	Triangular	Range: 0 to 0.6	RESRAD probabilistic default distribution used.
K_d (Uranium)	DCACTC	cm^3/g	8700	Lognormal-N	μ Normal: 9.07 σ Normal: 0.53	Contaminated Layer: Site-specific, uranium desorption Kd derived from two Kd studies done at the CE Windsor Site (WANG, 1996; ENSR, 2001).
	DCACTU1	cm^3/g	3300	Lognormal-N	μ Normal: 8.1 σ Normal: 0.03	Unsaturated Layer #1: Site-specific uranium adsorption Kd derived from Kd study done at the CE Windsor Site (ENSR, 2001).
	DCACTU2	cm^3/g	125	Lognormal-N	μ Normal: 4.84 σ Normal: 1.0	Unsaturated Layer #2: RESRAD probabilistic default distribution used with the standard deviation adjusted such that the distribution approximates the Site-specific uranium adsorption Kd measured in deep subsurface soils at the CE Windsor Site (ENSR, 2001).
	DCACTS	cm^3/g	125	Lognormal-N	μ Normal: 4.84 σ Normal: 1.0	Saturated Layer: RESRAD probabilistic default distribution used with the standard deviation adjusted such that the distribution approximates the Site-specific uranium adsorption Kd measured in deep subsurface soils at the CE Windsor Site (ENSR, 2001).
K_d (Cobalt)	DCACT(n)	cm^3/g	235	Lognormal-N	μ Normal: 5.46 σ Normal: 2.53	All Layers: RESRAD probabilistic default distribution used.
Source Term Factors						
Dose Conversion Factors	DCFX(n)	mrem/pCi	All DCFs used are RESRAD defaults			RESRAD defaults from FGR #11 (USEPA, 1988) and FGR #12 (USEPA, 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.

Table 3-10 Key Parameters—Recreational User / Visitor Scenario

(Year Around Adult Users Defined as the Critical Exposure Group)

Parameter			Central Tendency Value	Description of Parameter Distribution		Remark
Description	Code	Unit		Distribution	Range & Fit	
Source Isotopes			Uranium Isotopic Mix (% of total activity)			This isotopic mix is derived from Site-specific data and is consistent with the mixture expected for 3.5% enriched uranium. All percentages calculated as the fraction of total uranium activity in the mixture.
U-234	S1(6)	pCi/g	77.49%			
U-235	S1(7)	pCi/g	4.27%			
U-238	S1(8)	pCi/g	18.25%			
Source Isotopes			Byproduct Source Term			This byproduct source term is derived from three Site-specific sources: 1) Waste characterization data collected during the remediation of Buildings 2, 5, and 17; 2) sampling performed on site specifically designed to analyze "hard-to-detect" nuclides; and 3) waste stream profile data associated with reactor plant component maintenance activities with which the byproduct radioactivity on Site is associated. The source term accounts for the reactor plant byproduct isotopes with contributions of greater than 10.0% to the total annual effective dose equivalent. (See Appendix G for details on byproduct source term derivation).
Co-60	S1(1)	pCi/g	100%			

3.3.6 Commercial "Truck" Farmer Exposure Scenario

While subsistence farming at the Site is highly unlikely, it is plausible to consider that at least some portion of the Site might in the future be used for commercial crop farming. Land in the near vicinity of the Site is currently in use for such a purpose. There are essentially two types of commercial crop farming engaged in. The local soil and climate are ideal for producing high-grade tobacco plants from which the leaves are harvested for use as cigar wrappers.[8]

The second type of commercial farming practiced locally is called "truck" farming. Truck farming is a local term used to describe the bulk planting, cultivating, and harvesting of a single consumable crop (e.g., corn, cucumbers, squash) on a relatively large, dedicated plot of land. Several such fields are cared for on a rotating basis by groups of farm workers. The produce of these fields is harvested in large trucks, shipped, and sold in bulk to local produce distributors and resellers. While there are no stated or described plans for the use of the Site property for such a purpose, the predisposition factors for this type of use are in place for this scenario.

3.3.6.1 Conceptual Site Model for the Truck Farmer Scenario

The hydrogeologic and geologic features of the Site in the commercial truck farm scenario are consistent with those described and shown for previous future use scenarios. The Site conceptual model for this scenario allows for increased but controlled soil erosion properties, the addition of the potential use of Site groundwater for irrigation purposes, and incorporates the gleaning and ingestion of consumable vegetation by farm workers. Figure 3–10 illustrates the variation in the Site conceptual model for this scenario. The geologic strata below the groundwater-saturated zone are not shown in Figure 3–10 to allow the reader to focus on the variation that occurs in the upper most strata as a result of the assumptions made for this scenario.

3.3.6.2 Pathways Included in the Commercial Truck Farmer Scenario

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

3.3.6.3 Exposure Factor Parameters

This scenario is discrete in that it addresses a very special variation of an occupational farming 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 commercial farming 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 *critical exposure group* for this

[8] The sheer cost of the locally produced tobacco makes it unlikely that it would be used as bulk tobacco in common cigars or cigarettes.

scenario is the adult farmer who prepares fields, plants, maintains, and harvests crops for commercial sale. The critical exposure group receptor is also assumed to consume produce gleaned from the commercial agricultural activities at the Site.

The truck farmer scenario involves seasonal exposure factors attributable to members of the critical group. Key parameters used to define the commercial crop truck farm exposure scenario are presented in Table 3–12 along with specific remarks explaining the values selection.

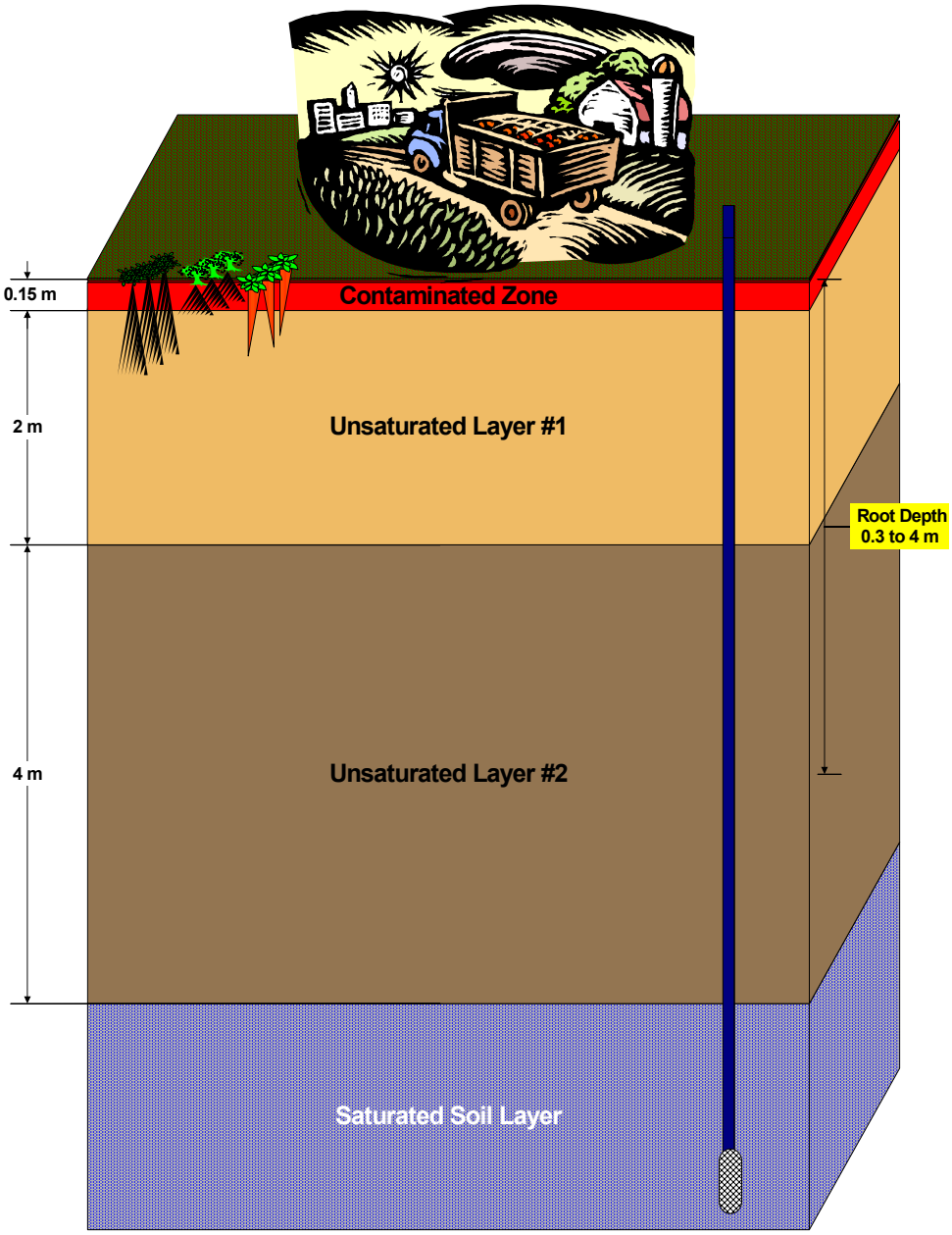

Figure 3–10. Conceptual Site Model Describing the Commercial Truck Farmer Scenario

Table 3-11 Evaluation of Pathways for the Commercial "Truck" Farmer 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.
Particulate Inhalation	Yes	Allowance is made for soils containing radiological constituents of the source being liberated and suspended in the breathing air of farm worker.
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 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. This pathway is complete since the truck farmer scenario specifically involves a receptor that gleans and consumes a portion of the food grown on the Site.
Drinking Water	No	A municipal potable drinking water supply system is available both on Site and in the immediate vicinity of the Site. The most probable source for drinking water for a farm worker at this Site is the local municipal water system either from onsite or nearby off-Site sources. It is prohibitively unlikely that drinking water might be drawn from potentially impacted surface or ground water, and so this pathway is considered incomplete.
Meat Ingestion	No	The fact that this Site is located in a populated suburban area makes the probability of livestock activities at the Site remote. Further, livestock activities are counter to the scenario under evaluation and are not expected to be raised for food at this Site. Thus, 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	Commercial farm workers are not expected to spend time fishing the surface water bodies on the Site. Therefore, the aquatic foods pathway is considered incomplete for this scenario.
Direct Ingestion	Yes	This pathway is conceivable because the 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.

Table 3-12 Key Parameters—Commercial Truck Farmer Scenario

(Adult Occupational Farm Worker Defined as the Critical Exposure Group)

Parameter			Central Tendency Value	Description of Parameter Distribution		Remark
Description	Code	Unit		Distribution	Range & Fit	
Receptor Exposure Factors						
Exposure Frequency (Total)	EF	Days per year	40	EF and ET are not input parameters used by RESRAD. They are presented here to disclose the calculation used to arrive at the parameters RESRAD uses to account for exposure frequency, FIND & FOTD.		Conservatively assumes 7-day workweeks. 1 week preparing field (tilling, fertilizing); 1 week planting; 1 day/week checking on field during growing season; 1 week harvesting; 1 week preparing field for winter.
Exposure Frequency (Outdoors)	EF	Days per year	40			Assumes all exposures occur outdoors.
Exposure Time	ET	Hours per Day	10			Assumes 10-hour workday at field.
Indoor Time Fraction	FIND	0 to 1	0	NA	NA	No exposure is assumed to occur indoors.
Outdoor Time Fraction	FOTD	0 to 1	0.0457	Triangular	Range: 0.03 to 0.06	The fraction of a total year (8760 hr) that is spent outdoors on Site. Equals 400 hrs outdoors on Site divided by 8760 hours.
Inhalation Rate	INHALR	m^3/yr	8400	Triangular	Range: 4380 to 13100	RESRAD default probabilistic distribution is used
Mass Loading for Inhalation	MLINH	g/m^3	0.00003	Continuous Linear	0.0 0.0000 0.000008 0.0151 0.000016 0.1365 0.00003 0.8119 0.00004 0.9495 0.00006 0.9937 0.000076 0.9983 0.0001 1.0000	Mass loading in air describes the airborne dust loading conditions on the Site. RESRAD default probabilistic distribution is used.
Soil Ingestion Rate	SOIL	g/y	18.3	Triangular	Range: 0 to 36.5	RESRAD default probabilistic distribution is used.

Table 3-12 Key Parameters—Commercial Truck Farmer Scenario

(Adult Occupational Farm Worker Defined as the Critical Exposure Group)

Parameter			Central Tendency Value	Description of Parameter Distribution		Remark
Description	Code	Unit		Distribution	Range & Fit	
Calculation Times	T(n)	Yrs.	0 1 10 30 100 300 1000	NA		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 (USNRC 1997, 2000).
Site Parameters						
Area of Contaminated Zone	AREA	m^2	2,023,000	Parameter uncertainty not evaluated since the area of the potentially impacted Site is known with high degree of certainty.		Area selected corresponds to the entire impacted portion of the Site (500 acres). Because the area selected in larger than the RESRAD default value (10,000 m^2) the area factor used in RESRAD to account for small source sizes is 1 indicating that while on Site, a receptor is continuously exposed over the contaminated area.
Cover Depth (thickness)	COVER0	m	0	NA		The DCGL has been conservatively derived assuming no advantage that would be associated with the attenuating nature of cover material overlying the source layer.
Thickness of Contaminated Zone	THICK0	m	0.075	Triangular	Range: 0 to 0.3	Site characterization data indicates that the residual radioactivity in soil on the Site is confined to the top 0-3 inches of surface soil on average. The source term thickness has been conservatively defined to be as thick as 1' (0.3m) thick to account for localized variability. Deeper deposits are covered with clean overburden, effectively attenuating radiation from these deep sources. Areas where the source thickness is greater than six inches are rare and typically associated with higher surface soil activity concentrations that warrant localized soil removal.

Table 3-12 Key Parameters—Commercial Truck Farmer Scenario

(Adult Occupational Farm Worker Defined as the Critical Exposure Group)

Parameter			Central Tendency Value	Description of Parameter Distribution		Remark
Description	Code	Unit		Distribution	Range & Fit	
Thickness of Unsaturated Zone #1	H(1)	m	2	Bounded Lognormal-N	μ Normal: .693 σ Normal: 0.25 min: 1.0 max: 4.0	Site characterization data indicates that the combined thickness of unsaturated strata underlying the contaminated zone at the Site is, on average, approximately 20 feet (6 meters) thick. The unsaturated zone is segmented into two strata such that they may be assigned separate uranium K_d values.
Thickness of Unsaturated Zone #2	H(2)	m	4	Bounded Lognormal-N	μ Normal: 1.386 σ Normal: 0.6 min: 2.0 max: 17.0	
Soil Density	DENS (zone)	g/cm^3	1.5	Single point (deterministic) estimate used		RESRAD deterministic default
Contaminated Zone Erosion Rate	VCZ	m/yr	0.001	Single point (deterministic) estimate used		RESRAD deterministic default
Depth of Roots	DROOT	m	1.85	Uniform	Range: 0.3 to 4.0	RESRAD default probabilistic distribution is used
Wet Weight Crop Yield (non-leafy)	YV(1)	Kg/m^2	0.7	Single point (deterministic) estimate used		RESRAD deterministic default
Fruit, Vegetable, and Grain Consumption	DIET(1)	Kg/yr	160	Single point (deterministic) estimate used		RESRAD deterministic default. Mean intake of fruits, vegetables, and grains is 160 kg/yr (wet weight, as consumed, or approximately 16.9 kg/yr dry weight) accounts for approximately 92% of the total mean intake of produce and grain by adults (USEPA, 1997). Remainder is accounted for in the consumption of leafy vegetables.
Leafy Vegetable Consumption	DIET(2)	Kg/yr	14	Single point (deterministic) estimate used		RESRAD deterministic default. Mean intake of leafy vegetables is 14 kg/yr (wet weight, as consumed). This accounts for approximately 8% of the total mean intake of produce and grain by adults (USEPA, 1997).

Table 3-12 Key Parameters—Commercial Truck Farmer Scenario

(Adult Occupational Farm Worker Defined as the Critical Exposure Group)

Parameter			Central Tendency Value	Description of Parameter Distribution		Remark
Description	Code	Unit		Distribution	Range & Fit	
Fraction of Produce that is Home-Grown	FPLANT	unitless	0.10	Single point (deterministic) estimate used		Value is calculated using the highest published 50th percentile intake of homegrown produce among all vegetables groups (USEPA, 1997). This value corresponds to 17.4 kg/y ingestion of "exposed vegetables" by an adult, and assumes that a "truck farm" farmer obtains his entire yearly intake of home-grown "exposed vegetables" from his own commercial farm. The value of 17.4 kg/yr corresponds to 10% of the total produce and grain intake by an adult. Hence, the fraction of produce that is homegrown is calculated to be 10% for a farmer.
Average Annual Wind Speed	WIND	m/sec	3.16	Truncated Lognormal-N	μ Normal: 1.15 σ Normal: 0.10 Quantile, min: 0.05 Quantile, max: 0.95	Site-specific annual average value, equal to 7.2 mph. (NOAA)
Precipitation Rate	PRECIP	m/year	1.12	Single point (deterministic) Site-specific value used		Annual average in Windsor (Hartford) area. Equals 44.1 inches per year. (NOAA)
Runoff Coefficient	RUNOFF	unitless	0.45	Uniform	Range: 0.1 to 0.8	The fraction of total annual precipitation that sheds off the surface and drains to the watershed drainage without percolating through the soil. The RESRAD default probabilistic distribution is used.
Evapo-transpiration Coefficient	EVAPTR	unitless	0.5	Single point (deterministic) estimate used		RESRAD deterministic default. The RESRAD default is conservative compared to typical values in New England (approximately 0.7).
Hydraulic Conductivity	HCCZ	m/yr	10	Single point (deterministic) estimate used		Contaminated Layer: RESRAD default
	HCUZ(1)		10			Unsaturated Layer #1: RESRAD default
	HCUZ(2)		10			Unsaturated Layer #2: RESRAD default
	HCSZ		100			Saturated Layer: RESRAD default

Table 3-12 Key Parameters—Commercial Truck Farmer Scenario

(Adult Occupational Farm Worker Defined as the Critical Exposure Group)

Parameter			Central Tendency Value	Description of Parameter Distribution		Remark
Description	**Code**	**Unit**		**Distribution**	**Range & Fit**	
Drinking Water Well Intake Depth	DWIBWT	m	10	Triangular	Range: 6 to 30	While the drinking water pathway for the Truck Farmer scenario is incomplete, allowance is made for the potential use of onsite groundwater for irrigation.
Depth of Soil Mixing Layer	DM	m	0.15	Triangular	Range: 0 to 0.6	RESRAD probabilistic default distribution used.
K_d (Uranium)	DCACTC	cm^3/g	8700	Lognormal-N	μ Normal: 9.07 σ Normal: 0.53	Contaminated Layer: Site-specific, uranium desorption Kd derived from two Kd studies done at the CE Windsor Site (WANG, 1996; ENSR, 2001).
	DCACTU1	cm^3/g	3300	Lognormal-N	μ Normal: 8.1 σ Normal: 0.03	Unsaturated Layer #1: Site-specific uranium adsorption Kd derived from Kd study done at the CE Windsor Site (ENSR, 2001).
	DCACTU2	cm^3/g	125	Lognormal-N	μ Normal: 4.84 σ Normal: 1.0	Unsaturated Layer #2: RESRAD probabilistic default distribution used with the standard deviation adjusted such that the distribution approximates the Site-specific uranium adsorption Kd measured in deep subsurface soils at the CE Windsor Site (ENSR, 2001).
	DCACTS	cm^3/g	125	Lognormal-N	μ Normal: 4.84 σ Normal: 1.0	Saturated Layer: RESRAD probabilistic default distribution used with the standard deviation adjusted such that the distribution approximates the Site-specific uranium adsorption Kd measured in deep subsurface soils at the CE Windsor Site (ENSR, 2001).
K_d (Cobalt)	DCACT(n)	cm^3/g	235	Lognormal-N	μ Normal: 5.46 σ Normal: 2.53	All Layers: RESRAD probabilistic default distribution used.
Source Term Factors						
Dose Conversion Factors	DCFX(n)	mrem/pCi	All DCFs used are RESRAD defaults			RESRAD defaults from FGR #11 (USEPA, 1988) and FGR #12 (USEPA, 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.

Table 3-12 Key Parameters—Commercial Truck Farmer Scenario

(Adult Occupational Farm Worker Defined as the Critical Exposure Group)

Parameter			Central Tendency Value	Description of Parameter Distribution		Remark
Description	Code	Unit		Distribution	Range & Fit	
Source Isotopes			Uranium Isotopic Mix (% of total activity)			This isotopic mix is derived from Site-specific data and is consistent with the mixture expected for 3.5% enriched uranium. All percentages calculated as the fraction of total uranium activity in the mixture.
U-234	S1(6)	pCi/g	77.49%			
U-235	S1(7)	pCi/g	4.27%			
U-238	S1(8)	pCi/g	18.25%			
Source Isotopes			Byproduct Source Term			This byproduct source term is derived from three Site-specific sources: 1) Waste characterization data collected during the remediation of Buildings 2, 5, and 17; 2) sampling performed on site specifically designed to analyze "hard-to-detect" nuclides; and 3) waste stream profile data associated with reactor plant component maintenance activities with which the byproduct radioactivity on Site is associated. The source term accounts for the reactor plant byproduct isotopes with contributions of greater than 10.0% to the total annual effective dose equivalent. (See Appendix G for details on byproduct source term derivation).
Co-60	S1(1)	pCi/g	100%			

3.3.7 Suburban Residential Exposure Scenario

As previously discussed, the circumstances in place at the Site make it very unlikely that future residential use of the CE property might occur. There are, however, some single family suburban home sites in the near vicinity of the CE property. There is also growing pressure in many suburban areas in the country, including the greater Hartford, Connecticut area, to make land available for residential building sites. It is therefore prudent to evaluate future residential uses of the Site as credible and plausible in deriving the soil DCGLs.

3.3.7.1 Conceptual Site Model for the Suburban Residential Scenario

A residence in this setting is likely to consist of single family housing units on plots of land smaller than one acre. The Site conceptual model describing the suburban 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 an office or warehousing complex. Figure 3–11 illustrates the conceptual description of the Site conditions that could be expected with a suburban residential exposure scenario.

3.3.7.2 Pathways Included in the Suburban Residential Scenario

Table 3–13 identifies the pathways that have been retained for the analysis and provides explanation for those pathways that were not retained.

3.3.7.3 Exposure Factor Parameters

This scenario supports a range of possible exposure durations as some spend more time at home than others. In addition, some residents may consume produce grown in a backyard garden, while others do not.[9] The exposure frequency and duration provide the greatest variability in the annual dose received by an exposed resident receptor. The adult who lives in a single-family suburban residential dwelling constructed at the Site and who spends the majority of the day at home on the Site is defined as the critical exposure group receptor. The same adult is assumed to engage in recreational "backyard" gardening and to consume produce grown in that garden. The adult is also assumed to engage in recreational fishing of the ponds located on the site and to consume the fish caught in the ponds. Examples of members of this group include retired people, those who work at home, as well as stay-at-home persons such as homemakers. This setting is characterized by yearlong exposure weighted for the seasonal variability prevalent in New England.

The suburban residential exposure scenario involves annualized exposure factors attributable to members of the critical group. Key parameters used to define the

[9] Fewer urban and suburban residents are maintaining backyard produce gardens today than did in years gone by.

residential exposure scenario are presented in Table 3–14 along with specific remarks explaining the values selection.

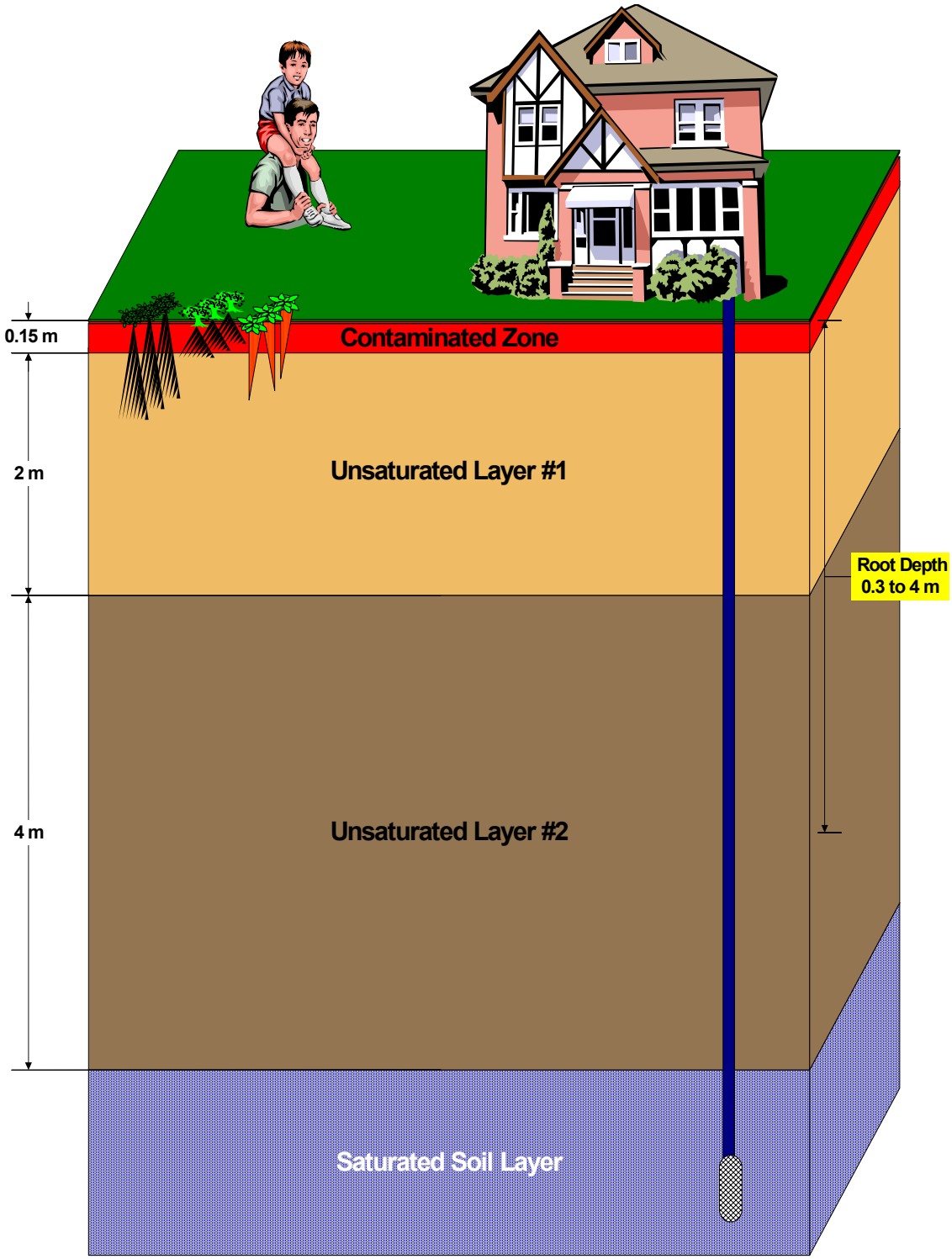

Figure 3–11. Conceptual Site Model Describing the Suburban Residential Scenario

Table 3-13. Evaluation of Pathways for the Suburban Residential Exposure 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.
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 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. The scenario also allows for a resident to raise a backyard garden and consume food grown on the Site, making this pathway complete.
Drinking Water	Yes	Aquifer beneath a portion of the Site is considered a potential source of potable water making this pathway potentially complete. However, use of groundwater for consumption is unlikely due to the availability of municipal drinking water from off-Site sources. Additionally, the Town of Windsor has indicated that it would require the use of publicly supplied drinking water from an off-Site source in the event that future development activities, such as a residential development, occur at the Site
Meat Ingestion	No	The fact that this Site is located in a populated suburban 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	Yes	This pathway is potentially complete for this scenario since there is a credible potential for aquatic foods (fish) to be available in the surface water bodies on the 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.

Table 3-14 Key Parameters—Urban Residential Scenario

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

Parameter			Central Tendency Value	Description of Parameter Distribution		Remark
Description	Code	Unit		Distribution	Range & Fit	
Receptor Exposure Factors						
Exposure Frequency (Total)	EF	Days per year	350	EF and ET are not input parameters used by RESRAD. They are presented here to disclose the calculation used to arrive at the parameters RESRAD uses to account for exposure frequency, FIND & FOTD.		This scenario involves yearlong exposure corresponding to seven days per week for 50 weeks (350 days). It allows for two weeks per year spent off-Site away from the residence while engaged in activities such as vacation (USEPA, 1994).
Exposure Frequency (Outdoors)	EF	Days per year	150			This value corresponds to five days per week for seven months of the year (April – October) corresponding to the typical New England seasonal conditions that limit outdoor activities (USEPA, 1994).
Exposure Time	ET	Hours per Day	21			It is assumed that the average member of the critical group will spend 21 hours per day at the residence. This allows for time spent off-Site for such activities as shopping, traveling, school, and visiting family and friends. The value is conservative for adults who work out of the home or attend school outside of the home.
Indoor Time Fraction	FIND	0 to 1	0.8048	Triangular	Range: 0.69 to 0.84	The fraction of a total year (8760 hr) that is spent indoors on Site. Assumes that an adult spends on average 2 hours per day outdoors on days when outdoor exposure occurs. Equals 7050 hrs (200 days * 21 hours + 150 days * 19 hours) indoors on Site divided by 8760 hours.
Outdoor Time Fraction	FOTD	0 to 1	0.0342	Triangular	Range: 0 to 0.15	The fraction of a total year (8760 hr) that is spent outdoors on Site. Assumes that an adult spends on average 2 hours per day outdoors on days when outdoor exposure occurs. Equals 300 hrs (150 days * 2 hours) outdoors on Site divided by 8760 hours.

Table 3-14 Key Parameters—Urban Residential Scenario

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

Parameter			Central Tendency Value	Description of Parameter Distribution		Remark
Description	Code	Unit		Distribution	Range & Fit	
Shielding Factor, External Gamma	SHF1	unit less	0.27	Bounded Lognormal-N	μ Normal: -1.3 σ Normal: 0.59 min: 0.044 max: 1.0	The structure itself provides an attenuating effect during indoor exposure periods. RESRAD default probabilistic distribution is used.
Shielding Factor, Inhalation	SHF3	unitless	0.4	Single point (deterministic) estimate used		RESRAD deterministic default value used. The RESRAD default is conservative for the critical exposure group evaluated in this scenario. A study designed to investigate the fraction of indoor dust relative to outdoor dust reported a range of values (0.2-0.3), less than the RESRAD default. (Rutz 1994)
Inhalation Rate	INHALR	m^3/yr	8400	Triangular	Range: 4380 to 13100	RESRAD default probabilistic distribution is used. The RESRAD default is conservative for the critical exposure group evaluated in this scenario. Studies of worker inhalation rates suggest that an appropriate annual inhalation rate for long-term exposure to adult males (geometric mean) is 5548 m^3/yr (USEPA 1997).
Mass Loading for Inhalation	MLINH	g/m^3	0.00003	Continuous Linear	0.0 0.0000 0.000008 0.0151 0.000016 0.1365 0.00003 0.8119 0.00004 0.9495 0.00006 0.9937 0.000076 0.9983 0.0001 1.0000	Mass loading in air describes the airborne dust loading conditions on the Site. RESRAD default probabilistic distribution is used. The RESRAD default is conservative for the critical exposure group evaluated in this scenario. This is evident given that the arithmetic mean of the annual average PM10 concentrations reported among measurement stations in E. Hartford, Hartford, and Enfield, CT indicate that the regional dust loading in air in the vicinity of the site is approximately a factor of three lower than the RESRAD default (CTDEP, 1998).

Table 3-14 Key Parameters—Urban Residential Scenario

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

Parameter			Central Tendency Value	Description of Parameter Distribution		Remark
Description	Code	Unit		Distribution	Range & Fit	
Soil Ingestion Rate	SOIL	g/y	18.3	Triangular	Range: 0 to 36.5	RESRAD default probabilistic distribution is used.
Calculation Times	T(n)	Yrs.	0 1 10 30 100 300 1000	NA		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 (USNRC 1997, 2000).
Site Parameters						
Area of Contaminated Zone	AREA	m^2	2,023,000	Parameter uncertainty not evaluated since the area of the potentially impacted Site is known with high degree of certainty.		Area selected conservatively corresponds to the entire Site (~500 acres).
Cover Depth (thickness)	COVER0	m	0	NA		The DCGL has been conservatively derived assuming no advantage that would be associated with the attenuating nature of cover material overlying the source layer.
Thickness of Contaminated Zone	THICK0	m	0.075	Triangular	Range: 0 to 0.3	Site characterization data indicates that the residual radioactivity in soil on the Site is confined to the top 0-3 inches of surface soil on average. The source term thickness has been conservatively defined to be as thick as 1' (0.3m) thick to account for localized variability. Deeper deposits are covered with clean overburden, effectively attenuating radiation from these deep sources. Areas where the source thickness is greater than six inches are rare and typically associated with higher surface soil activity concentrations that warrant localized soil removal.

Table 3-14 Key Parameters—Urban Residential Scenario

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

Parameter			Central Tendency Value	Description of Parameter Distribution		Remark
Description	Code	Unit		Distribution	Range & Fit	
Thickness of Unsaturated Zone #1	H(1)	m	2	Bounded Lognormal-N	μ Normal: .693 σ Normal: 0.25 min: 1.0 max: 4.0	Site characterization data indicates that the combined thickness of unsaturated strata underlying the contaminated zone at the Site is, on average, approximately 20 feet (6 meters) thick. The unsaturated zone is segmented into two strata such that they may be assigned separate uranium K_d values.
Thickness of Unsaturated Zone #2	H(2)	m	4	Bounded Lognormal-N	μ Normal: 1.386 σ Normal: 0.6 min: 2.0 max: 17.0	
Soil Density	DENS (zone)	g/cm^3	1.5	Single point (deterministic) estimate used		RESRAD deterministic default
Contaminated Zone Erosion Rate	VCZ	m/yr	0.001	Single point (deterministic) estimate used		RESRAD deterministic default
Depth of Roots	DROOT	m	1.85	Uniform	Range: 0.3 to 4.0	RESRAD default probabilistic distribution is used
Fruit, Vegetable, and Grain Consumption	DIET(1)	Kg/yr	160	Single point (deterministic) estimate used		RESRAD deterministic default. Mean intake of fruits, vegetables, and grains is 160 kg/yr (wet weight, as consumed, or approximately 16.9 kg/yr dry weight) accounts for approximately 92% of the total mean intake of produce and grain by adults (USEPA, 1997). Remainder is accounted for in the consumption of leafy vegetables.
Leafy Vegetable Consumption	DIET(2)	Kg/yr	14	Single point (deterministic) estimate used		RESRAD deterministic default. Mean intake of leafy vegetables is 14 kg/yr (wet weight, as consumed). This accounts for approximately 8% of the total mean intake of produce and grain by adults (USEPA, 1997).
Fraction of Produce that is Home-Grown	FPLANT	unitless	0.043	Single point (deterministic) estimate used		Value is the percentage of fruits and vegetables that are homegrown in the northeastern US (USEPA 1997).

Table 3-14 Key Parameters—Urban Residential Scenario

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

Parameter			Central Tendency Value	Description of Parameter Distribution		Remark
Description	Code	Unit		Distribution	Range & Fit	
Fish Consumption	DIET(5)	kg/y	5.4	Single point (deterministic) estimate used		RESRAD deterministic default value used. The RESRAD default is very conservative for the critical exposure group evaluated in this scenario as it includes the annual average fish consumption including both freshwater and saltwater species and does not differentiate between the amount of recreationally-caught fish and that provided commercially (USEPA, 1997).
Contaminated Fraction of Aquatic Food	FR9	0 to 1	0.39	Triangular	Range: 0 to 1.0	RESRAD default probabilistic distribution is used
Drinking Water Intake	DWI	L/yr	584	Single point (deterministic) estimate used		Value based on CTDEP specification of 2 liters per day total fluid intake, of which 1.6 liters per day is apportioned to drinking water with the remainder apportioned to milk. The value is conservative compared with the RESRAD default drinking water ingestion rate based on the mean rate for adults (1.4 L/day) (USEPA, 1997).
Average Annual Wind Speed	WIND	m/sec	3.16	Truncated Lognormal-N	μ Normal: 1.15 σ Normal: 0.10 Quantile, min: 0.05 Quantile, max: 0.95	Site-specific annual average value, equal to 7.2 mph. (NOAA)
Precipitation Rate	PRECIP	m/year	1.12	Single point (deterministic) Site-specific value used		Annual average in Windsor (Hartford) area. Equals 44.1 inches per year. (NOAA)
Runoff Coefficient	RUNOFF	unitless	0.45	Uniform	Range: 0.1 to 0.8	The fraction of total annual precipitation that sheds off the surface and drains to the watershed drainage without percolating through the soil. The RESRAD default probabilistic distribution is used.

Table 3-14 Key Parameters—Urban Residential Scenario

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

Parameter			Central Tendency Value	Description of Parameter Distribution		Remark
Description	Code	Unit		Distribution	Range & Fit	
Evapo-transpiration Coefficient	EVAPTR	unitless	0.5	Single point (deterministic) estimate used		RESRAD deterministic default. The RESRAD default is conservative compared to typical values in New England (approximately 0.7).
Hydraulic Conductivity	HCCZ	m/yr	10	Single point (deterministic) estimate used		Contaminated Layer: RESRAD default
	HCUZ(1)		10			Unsaturated Layer #1: RESRAD default
	HCUZ(2)		10			Unsaturated Layer #2: RESRAD default
	HCSZ		100			Saturated Layer: RESRAD default
Well Pump Intake Depth	DWIBWT	m	10	Triangular	Range: 6 to 30	RESRAD default probabilistic distribution is used
Depth of Soil Mixing Layer	DM	m	0.15	Triangular	Range: 0 to 0.6	RESRAD probabilistic default distribution used.
K_d (Uranium)	DCACTC	cm^3/g	8700	Lognormal-N	μ Normal: 9.07 σ Normal: 0.53	Contaminated Layer: Site-specific, uranium desorption Kd derived from two Kd studies done at the CE Windsor Site (WANG, 1996; ENSR, 2001).
	DCACTU1	cm^3/g	3300	Lognormal-N	μ Normal: 8.1 σ Normal: 0.03	Unsaturated Layer #1: Site-specific uranium adsorption Kd derived from Kd study done at the CE Windsor Site (ENSR, 2001).
	DCACTU2	cm^3/g	125	Lognormal-N	μ Normal: 4.84 σ Normal: 1.0	Unsaturated Layer #2: RESRAD probabilistic default distribution used with the standard deviation adjusted such that the distribution approximates the Site-specific uranium adsorption Kd measured in deep subsurface soils at the CE Windsor Site (ENSR, 2001).

Table 3-14 Key Parameters—Urban Residential Scenario

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

Parameter			Central Tendency Value	Description of Parameter Distribution		Remark
Description	Code	Unit		Distribution	Range & Fit	
	DCACTS	cm^3/g	125	Lognormal-N	μ Normal: 4.84 σ Normal: 1.0	Saturated Layer: RESRAD probabilistic default distribution used with the standard deviation adjusted such that the distribution approximates the Site-specific uranium adsorption Kd measured in deep subsurface soils at the CE Windsor Site (ENSR, 2001).
K_d (Cobalt)	DCACT(n)	cm^3/g	235	Lognormal-N	μ Normal: 5.46 σ Normal: 2.53	All Layers: RESRAD probabilistic default distribution used.
Source Term Factors						
Dose Conversion Factors	DCFX(n)	mrem/pCi	All DCFs used are RESRAD defaults			RESRAD defaults from FGR #11 (USEPA, 1988) and FGR #12 (USEPA, 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			Uranium Isotopic Mix (% of total activity)			This isotopic mix is derived from Site-specific data and is consistent with the mixture expected for 3.5% enriched uranium. All percentages calculated as the fraction of total uranium activity in the mixture.
U-234	S1(6)	pCi/g	77.49%			
U-235	S1(7)	pCi/g	4.27%			
U-238	S1(8)	pCi/g	18.25%			
Source Isotopes			Byproduct Source Term			This byproduct source term is derived from three

Table 3-14 Key Parameters—Urban Residential Scenario

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

Parameter			Central Tendency Value	Description of Parameter Distribution		Remark
Description	Code	Unit		Distribution	Range & Fit	
Co-60	S1(1)	pCi/g	100%			Site-specific sources: 1) Waste characterization data collected during the remediation of Buildings 2, 5, and 17; 2) sampling performed on site specifically designed to analyze "hard-to-detect" nuclides; and 3) waste stream profile data associated with reactor plant component maintenance activities with which the byproduct radioactivity on Site is associated. The source term accounts for the reactor plant byproduct isotopes with contributions of greater than 10.0% to the total annual effective dose equivalent. (See Appendix G for details on byproduct source term derivation).

3.3.8 Residential Farming Exposure Scenario

As previously discussed, the circumstances in place at the Site make it exceedingly unlikely that any form of residential (subsistence) farming might occur on the CE Windsor Site property. However, evaluation of this scenario serves as an indicator of the extent of radiation exposure that might occur in even marginally credible land use assumptions. In this capacity, the residential farming exposure scenario serves as a measure of the upper range of the uncertainty in the assumption of future Site land use.

3.3.8.1 Conceptual Site Model for the Residential Farming Scenario

A residential farm in this setting is conceived as consisting of single-family housing on plots of land large enough to support the production of crops for food and pasturage for livestock. The Site conceptual model describing the residential farming scenario includes the same physical and geological conditions described for the residential scenario except that the receptor is assumed to produce a significant fraction of their annual dietary intake on site. Figure 3–12 illustrates the conceptual description of the Site conditions that could be expected with a residential farming exposure scenario.

3.3.8.2 Pathways Included in the Resident Farmer Scenario

The resident farming exposure scenario includes a complete suite of exposure pathways used to calculate potential future dose. Table 3–15 identifies the pathways that have been retained for the analysis and provides explanation for the single pathway that is not retained (radon).

3.3.8.3 Exposure Factor Parameters

This scenario supports a range of possible exposure durations as current agricultural land use statistics suggest that nearly half of all residents residing on lands used for farming (30 to 60%) spend a significant portion of their work year working off of the farm (NASS, 1997) (See Figure 3–13).

Fractions of produce and animal products consumed by farm residents are also likely to vary rather significantly. The exposure frequency and duration along with the fraction of consumed plant food grown on site provide the greatest variability in the annual dose received by an exposed resident farm receptor. The critical exposure group is defined as an adult who lives in a single-family residential dwelling constructed at the Site and who spends the majority of the day at home on the Site. The same adult is assumed to engage in farming, fishing, and raising livestock at the site and to derive all, or a significant portion of, his annual dietary intake from foods grown onsite. This setting is characterized by yearlong exposure and conservatively overestimates the exposure factors typical in a New England setting. The resident farmer exposure scenario involves annualized exposure factors attributable to members of the critical group. Key parameters used to define the resident farmer exposure scenario are presented in Table 3-16 below along with specific remarks explaining the values selection.

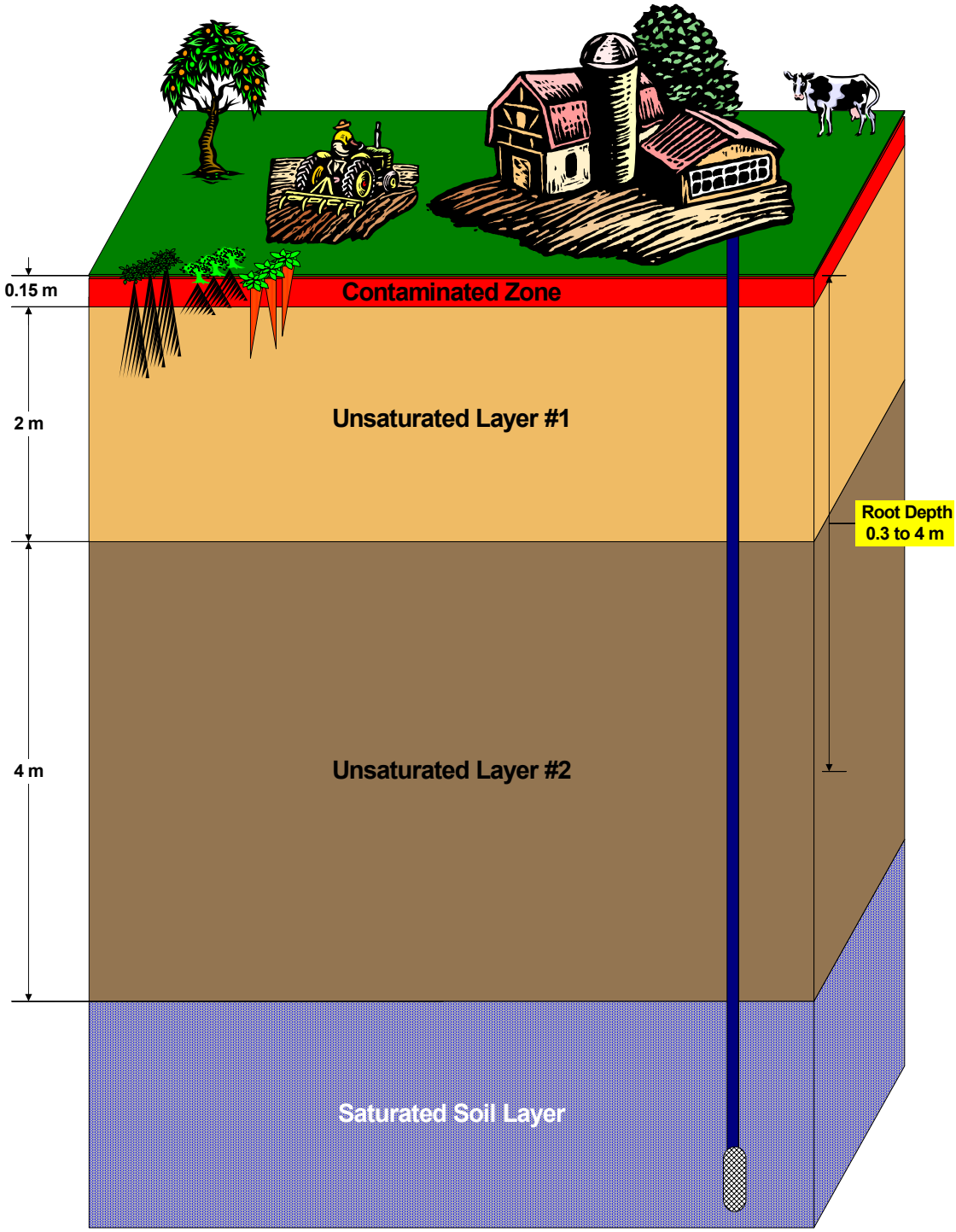

Figure 3–12. Conceptual Site Model Describing the Residential Farming Scenario

Table 3-15 Evaluation of Pathways for the Resident Farmer Exposure 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.
Particulate Inhalation	Yes	Allowance is made for soils containing radiological constituents of the source being liberated and suspended in the breathing air of the resident farmer. 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 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. The scenario allows a resident farmer to raise (and consume) a significant fraction of his plant food diet on the Site, making this pathway complete.
Drinking Water	Yes	Aquifer beneath a portion of the Site is considered a potential source of potable water making this pathway potentially complete. However, use of groundwater for consumption is unlikely due to the availability of municipal drinking water from off-Site sources. Additionally, the Town of Windsor has indicated that it would require the use of publicly supplied drinking water from an offsite source in the event that future development activities occur.
Meat Ingestion	Yes	The scenario allows for the possibility that a significant fraction of a resident farmer's meat diet is derived from livestock that are pastured and watered at this Site.
Milk Ingestion	Yes	Milk ingestion pathway is considered complete since it is assumed for the resident farmer scenario that milk cows might be grazed on this Site.
Aquatic Foods Ingestion	Yes	This pathway is potentially complete for this scenario since there is a credible potential for aquatic foods (fish) to be available in the surface water bodies on the 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.

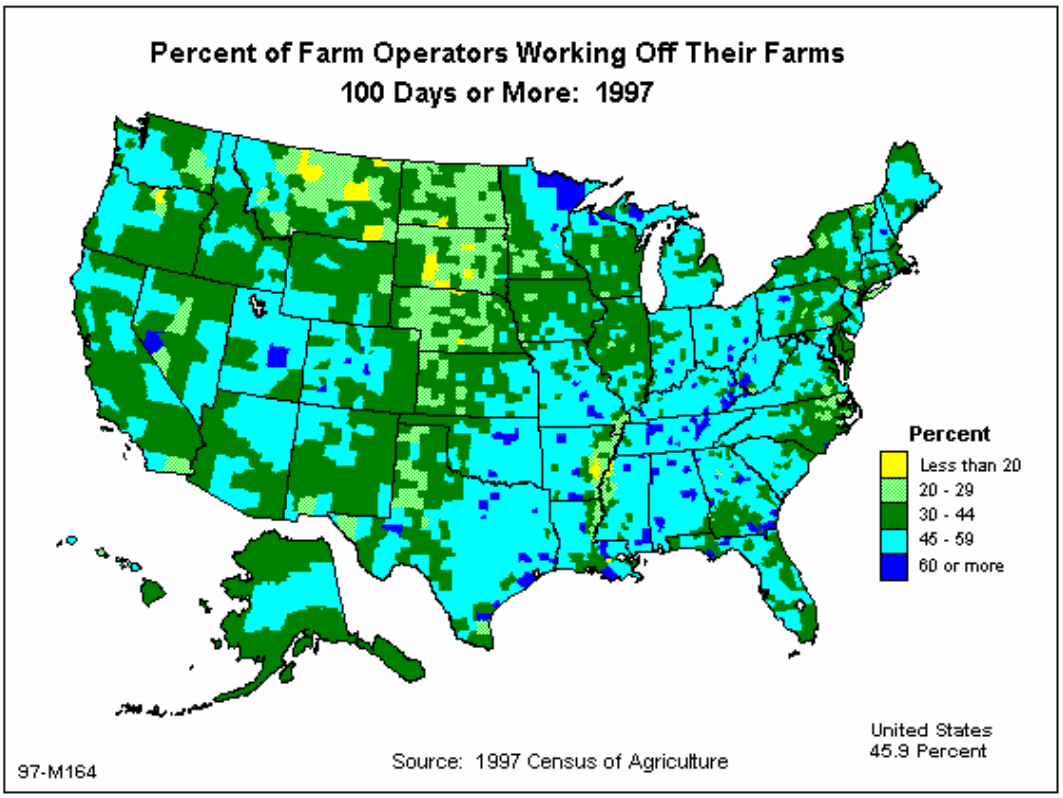

Figure 3–13 Percent of Farm Operators Working Off Their Farms

Table 3-16 Key Parameters—Residential Farming Scenario

(Adult Resident Farmer Defined as the Critical Exposure Group)

Parameter			Central Tendency Value	Description of Parameter Distribution		Remark
Description	Code	Unit		Distribution	Range & Fit	
Receptor Exposure Factors						
Indoor Time Fraction	FIND	0 to 1	0.5	Continuous Linear	0.0 0.000 0.05 0.375 0.25 0.521 0.5 0.625 0.75 0.809 0.9 0.938 0.95 0.992 1.0 1.000	The RESRAD default probabilistic distribution is used. FIND is 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.
Outdoor Time Fraction	FOTD	0 to 1	0.25	Single point (deterministic) estimate used		The RESRAD deterministic default value is used. FOTD is the fraction of a total year (8760 hr) that is spent outdoors on Site.
Inhalation Rate	INHALR	m^3/yr	8400	Triangular	Range: 4380 to 13100	The RESRAD default probabilistic distribution is used.
Mass Loading for Inhalation	MLINH	g/m^3	0.00003	Continuous Linear	0.0 0.0000 0.000008 0.0151 0.000016 0.1365 0.00003 0.8119 0.00004 0.9495 0.00006 0.9937 0.000076 0.9983 0.0001 1.0000	Mass loading in air describes the airborne dust loading conditions on the Site. RESRAD default probabilistic distribution is used.
Soil Ingestion Rate	SOIL	g/y	18.3	Triangular	Range: 0 to 36.5	RESRAD default probabilistic distribution is used.
Shielding Factor, External Gamma	SHF1	unit less	0.27	Bounded Lognormal-N	μ Normal: -1.3 σ Normal: 0.59 min: 0.044 max: 1.0	The structure itself provides an attenuating effect during indoor exposure periods. RESRAD default probabilistic distribution is used.

Table 3-16 Key Parameters—Residential Farming Scenario

(Adult Resident Farmer Defined as the Critical Exposure Group)

Parameter			Central Tendency Value	Description of Parameter Distribution		Remark
Description	Code	Unit		Distribution	Range & Fit	
Shielding Factor, Inhalation	SHF3	unitless	0.4	Single point (deterministic) estimate used		RESRAD deterministic default value used. The RESRAD default is conservative for the critical exposure group evaluated in this scenario. A study designed to investigate the fraction of indoor dust relative to outdoor dust reported a range of values (0.2-0.3), less than the RESRAD default. (Rutz, 1994)
Calculation Times	T(n)	Yrs.	0 1 10 30 100 300 1000	NA		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 (USNRC, 1997; 2000).
Site Parameters						
Area of Contaminated Zone	AREA	m^2	2,023,000	Parameter uncertainty not evaluated since the area of the potentially impacted Site is known with high degree of certainty.		Area selected conservatively corresponds to the entire Site (~500 acres).
Cover Depth (thickness)	COVER0	m	0	NA		The DCGL has been conservatively derived assuming no advantage that would be associated with the attenuating nature of cover material overlying the source layer.

Table 3-16 Key Parameters—Residential Farming Scenario

(Adult Resident Farmer Defined as the Critical Exposure Group)

Parameter			Central Tendency Value	Description of Parameter Distribution		Remark
Description	Code	Unit		Distribution	Range & Fit	
Thickness of Contaminated Zone	THICK0	m	0.075	Triangular	Range: 0 to 0.3	Site characterization data indicates that the residual radioactivity in soil on the Site is confined to the top 0-3 inches of surface soil on average. The source term thickness has been conservatively defined to be as thick as 1' (0.3m) thick to account for localized variability. Deeper deposits are covered with clean overburden, effectively attenuating radiation from these deep sources. Areas where the source thickness is greater than six inches are rare and typically associated with higher surface soil activity concentrations that warrant localized soil removal.
Thickness of Unsaturated Zone #1	H(1)	m	2	Bounded Lognormal-N	μ Normal: .693 σ Normal: 0.25 min: 1.0 max: 4.0	Site characterization data indicates that the combined thickness of unsaturated strata underlying the contaminated zone at the Site is, on average, approximately 20 feet (6 meters) thick. The unsaturated zone is segmented into two strata such that they may be assigned separate uranium K_d values.
Thickness of Unsaturated Zone #2	H(2)	m	4	Bounded Lognormal-N	μ Normal: 1.386 σ Normal: 0.6 min: 2.0 max: 17.0	
Soil Density	DENS (zone)	g/cm^3	1.5	Single point (deterministic) estimate used		RESRAD deterministic default
Contaminated Zone Erosion Rate	VCZ	m/yr	0.001	Single point (deterministic) estimate used		RESRAD deterministic default
Depth of Roots	DROOT	m	1.85	Uniform	Range: 0.3 to 4.0	RESRAD default probabilistic distribution is used

Table 3-16 Key Parameters—Residential Farming Scenario

(Adult Resident Farmer Defined as the Critical Exposure Group)

Parameter			Central Tendency Value	Description of Parameter Distribution		Remark
Description	Code	Unit		Distribution	Range & Fit	
Fruit, Vegetable, and Grain Consumption	DIET(1)	Kg/yr	160	Single point (deterministic) estimate used		The RESRAD deterministic default is used. Mean intake of fruits, vegetables, and grains is 160 kg/yr (wet weight, as consumed, or approximately 16.9 kg/yr dry weight) accounts for approximately 92% of the total mean intake of produce and grain by adults (USEPA, 1997). Remainder is accounted for in the consumption of leafy vegetables.
Leafy Vegetable Consumption	DIET(2)	Kg/yr	14	Single point (deterministic) estimate used		The RESRAD deterministic default is used. Mean intake of leafy vegetables is 14 kg/yr (wet weight, as consumed). This accounts for approximately 8% of the total mean intake of produce and grain by adults (USEPA, 1997).
Contaminated Fraction of Plant Food	FPLANT	unitless	0.5	Single point (deterministic) estimate used		The RESRAD deterministic default is used.
Milk Consumption	DIET(3)	L/yr	146	Single point (deterministic) estimate used		Value based on CTDEP specification of 0.4 liters per day milk consumption. The value is conservative compared with the RESRAD default milk ingestion rate of 92 L/yr (0.25 L/day).
Contaminated Fraction of Milk	FMILK	0 to 1	1	Single point (deterministic) estimate used		The RESRAD deterministic default is used. Assumes all milk is derived from animals grazed and watered onsite.
Meat & Poultry Consumption	DIET(4)	Kg/yr	63	Single point (deterministic) estimate used		The RESRAD deterministic default is used.
Contaminated Fraction of Meat	FMEAT	0 to 1	1	Single point (deterministic) estimate used		The RESRAD deterministic default is used.

Table 3-16 Key Parameters—Residential Farming Scenario

(Adult Resident Farmer Defined as the Critical Exposure Group)

Parameter			Central Tendency Value	Description of Parameter Distribution		Remark
Description	Code	Unit		Distribution	Range & Fit	
Fish Consumption	DIET(5)	kg/y	5.4	Single point (deterministic) estimate used		RESRAD deterministic default value used. The RESRAD default is very conservative for the critical exposure group evaluated in this scenario as it includes the annual average fish consumption including both freshwater and saltwater species and does not differentiate between the amount of recreationally-caught fish and that provided commercially (USEPA, 1997).
Contaminated Fraction of Aquatic Food	FR9	0 to 1	0.39	Triangular	Range: 0 to 1.0	The RESRAD default probabilistic distribution is used
Drinking Water Intake	DWI	L/yr	584	Single point (deterministic) estimate used		Value based on CTDEP specification of 2 liters per day total fluid intake, of which 1.6 liters per day is apportioned to drinking water with the remainder apportioned to milk. The value is conservative compared with the RESRAD default drinking water ingestion rate based on the mean rate for adults (1.4 L/day) (USEPA, 1997).
Contaminated Fraction of Drinking Water	FDW	0 to 1	1	Single point (deterministic) estimate used		The RESRAD deterministic default is used. Assumes all drinking water is derived from contaminated onsite well.
Contaminated Fraction of Livestock Water	FLW	0 to 1	1	Single point (deterministic) estimate used		The RESRAD deterministic default is used. Assumes all livestock water is derived from contaminated onsite sources.
Contaminated Fraction of Irrigation Water	FIRW	0 to 1	1	Single point (deterministic) estimate used		The RESRAD deterministic default is used. Assumes all drinking water is derived from contaminated onsite sources.

Table 3-16 Key Parameters—Residential Farming Scenario

(Adult Resident Farmer Defined as the Critical Exposure Group)

Parameter			Central Tendency Value	Description of Parameter Distribution		Remark
Description	Code	Unit		Distribution	Range & Fit	
Average Annual Wind Speed	WIND	m/sec	3.16	Truncated Lognormal-N	μ Normal: 1.15 σ Normal: 0.10 Quantile, min: 0.05 Quantile, max: 0.95	Site-specific annual average value, equal to 7.2 mph. (NOAA)
Precipitation Rate	PRECIP	m/year	1.12	Single point (deterministic) Site-specific value used		Annual average in Windsor (Hartford) area. Equals 44.1 inches per year. (NOAA)
Runoff Coefficient	RUNOFF	unitless	0.45	Uniform	Range: 0.1 to 0.8	The fraction of total annual precipitation that sheds off the surface and drains to the watershed drainage without percolating through the soil. The RESRAD default probabilistic distribution is used.
Evapo-transpiration Coefficient	EVAPTR	unitless	0.5	Single point (deterministic) estimate used		RESRAD deterministic default. The RESRAD default is conservative compared to typical values in New England (approximately 0.7).
Hydraulic Conductivity	HCCZ	m/yr	10	Single point (deterministic) estimate used		Contaminated Layer: RESRAD default
	HCUZ(1)		10			Unsaturated Layer #1: RESRAD default
	HCUZ(2)		10			Unsaturated Layer #2: RESRAD default
	HCSZ		100			Saturated Layer: RESRAD default
Well Pump Intake Depth	DWIBWT	m	10	Triangular	Range: 6 to 30	While the drinking water pathway for the Truck Farmer scenario is incomplete, allowance is made for the potential use of onsite groundwater for irrigation.
Depth of Soil Mixing Layer	DM	m	0.15	Triangular	Range: 0 to 0.6	RESRAD probabilistic default distribution used.

Table 3-16 Key Parameters—Residential Farming Scenario

(Adult Resident Farmer Defined as the Critical Exposure Group)

Parameter			Central Tendency Value	Description of Parameter Distribution		Remark
Description	Code	Unit		Distribution	Range & Fit	
K_d (Uranium)	DCACTC	cm^3/g	8700	Lognormal-N	μ Normal: 9.07 σ Normal: 0.53	Contaminated Layer: Site-specific, uranium desorption Kd derived from two Kd studies done at the CE Windsor Site (WANG, 1996; ENSR, 2001).
	DCACTU1	cm^3/g	3300	Lognormal-N	μ Normal: 8.1 σ Normal: 0.03	Unsaturated Layer #1: Site-specific uranium adsorption Kd derived from Kd study done at the CE Windsor Site (ENSR, 2001).
	DCACTU2	cm^3/g	125	Lognormal-N	μ Normal: 4.84 σ Normal: 1.0	Unsaturated Layer #2: RESRAD probabilistic default distribution used with the standard deviation adjusted such that the distribution approximates the Site-specific uranium adsorption Kd measured in deep subsurface soils at the CE Windsor Site (ENSR, 2001).
	DCACTS	cm^3/g	125	Lognormal-N	μ Normal: 4.84 σ Normal: 1.0	Saturated Layer: RESRAD probabilistic default distribution used with the standard deviation adjusted such that the distribution approximates the Site-specific uranium adsorption Kd measured in deep subsurface soils at the CE Windsor Site (ENSR, 2001).
K_d (Cobalt)	DCACT(n)	cm^3/g	235	Lognormal-N	μ Normal: 5.46 σ Normal: 2.53	All Layers: RESRAD probabilistic default distribution used.
Source Term Factors						
Dose Conversion Factors	DCFX(n)	mrem/pCi	All DCFs used are RESRAD defaults			RESRAD defaults from FGR #11 (USEPA, 1988) and FGR #12 (USEPA, 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.

Table 3-16 Key Parameters—Residential Farming Scenario

(Adult Resident Farmer Defined as the Critical Exposure Group)

Parameter			Central Tendency Value	Description of Parameter Distribution		Remark
Description	Code	Unit		Distribution	Range & Fit	
Source Isotopes			Uranium Isotopic Mix (% of total activity)			This isotopic mix is derived from Site-specific data and is consistent with the mixture expected for 3.5% enriched uranium. All percentages calculated as the fraction of total uranium activity in the mixture.
U-234	S1(6)	pCi/g	77.49%			
U-235	S1(7)	pCi/g	4.27%			
U-238	S1(8)	pCi/g	18.25%			
Source Isotopes			Byproduct Source Term			This byproduct source term is derived from three Site-specific sources: 1) Waste characterization data collected during the remediation of Buildings 2, 5, and 17; 2) sampling performed on site specifically designed to analyze "hard-to-detect" nuclides; and 3) waste stream profile data associated with reactor plant component maintenance activities with which the byproduct radioactivity on Site is associated. The source term accounts for the reactor plant byproduct isotopes with contributions of greater than 10.0% to the total annual effective dose equivalent. (See Appendix G for details on byproduct source term derivation).
Co-60	S1(1)	pCi/g	100%			

3.4 COMPUTER MODELING CODES

The computer modeling code selected to evaluate the annual dose potential to individuals from residual radioactive materials in soil at the Site was selected on the basis of its ability to represent the conditions of the scenarios being evaluated and its acceptance within the regulatory and health physics communities as an effective and suitable modeling tool.

The temptation in using models of any description to predict 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 values for 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 Site.

The RESRAD code has been in use in various versions for several years and has been extensively employed for applications such as the Site DCGL derivation. The USNRC has approved the use of RESRAD for demonstrating compliance with the license termination criteria for its licensees and has recently sponsored the addition of a probabilistic module to new versions of the code. The USEPA has used the RESRAD code to develop soil cleanup standards for radionuclides (USEPA, 1994). The USEPA has accepted the use of RESRAD on sites having residual radioactivity. The calculations and algorithms in RESRAD have been extensively verified and validated. The project stakeholders unanimously agreed that the most current, approved, non-beta version of the RESRAD code available at the outset of this project (Version 6.0) should be used to evaluate potential future doses from exposure to residual radioactivity at the Site and that the same version should be used throughout the duration of the project[10].

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 at the beginning of this DCGL project (RESRAD

[10] All parties agreed that the only circumstance that might give rise to consideration of updated or newer versions of the RESRAD code was the unlikely event that a technical or mathematical flaw was discovered in RESRAD Version 6.0. Version 6.0 has been thoroughly tested and validated and was, at the inception of this process, the accepted version. The decision to stick with Version 6.0 was made to preclude the unnecessary introduction of variability as the project progresses.

for Windows, Version 6.0 [Yu, 2000]) has been used to evaluate the exposure scenarios described above and to calculate the DCGL for the Site.

The transport of radioactive material through the environment is calculated and the annualized, time integrated doses to potential receptors are determined in the modeling code. 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 included in the RESRAD code's algorithms with the opportunity for the user to determine which are potentially complete, including:

- External exposure (penetrating gamma) directly from contaminated soil;
- Inhalation of airborne radioactive particulates;
- Inhalation of aerosol radon and radon progeny;
- Ingestion of radioactive material directly from the soil; and
- 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. A description of the parameter distributions used in the probabilistic uncertainty analysis is presented in Section 4.0. The results of the probabilistic calculations of the DCGL for enriched uranium and byproduct materials in soil using RESRAD 6.0 are summarized in Section 5.0 of this report. Complete reports detailing the calculations of dose for each scenario are contained in Appendices A through F.

4.0 UNCERTAINTY ANALYSIS

4.1 MANAGING UNCERTAINTY

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 and to understand the uncertainty associated with such projections.

In the past, dose assessments in support of USNRC 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 a deterministic analysis had a high probability of erring conservatively, 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 to an exposed receptor. Uncertainty analysis imparts more information to the decision maker than deterministic analysis. It characterizes a range of potential doses and the likelihood that a particular dose would be exceeded.

Regardless of the method, uncertainty is inherent in all dose and 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. It is important to recognize that the outlook evaluation time criterion (1000 years) is not intended to predict future scenarios for the next 1000 years, but to evaluate the continued protectiveness of a given DCGL for 1000 years into the future given the reasonable and plausible future uses of the Site in today's social and economic conditions.

Parameter uncertainty results from incomplete knowledge of the coefficients that describe the model. However, with the selection of a suitable model for the Site conditions and scenarios to be considered 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 USNRC has adopted a risk-informed approach to regulatory decision-making suggesting that an assessment of uncertainty be included in dose assessments (USNRC, 2000b). The USNRC's Probabilistic Risk Assessment (PRA) Policy Statement (USNRC, 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 USNRC's deterministic approach…."*

Even with the use of probabilistic analyses, it should be recognized that not all sources of uncertainty could be, or need to be, considered in a dose 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.

4.2 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 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 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 residential use scenarios obtaining drinking water from potentially impacted, onsite, groundwater sources even though future beneficial use of the Site in such a scenario would undoubtedly make use of municipally supplied potable water from offsite sources, effectively eliminating the drinking water pathway.

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

4.3 METHOD OF ADDRESSING UNCERTAINTY

In the first stakeholder meeting, it was agreed that the most current version of RESRAD available at the time the DCGL project began would be used (Meeting Minutes ABB, 6/21/01, [ABB, 2001a]). It was known then that RESRAD, Version 6.0, had recently been made available and that it contained a new probabilistic module that could be used to assess the uncertainty in the relationship between a concentration of radioactivity in soil and the dose it might produce. Thus, RESRAD 6.0 is used as the platform to conduct the uncertainty analysis. It uses an enhanced random sampling algorithm called Latin Hypercube sampling in which input parameter values 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 its 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 residential farming scenario yielded the smallest concentration corresponding to the regulatory limit.

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. The direct exposure pathway, or "ground" pathway was consistently the dominant pathway for the byproduct source term, and by a significant margin. For the enriched uranium source term, the soil ingestion pathway dominated all scenarios.

4. 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.

5. 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 in the Monte Carlo Summary Reports for each scenario (Appendices A through F).

4.4 PARAMETER DISTRIBUTIONS

4.4.1 Depth of Plant Roots

The depth of plant roots is relevant for the truck farmer, suburban resident, and resident farmer scenarios (scenarios in which ingestion of plants grown on Site is considered) as it is one of several parameters used to calculate dose from the intake of produce grown in soils having residual radioactivity. Sensitivity analysis showed that the plant ingestion pathway was somewhat sensitive to root depth, but small compared with other pathways. Root Depth (DROOT) is represented with a uniform distribution (the RESRAD default) with a range of root depths between 0.3 and 4.0 meters. Figure 4–1 graphically illustrates the distribution from which values of root depth were sampled.

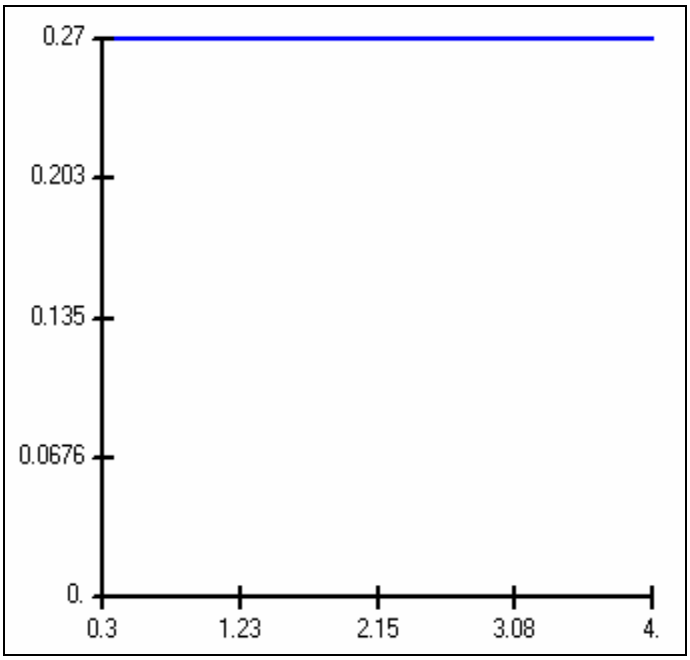

Figure 4–1 Depth of Plant Roots (m)

4.4.2 Thickness of the Unsaturated Zone

The total unsaturated zone thickness at the Site varies from 4.5 to 6 meters in the southern portion of the Site to approximately 17 meters in central and northern portions of the Site. This parameter that is relevant only for the truck farmer, suburban resident, and resident farmer scenarios (scenarios in which ingestion of plants irrigated with onsite groundwater or groundwater as a drinking water source are considered). Sensitivity analysis showed that the drinking water pathway was most sensitive to unsaturated zone thickness, but was insensitive over the range of groundwater depths reported.

The unsaturated zone is subdivided into two strata to enable the use of two different uranium K_d values in the unsaturated layer. The upper stratum (designated Unsaturated Layer #1) is associated with soils immediately underlying the surface soil layer in which residual radioactivity might be present down to a nominal depth of approximately 2 meters bgs. The lower stratum (designated Unsaturated Layer #2) is associated with soils beneath layer #1 down to the depth at which ground water is encountered (the top of the saturated layer). Unsaturated layer #2 has a nominal thickness of approximately 4 meters. The thickness of Unsaturated Layer #1, *H(1)*, is represented with a bounded lognormal-N distribution (the RESRAD default) with a central tendency value of 2 meters and lower and upper bounds of 1 and 4 meters respectively. Figure 4–2 graphically illustrates the distribution from which values of unsaturated zone thickness are sampled.

The thickness of Unsaturated Layer #2, *H(2)*, is also represented with a bounded lognormal-N distribution (the RESRAD default) with a central tendency value of 4 meters and lower and upper bounds of 2 and 17 meters respectively. Figure 4–3

graphically illustrates the distribution from which values of unsaturated zone thickness are sampled.

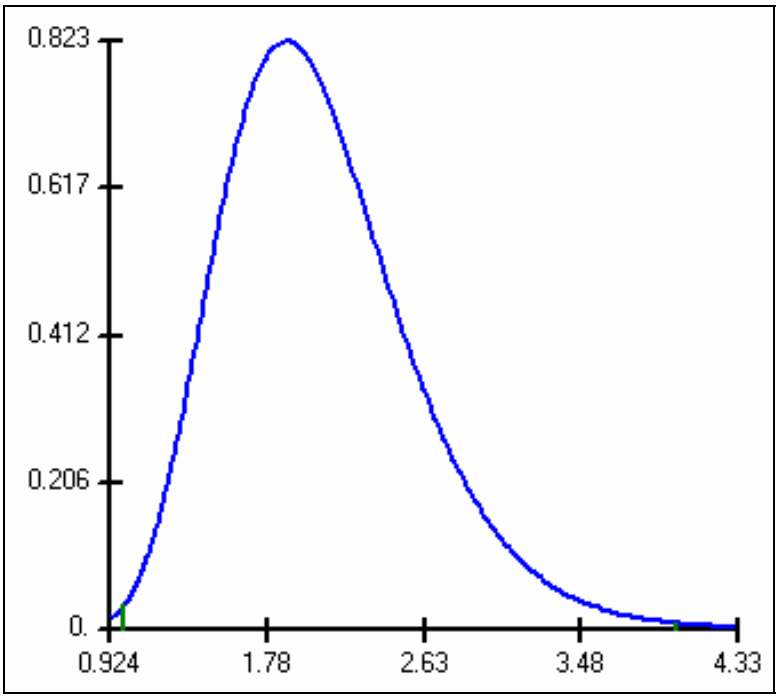

Figure 4–2 Thickness, Unsaturated Layer #1 (m)

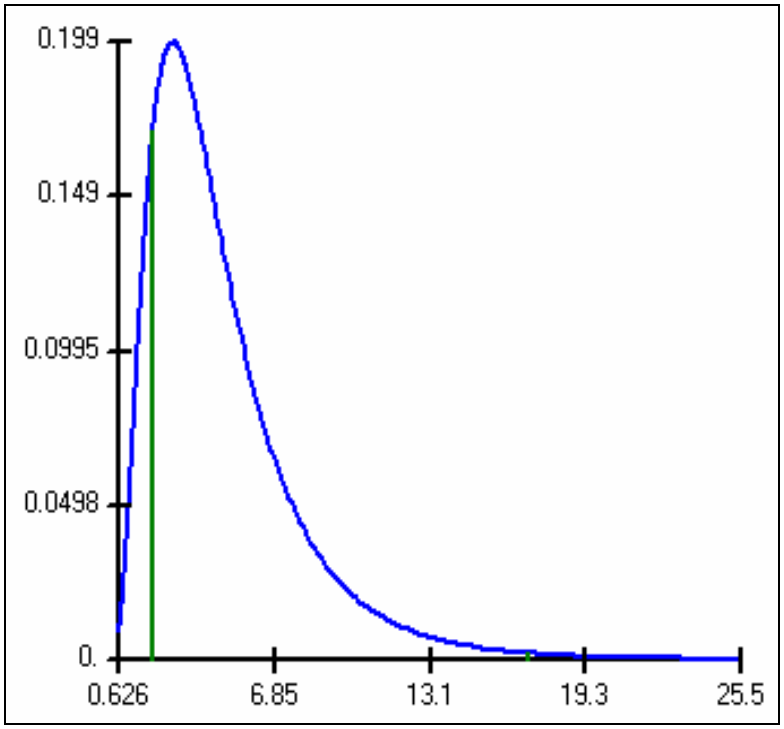

Figure 4–3 Thickness, Unsaturated Layer #2 (m)

4.4.3 Runoff Coefficient

The runoff coefficient is one of a number of parameters used to calculate radionuclide leaching from the contaminated zone. It is the fraction of precipitation that does not penetrate the top soil layer. No loss due to runoff is assumed for irrigation water. Runoff is relevant only for the truck farmer, suburban resident, and residential farmer scenarios (scenarios in which the consumption of plants irrigated with onsite groundwater or ingestion of onsite groundwater as drinking water are considered). The runoff coefficient (*RUNOFF*) varies with topography, amount of pavement, precipitation patterns in the region, and soil type. Sensitivity analysis showed that annual dose is insensitive to values of runoff coefficient over the entire range of plausible values. Runoff coefficient is represented with a uniform distribution ranging between 0.1 and 0.8 (the RESRAD default). Considering the topography of the site and the amount of surface pavement present, it would be reasonable to conclude that a relatively high fraction of precipitation runs off of the site rather than penetrate to the saturated layer. Figure 4-4 graphically illustrates the distribution from which values of runoff coefficient are sampled.

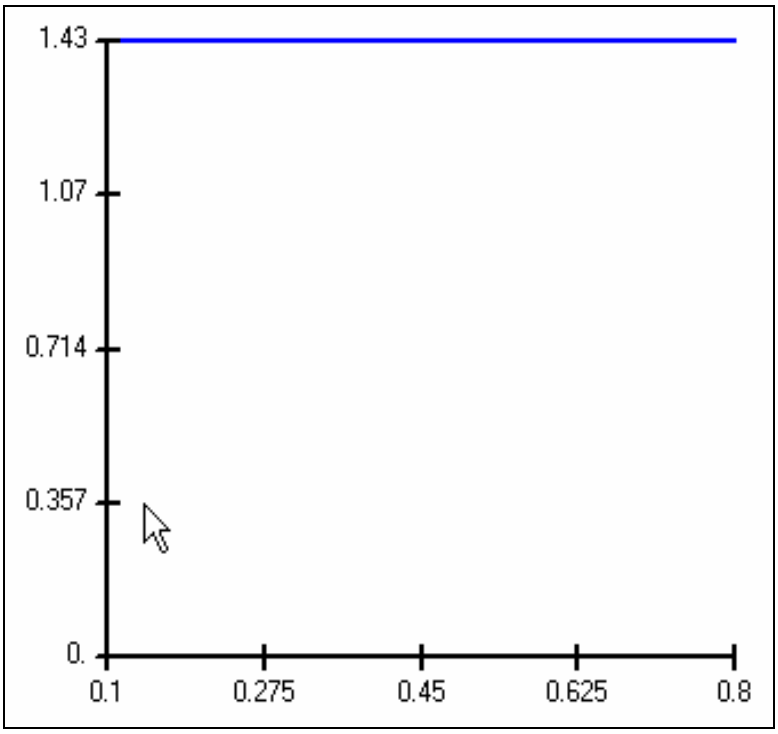

Figure 4–4 Runoff Coefficient (unitless)

4.4.4 Wind Speed

Average annual wind speed is used to calculate the dose from the inhalation pathway. The wind speed is used to transport airborne dust generated on Site in a standard air dispersion model. Through the transport calculations, the radioactive fraction of the total dust loading in air is derived. The fraction is then used to calculate particle inhalation intake. While wind speeds do vary from day-to-day and season-to-season, the annual

average wind speed is reasonably steadfast. Sensitivity analysis shows that the inhalation pathway is insensitive to this parameter because, in the conceptual site model, the entire Site is assumed to be impacted with residual radioactivity and because the inhalation pathway is not a significant contributor to total annual dose. Wind speed is represented with a truncated lognormal-N distribution (the RESRAD default) using the site-specific mean and values ranging from the 5th to the 95th percentiles of the distribution. Figure 4–5 graphically illustrates the distribution from which values of annual average wind are sampled.

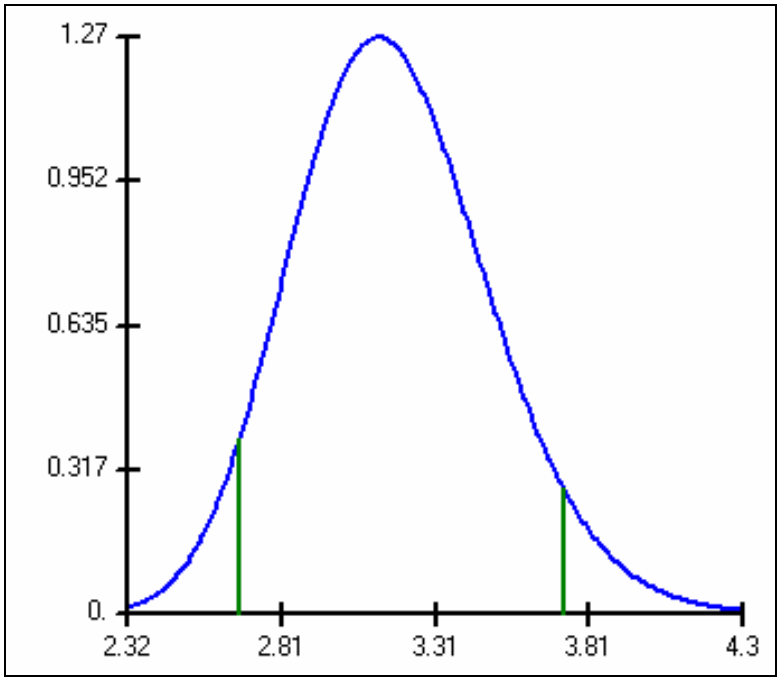

Figure 4–5 Average Annual Wind Speed (m/sec)

4.4.5 Well Pump Intake Depth

The well pump intake depth (*DWIBWT*) is used to calculate the transport of radioactivity through the saturated layer. It is described by the depth (in meters) that an intake well is located below the surface of a water table from which groundwater might be drawn for drinking water or irrigation water supply. Again, it is relevant only for the resident and truck farmer scenarios (scenarios in which drinking water or irrigation water are supplied from on-Site groundwater). Sensitivity analysis shows that annual dose is insensitive to this parameter, thus, the RESRAD default distribution (triangular) and range was used. Figure 4–6 graphically illustrates the distribution from which values of the well pump intake depth parameter is sampled.

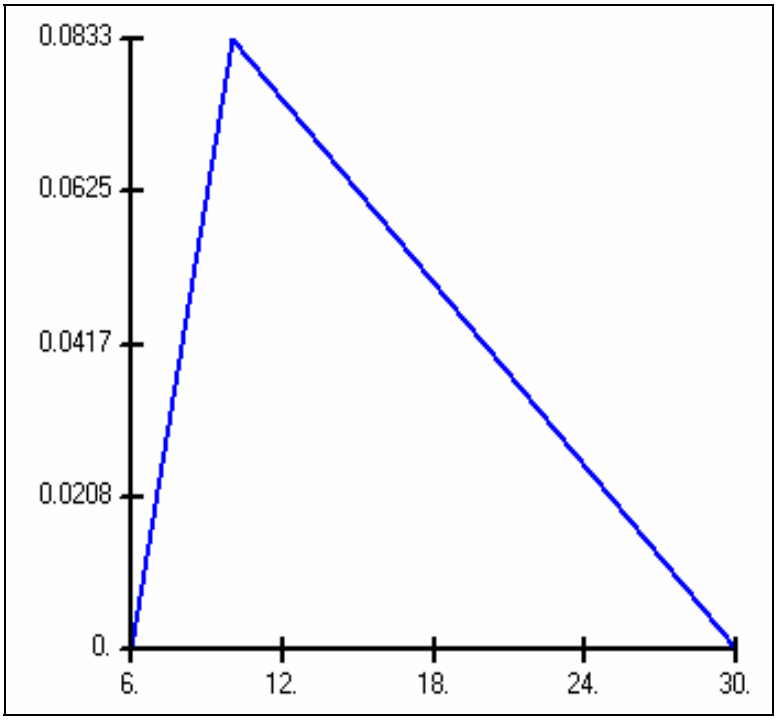

Figure 4–6 Well Pump Intake Depth (meters below groundwater surface)

4.4.6 Mass Loading for Inhalation

Mass loading for inhalation (MLINH) is the air/soil concentration ratio. It is used to calculate the dose from the particle inhalation pathway. The parameter represents the dust (mass) loading onsite conservatively assuming that all airborne dust is generated onsite and is radioactive. Other parameters, derived by the RESRAD code and based upon the site-specific parameters input, are used to modify this assumption, as appropriate. Mass loading does vary from season to season and depends upon the tasks that are being performed at the Site. Data from three local meteorological data collection stations suggest that the annual average and 24-hour maximum PM-10 (dust loading) concentrations in the area (0.00004 g/m^3) are lower than that associated with the RESRAD default which has a central tendency value of approximately 0.00003 g/m^3 and a maximum of 0.0001 g/m^3. Nonetheless, the RESRAD probabilistic default distribution has been used in order to bound the potential dose that might occur with particulate inhalation. Use of the RESRAD default is considered to be bounding for the construction worker, truck farmer, and residential farmer scenarios and substantially conservative for the other scenarios evaluated.

Sensitivity analysis shows that the inhalation pathway is sensitive to this parameter, but total annual dose is not because, the inhalation pathway is not a significant contributor to total annual dose. Mass loading for inhalation is represented with a continuous linear distribution using the RESRAD default values. Figure 4–7 graphically illustrates the distribution from which values of mass loading in air are sampled.

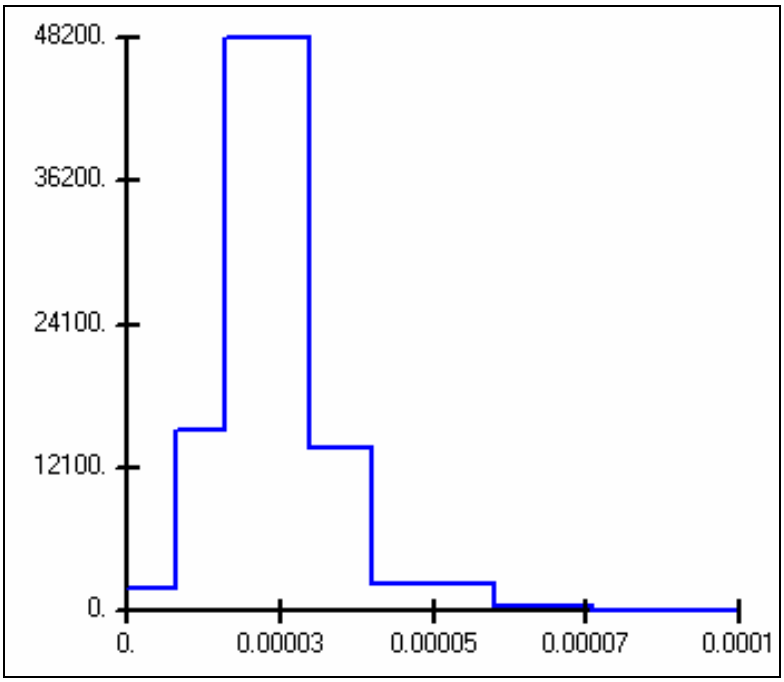

Figure 4–7 Mass Loading for Inhalation (g/m^3)

4.4.7 External Gamma Shielding Factor

The external gamma shielding factor (SHF1) is used to calculate the dose from the external (penetrating gamma radiation) pathway. The bare, unattenuated, gamma flux present when a receptor is outdoors and directly over the source term is modified by the external gamma shielding factor during the period of time a receptor is indoors on Site. The external gamma shielding factor accounts for the attenuation afforded by the materials used to build the structure. Sensitivity analysis shows that the external gamma pathway and the overall dose (particularly the dose from a byproduct source term for which the dominant pathway is external gamma radiation) are sensitive to this parameter. In recognition of this sensitivity, SHF1 has been conservatively represented with the RESRAD default probabilistic distribution (bounded lognormal-N) with a central tendency value of 0.27 and ranging from 0.044 to 1.0. The RESRAD default is extremely conservative for construction methods typically required and used in New England. The upper bound of the distribution considers the case in which a residential structure with no floors is occupied year-round. Figure 4–8 graphically illustrates the distribution from which values of the external gamma shielding factor are sampled.

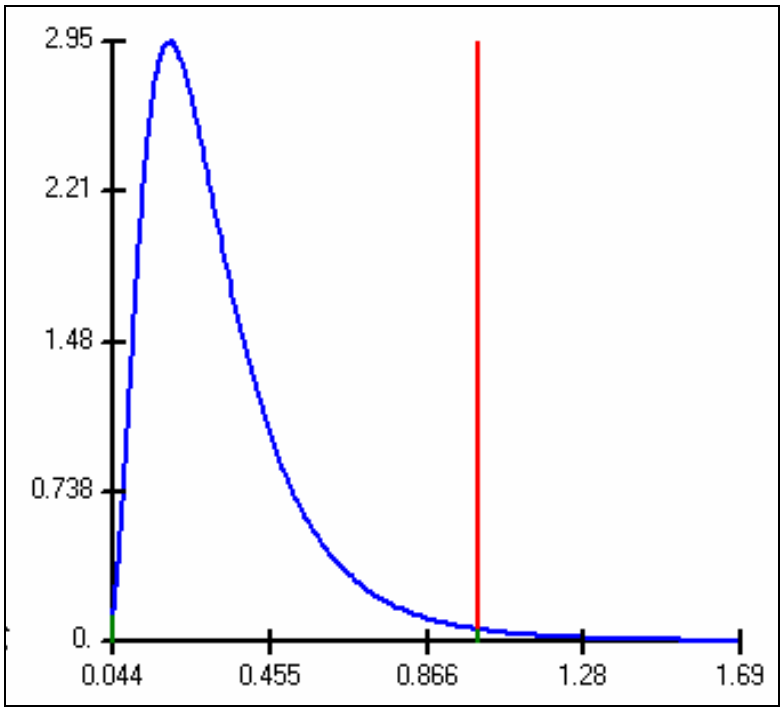

Figure 4–8 External Gamma Shielding Factor (unitless)

4.4.8 Depth of Soil Mixing Layer

This parameter (DM) is used in calculating the depth factor for the dust inhalation and soil ingestion pathways and for foliar deposition for the ingestion pathways. The depth factor is the fraction of resuspendable soil particles at the ground surface that are contaminated, which is calculated by assuming that mixing of the soil will occur within a layer of thickness, DM, at the surface. The RESRAD default distribution (triangular) and range is used. Figure 4–9 graphically illustrates the distribution from which values of the depth of the soil mixing layer is sampled.

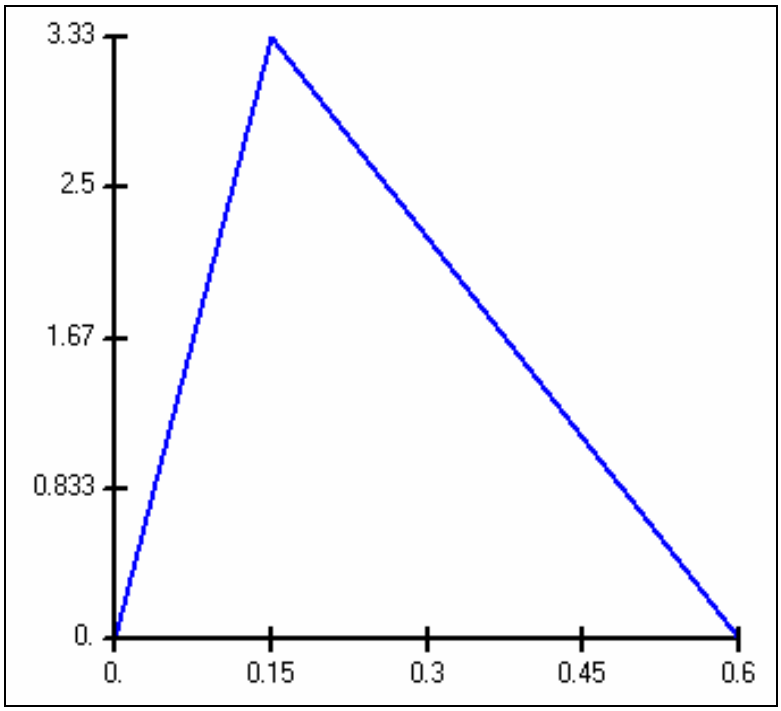

Figure 4–9 Depth of Soil Mixing Layer (m)

4.4.9 Inhalation Rate

Inhalation rate (INHALR) is the air intake in m^3 per year. It is used to calculate the dose from the inhalation pathway. The parameter represents the annual average breathing rate for a receptor from the critical exposure group subpopulation performing tasks under evaluation in a given scenario.

Sensitivity analysis shows that while the inhalation pathway is sensitive to this parameter, the total annual dose is not because the inhalation pathway is not a significant contributor to total annual dose. Inhalation rate is represented with the RESRAD default probabilistic distribution—a triangular distribution with a range of 4380 to 13100 m^3/yr and a mode of 8400 m^3/yr. Figure 4–10 graphically illustrates the distribution from which values of inhalation rate are sampled.

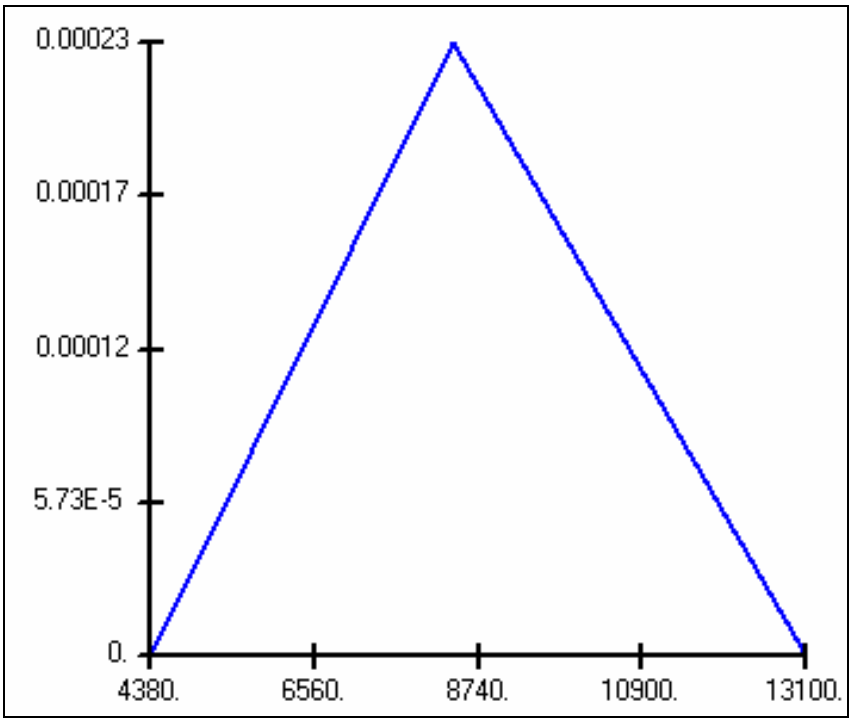

Figure 4–10 Inhalation Rate (m^3/yr)

4.4.10 Indoor & Outdoor Time Fractions

RESRAD uses fractions of a whole year spent onsite to calculate annual dose to a receptor. The total fraction of a year spent on site is divided between two parameters: indoor time fraction (FIND) and outdoor time fraction (FOTD). Onsite time fractions are wholly dependent upon the scenario under consideration. Each of the five scenarios evaluated in the derivation of the Site soil DCGLs has a discrete set of indoor and outdoor time fractions consistent with the specific scenario. The values used to describe the onsite time fractions are derived from conservative assumptions attributed to members of the critical exposure group and designed to be conservative for the general population of potentially exposed individuals. Sensitivity analysis indicates that total annual dose is most sensitive to variability in these two parameters as all of the exposure pathways are strongly dependent on exposure duration.

The occupational worker, suburban resident, and resident farmer scenarios include exposure time both indoors and outdoors onsite, while the construction worker, recreational user, and truck farmer scenarios consider that all exposure on site occurs outdoors.

For the construction worker, recreational user, and truck farmer scenarios, FIND is set to zero in the deterministic module and is not described with a probabilistic distribution. Uncertainty in onsite exposure time is accounted for with the outdoor time fraction parameter. In these scenarios, FOTD is represented with a triangular distribution adjusted such that the range and mode are appropriate for the specific scenario. The

distributions from which values of outdoor time fractions are sampled for each of the three scenarios are graphically illustrated in Figure 4–11, Figure 4–12, and Figure 4–13.

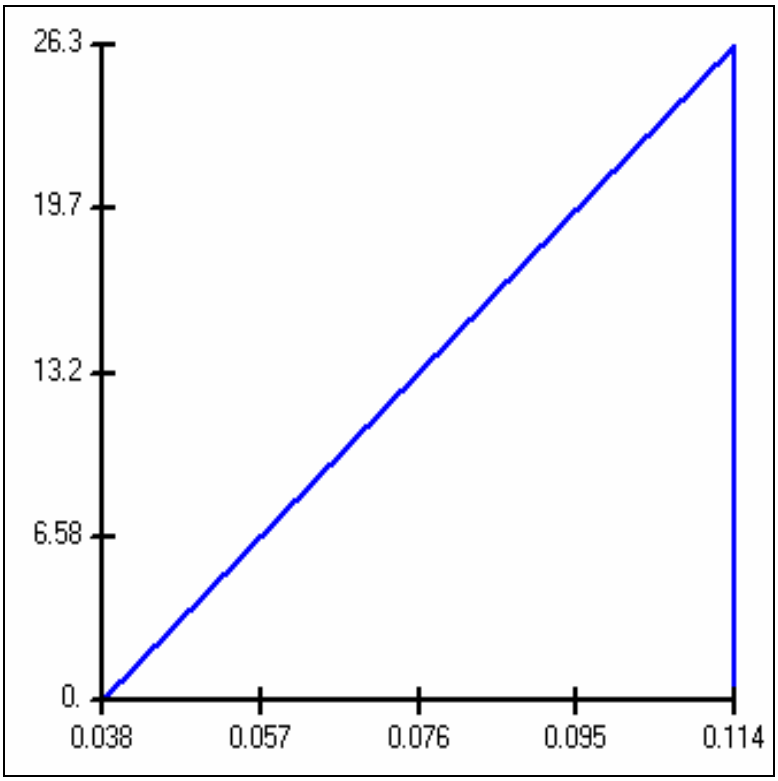

Figure 4–11 Outdoor Time Fraction, Construction Worker (unitless)

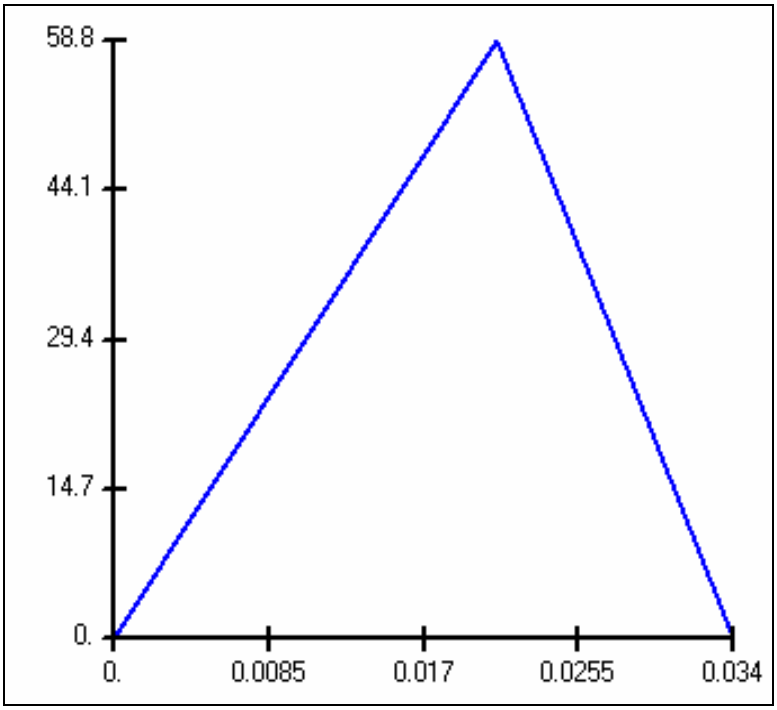

Figure 4–12 Outdoor Time Fraction, Recreational User (unitless)

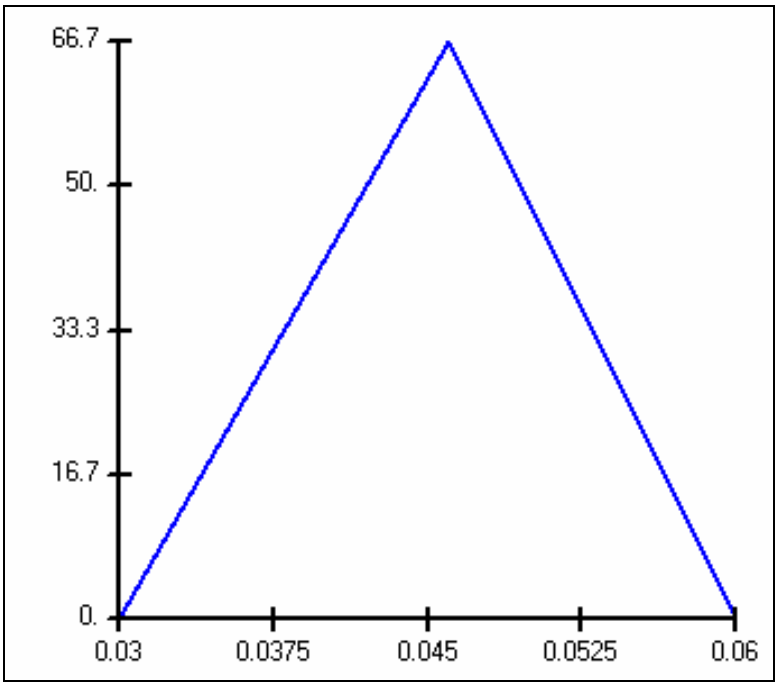

Figure 4–13 Outdoor Time Fraction, Truck Farmer (unitless)

The occupational worker, suburban resident, and resident farmer scenarios include exposure both indoors and outdoors. The indoor and outdoor time fractions for the occupational worker are reflective of the defined critical exposure group for which 25 to 50% of the exposure time is assigned to outdoor exposures. In this scenario, both FIND and FOTD are represented with triangular distributions adjusted such that the range and mode are appropriate for the scenario. In setting up the uncertainty analysis for the occupational worker scenario, the FIND and FOTD parameters were inversely correlated with one another so that unrealistically large or small total onsite times would not be randomly selected in the Latin hypercube sampling process. Figure 4–14 and Figure 4–15 graphically illustrate the distributions from which values of indoor and outdoor time fractions are sampled in the occupational worker scenario.

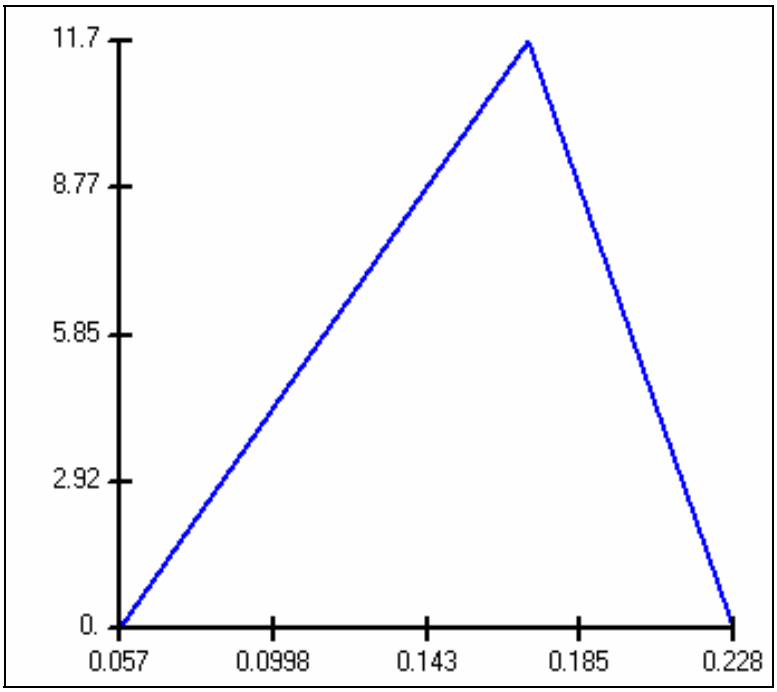

Figure 4–14 Indoor Time Fraction, Occupational Worker (unitless)

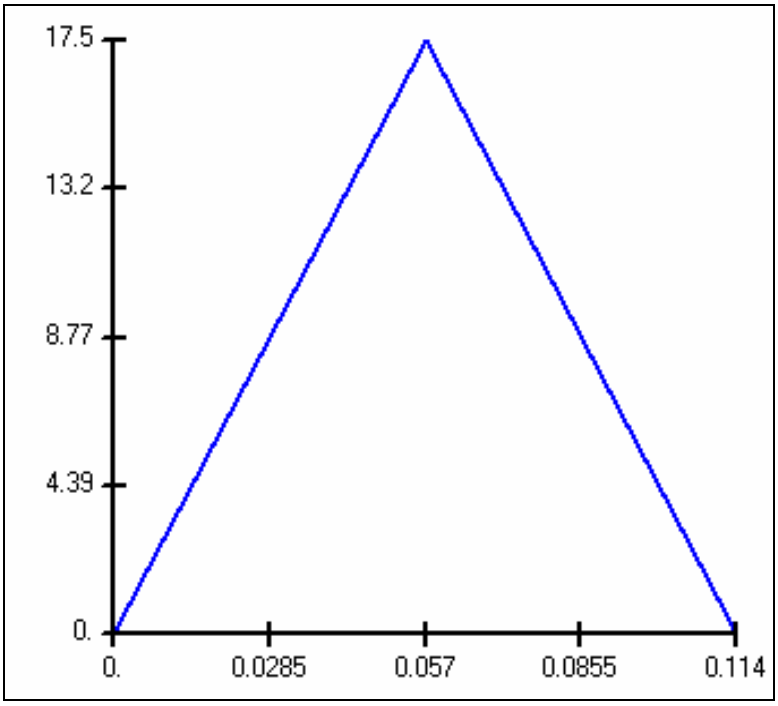

Figure 4–15 Outdoor Time Fraction, Occupational Worker (unitless)

For the suburban resident and residential farmer scenarios, both the indoor and outdoor time fractions are represented with the RESRAD deterministic defaults values.

4.4.11 Soil Ingestion Rate

RESRAD uses the annual average soil ingestion rate (SOIL) to calculate the dose from the direct soil ingestion pathway. Studies show that soil ingestion rates are correlated both with age and with the nature of activities that result in contact with soils. Therefore, it is appropriate that a distribution of possible soil ingestion rates be considered in the derivation of the DCGLs. Sensitivity analysis shows that both the soil ingestion pathway and annual dose is sensitive to this parameter in the case of enriched uranium radioactivity in soil. In fact, the soil ingestion pathway is a significant pathway contributor to total annual dose.

To account for the variability and provide a reasonable bounding condition for the various scenarios evaluated, the soil ingestion rate parameter is represented with the RESRAD probabilistic default distribution—a triangular distribution with a mode of 18.3 grams per year and a range from 0 to 36.5 grams per year. Figure 4–16 graphically illustrates the distribution from which values of soil ingestion rate are sampled.

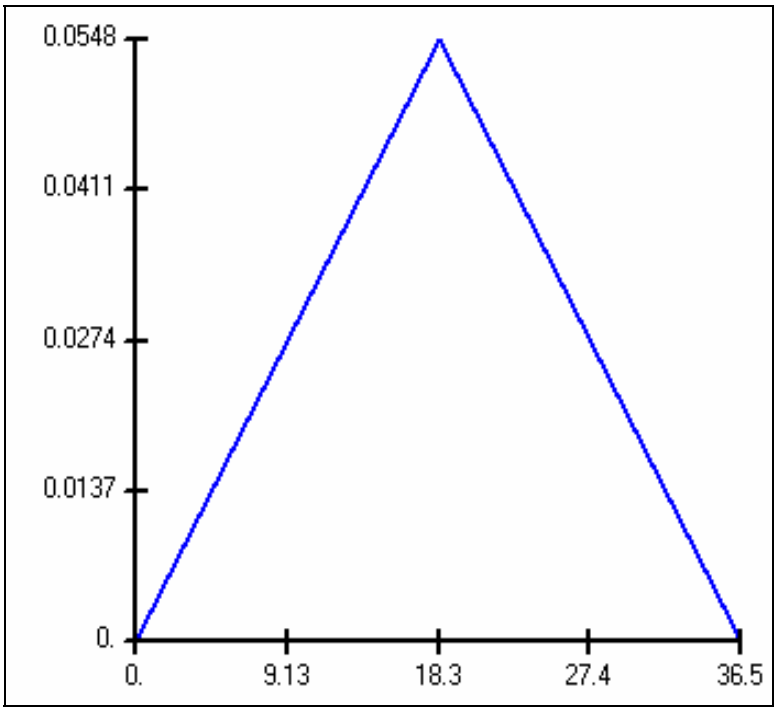

Figure 4–16 Soil Ingestion Rate (g/yr)

4.4.12 Distribution Coefficients

Distribution coefficients (K_d) describe the partitioning of soluble concentrations of radionuclides introduced to a soil column between solid (soil) and liquid phases. It is a key parameter influencing the migration of radioactivity from surface soils to groundwater. Distribution coefficients for a given chemical species (e.g., uranium) can

vary over many orders of magnitude depending on the soil type, pH, redox potential, and presence of other ions.

Two site-specific sampling programs have been undertaken at the Site to assess the site-specific K_d for uranium (Wang, 1996; ENSR, 2001). From these studies, site-specific values for uranium K_d have been developed (see Section 3.3.2) for the contaminated layer, for two underlying unsaturated soil layers, and the uppermost saturated soil layer. Sensitivity analysis shows that none of the water dependent pathways in any of the scenarios evaluated is particularly sensitive to variation in either uranium or cobalt distribution coefficients over the range of measured or expected values.

Distribution coefficient data compiled from the two sampling programs were fit to a lognormal-N distribution (the RESRAD default) with central tendency values and ranges corresponding to the stratum from which the data were derived.

Three different distributions are used to represent the uranium K_d parameter. One distribution, based on measured desorption K_d in contaminated surface soils is used for the "contaminated layer" in the RESRAD model. A second distribution, based on measured adsorption K_d in soils lying within the top 2 meters bgs is used for "unsaturated layer #1" in the RESRAD model. A third distribution, based on measured adsorption K_d in soils lying more than 3 meters bgs is used for both the "unsaturated layer #2" and "saturated layer" in the RESRAD model. Figure 4–17, Figure 4–18, and Figure 4–19 graphically illustrate the distributions from which values of the uranium distribution coefficients (DCACT(X)) were sampled.

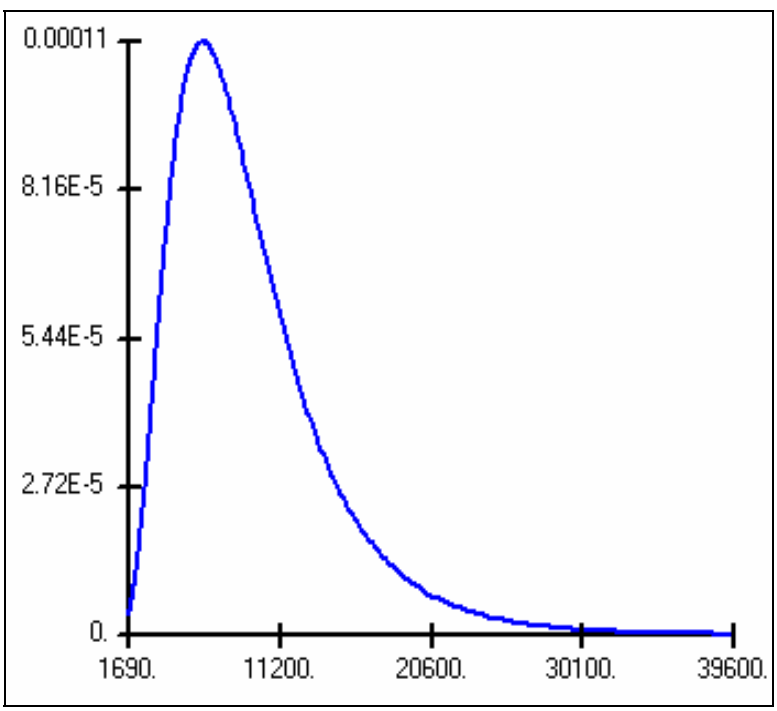

Figure 4–17 Uranium K_d (ml/g), Contaminated Layer

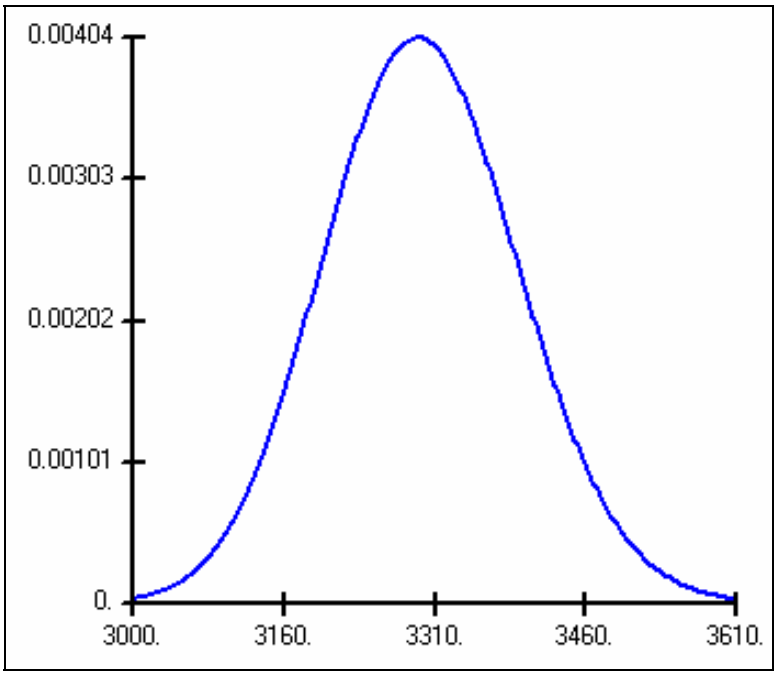

Figure 4–18 Uranium K_d (ml/g), Unsaturated Layer #1

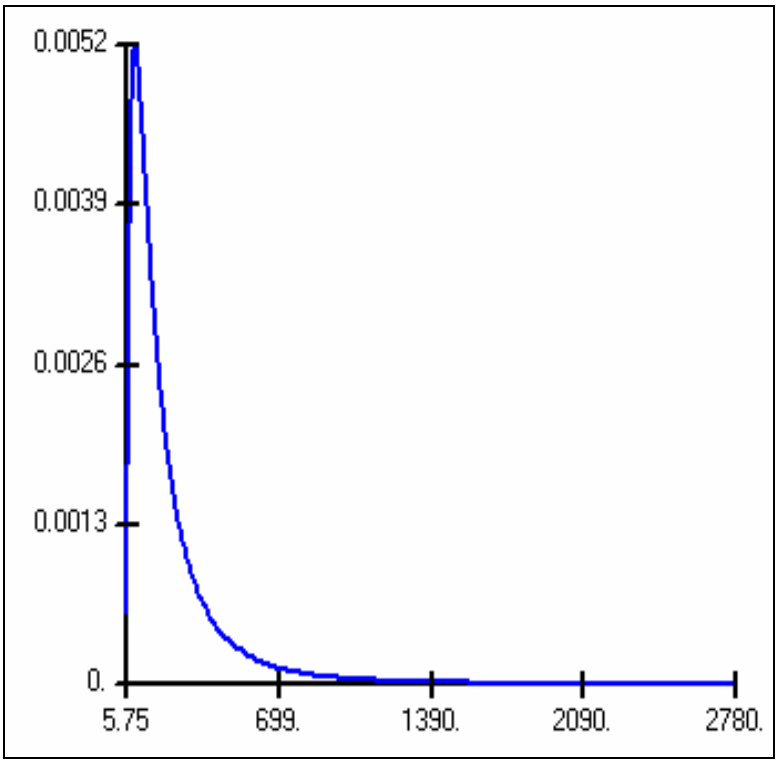

Figure 4–19 Uranium K_d (ml/g), Unsaturated Layer #2 & Saturated Layer

When modeling the dose resulting from the byproduct source term, the distribution coefficient for cobalt is represented with the RESRAD probabilistic default distribution in each of the four soil layers in the model. Figure 4–20 graphically illustrates the

distribution from which values of the cobalt distribution coefficient (DCACT(X)) were sampled.

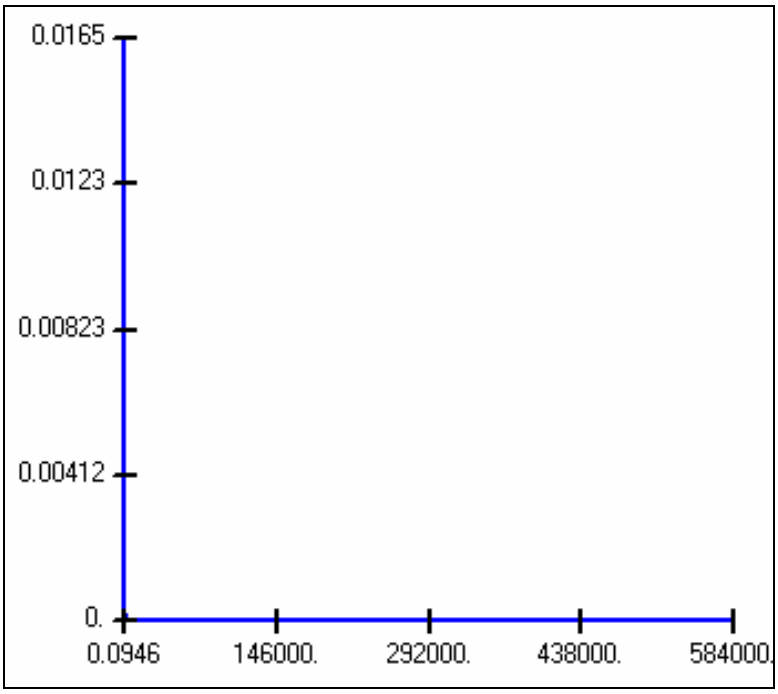

Figure 4–20 Cobalt K_d (ml/g), All Layers

4.4.13 Thickness of Contaminated Zone

Thickness of the contaminated zone (THICK0) describes the depth profile of the residual radioactivity expected to be present following any remedial activities that might be implemented on the site.

Over the vast majority of the Site (≈500 acres), only surface deposition mechanisms are involved. A review of the characterization data collected to date supports this aspect of the conceptual site model wherein residual radioactivity is generally confined to the very near surface soil layer (generally in the top 1 to 3 inches, with elevated activity detected rarely at depths of 6 inches). It is acknowledged that there are discrete areas on Site where it is known that residual radioactivity in excess of background concentrations for uranium are present or might reasonably be expected to occur in deeper soils (e.g., the drum burial area, the clamshell pile, industrial waste lines). Yet, in these areas, it is conceded that remedial activities will be implemented to remove the anomaly. Soil removal in these areas will result in a new ground surface in which the "surface soil" layer will be subject to the DCGLs.

RESRAD does not offer a recommended (or default) distribution for the thickness of contaminated zone parameter (THICK0). However, screening level analysis indicates that surface soil radioactivity is confined to the very near surface soil veneer, where it is found at all, and typically to the top 3 to 6 inches of surface soil. To address the uncertainty and variability associated with the thickness of the contaminated zone in the

RESRAD model, the thickness is represented with a triangular distribution having a mode of 3 inches (0.075 meters) and a range of 0" to 12" (0 to 0.3 meters). The distribution from which values of Contaminated Zone Thickness are sampled in all of the scenarios is graphically illustrated in Figure 4–21.

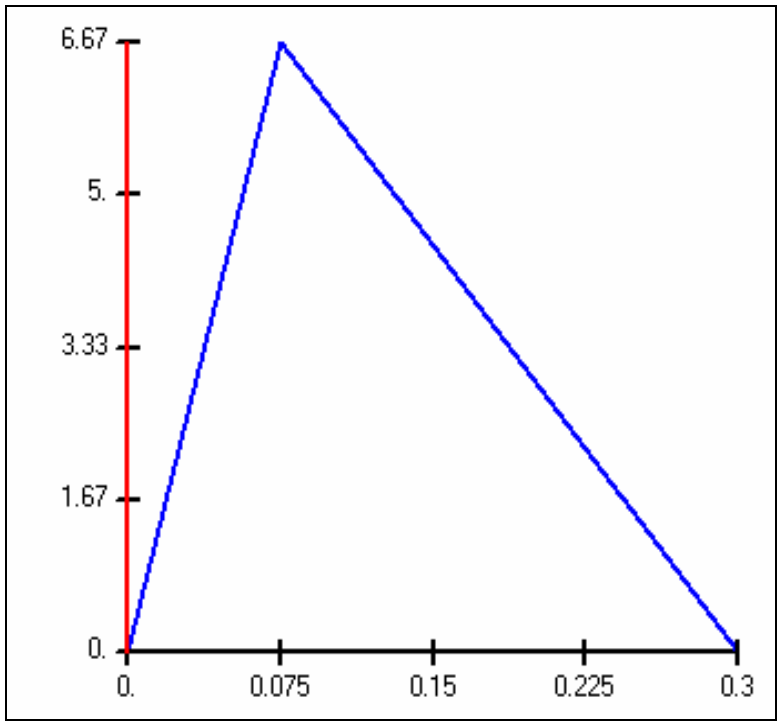

Figure 4–21 Contaminated Zone Thickness (m)

4.4.14 Contaminated Fraction of Aquatic Food

The contaminated fraction of aquatic food parameter (FR9) is used to determine what portion of the annual fish and other aquatic foods diet is derived from onsite sources, which are assumed to be impacted by residual radioactivity. The parameter is used only in the recreational user, suburban resident, and resident farmer scenarios; scenarios in which the consumption of aquatic foods from onsite sources are considered.

Sensitivity analysis shows that aquatic foods pathway is sensitive to this parameter but that the total annual dose is not because the aquatic foods pathway is not a significant contributor to total annual dose. The contaminated fraction of aquatic foods parameter is represented with the RESRAD default probabilistic distribution—a triangular distribution with a range of 0 to 1.0 and a mode of 0.39. Figure 4–22 graphically illustrates the distribution from which values of the contaminated fraction of aquatic food are sampled.

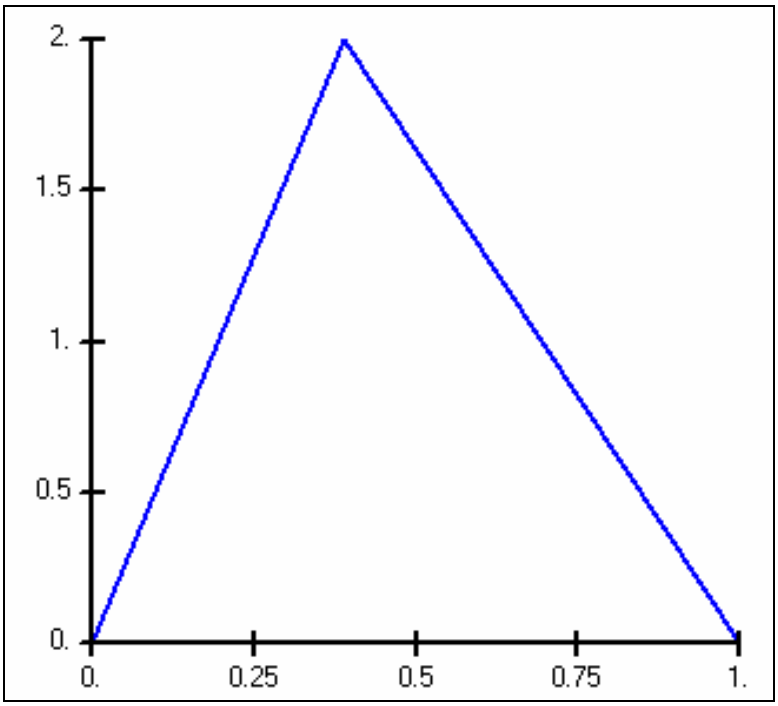

Figure 4–22 Contaminated Fraction of Aquatic Food (unitless)

4.5 INTERPRETING UNCERTAINTY ANALYSIS RESULTS

Because the result of the uncertainty analysis provides a distribution of doses, 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 a deterministic dose calculated using single point estimates of the various parameters.

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 a deterministic analysis, it should be recognized that the reported dose is simply one of a range of possible doses that could be calculated for the Site and scenario. In this analysis, the peak of the mean dose for the critical exposure group (the most exposed subpopulation) is presented for comparison with the deterministic regulatory limit as required by regulation. 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. Results of the probabilistic dose modeling including an evaluation of the uncertainty analysis are presented in Section 5.0.

5.0 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 of residual radioactivity in soil that yield a peak mean total annual dose of 19 mrem to a single receptor from among the critical exposure group. The computer code was set up to model each scenario with the input parameters identified and explained in Section 3.0. Separate soil DCGLs are derived for enriched uranium and byproduct materials, as it is expected (based on Site history and previous analytical results) that isotopes found in byproduct materials will not be prevalent in soils across the Site.

Since separate DCGLs for enriched uranium and byproduct materials are derived, and each is derived independently to satisfy the 19 mrem/y annual dose limit, a unity summation (Equation 5–1) must be employed in the data evaluation process for demonstrating compliance with the soil DCGLs where both enriched uranium and byproducts are present together. This process is applied not in the derivation of the soil DCGLs themselves, but rather in the future sampling and measurement process—the radiological Final Status Survey (FSS).

$$\sum\left[\left(\frac{[U_{ENRICHED}]}{DCGL_{U-ENRICHED}}\right)+\left(\frac{[Byproduct]}{\mathrm{DCGL}_{\mathrm{BYPRODUCT}}}\right)\right] \leq 1$$

Equation 5-1. Unity Summation

The following sections present the results of the computer modeling relating both the enriched uranium source concentrations in soil and byproduct source concentrations[11] in soil with potential future doses in each of the five scenarios evaluated. Additional graphics showing the relationships between pathways and annual effective dose equivalent as well as probability densities for dose contributed from each pathway are provided in Appendix H.

5.1 MODEL RESULTS FOR ENRICHED URANIUM IN SOIL

5.1.1 Occupational Worker

A light industrial or corporate business center setting, the most likely future use scenario for this Site, would require an array of staff positions such as managers, office and support personnel, and maintenance and operations personnel, among others. Whereas the persons associated with each of these occupations might spend different amounts of time at the Site, most predominantly indoors, the critical exposure group receptor for this scenario is a full-time maintenance worker performing a full range of maintenance and support tasks at the facility, providing a conservative evaluation for all these potential occupational workers.

[11] The isotope mixture in byproduct materials found at the Site and the potential future dose from byproduct materials in soil are dominated by Co-60. As a result, the byproduct soil DCGL is presented in terms of the Co-60 concentration.

Table 5–1 summarizes the results of modeling the projected future exposure potential for the scenario involving exposure while occupationally employed at the Site. The isotope mixtures used are typical of, and consistent with, the isotopic mixture in soil at the Site.

Table 5-1. Occupational Worker Scenario

Public Health Limit	Average Residual Radioactivity Concentration in Soil (pCi/g)	
	Total Uranium	***Co-60***
Annual Dose (25 mrem/y)	4167	22.8
Annual Dose (19 mrem/y)	3167	17.3
Computer printouts showing source term, dose, and radionuclide contribution distributions are in Appendix A. The soil concentration corresponding to an annual dose of 25 mrem is also presented for comparison purposes.		

A review of the computer modeling printouts for the enriched uranium source term (Appendix A) reveals that exposure from gamma radiation dominates the exposure pathways for the occupational worker scenario and that the uranium 235 isotope is marginally the most significant contributor to total effective annual dose. For the byproduct materials source term, exposure from direct penetrating gamma radiation is by far the principal exposure pathway as cobalt 60 is the most significant contributor to total effective annual dose. Figures 5–1 through 5–3 illustrate the relative pathway and isotopic contributions to total effective dose equivalent for the occupational worker scenario.

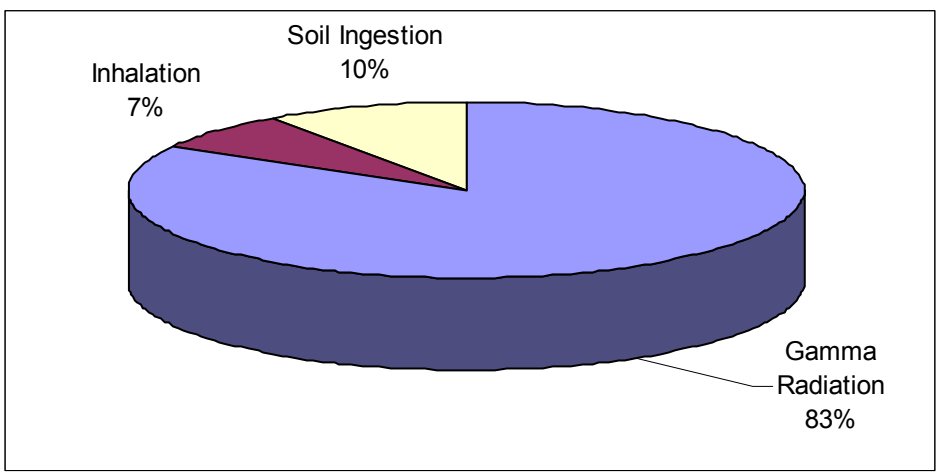

Figure 5–1 Occupational Worker—Pathway Contributions to TEDE—Enriched Uranium

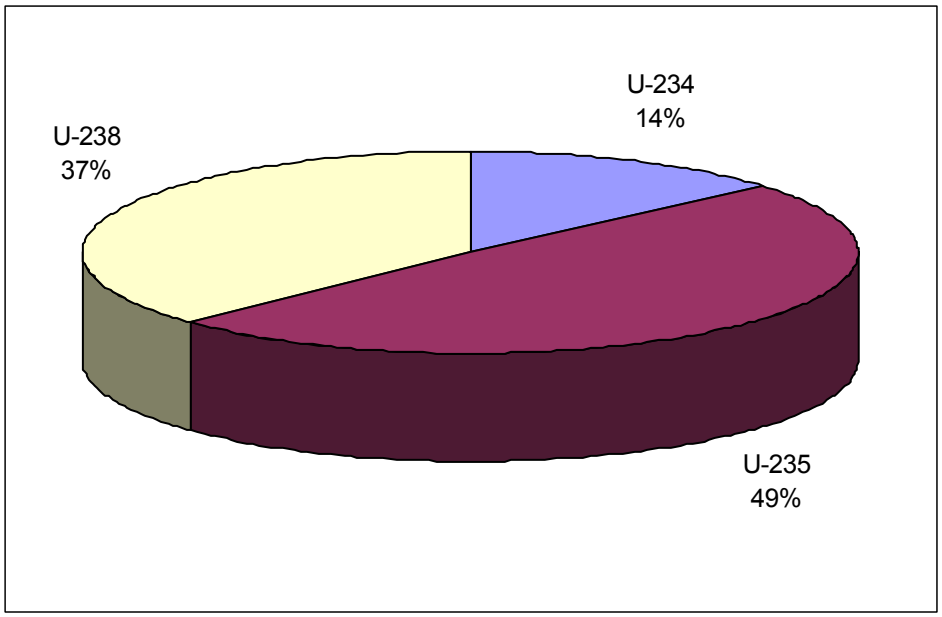

Figure 5–2 Occupational Worker—Isotopic Contributions to TEDE—Enriched Uranium

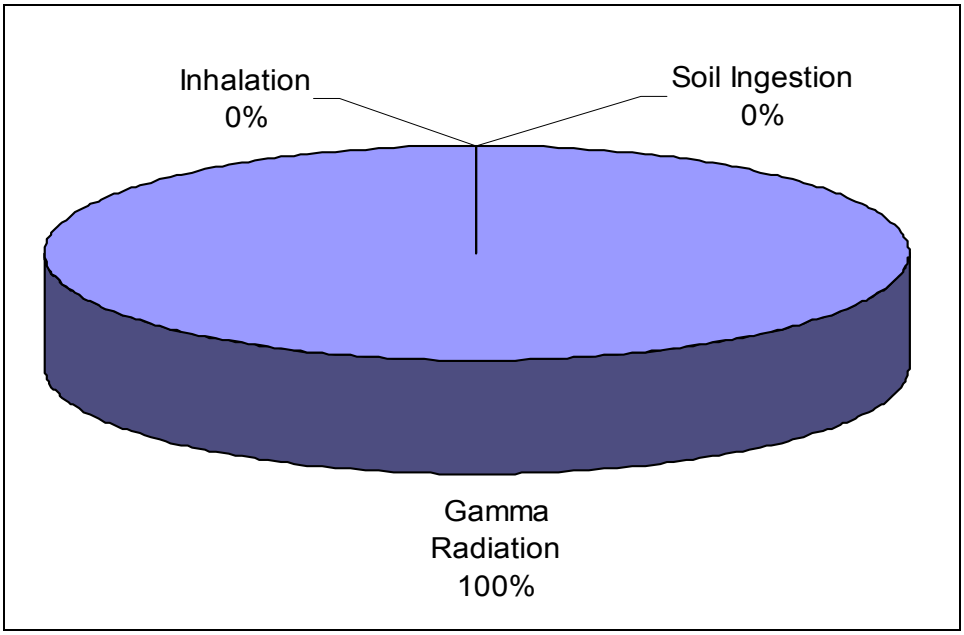

Figure 5–3 Occupational Worker—Pathway Contributions to TEDE—Byproduct

5.1.2 Construction Worker

Table 5–2 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 is identified as the workers who perform earth moving and excavation activities.

The isotope mixtures used are typical of, and consistent with, the isotopic mixture in soil at the Site.

Table 5-2. Construction Worker Scenario

Public Health Limit	Average Residual Radioactivity Concentration in Soil (pCi/g)	
	Total Uranium	*Co-60*
Annual Dose (25 mrem/y)	6079	31.3
Annual Dose (19 mrem/y)	4620	23.8
Computer printouts showing source term, dose, and radionuclide contribution distributions are in Appendix B. The soil concentration corresponding to an annual dose of 25 mrem is also presented for comparison purposes.		

A review of the computer modeling printouts for the enriched uranium source term (Appendix B) reveals that exposure from gamma radiation is again the most significant exposure pathway for the construction worker scenario and that the uranium 235 isotope is the most significant contributor to total effective annual dose. For the byproduct materials source term, exposure from direct penetrating gamma radiation accounts for essentially the entire projected total effective annual dose. Figures 5–4 through 5–6 illustrate the relative pathway and isotopic contributions to total effective dose equivalent for the construction worker scenario.

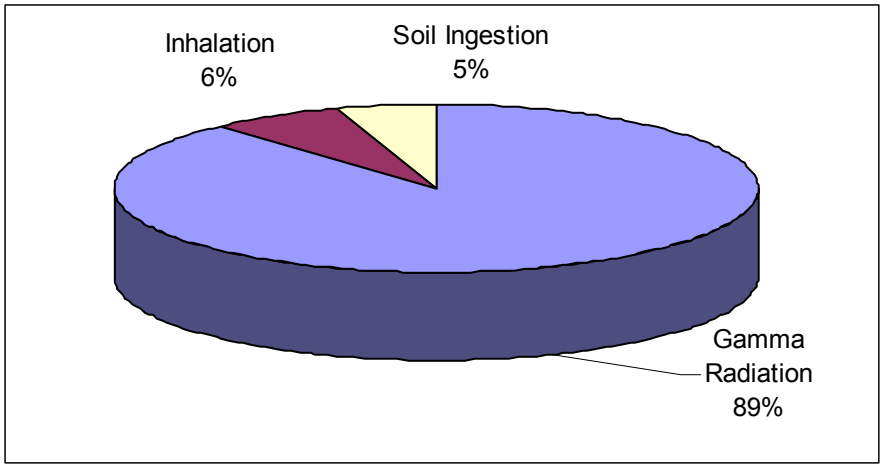

Figure 5–4 Construction Worker—Pathway Contributions to TEDE—Enriched Uranium

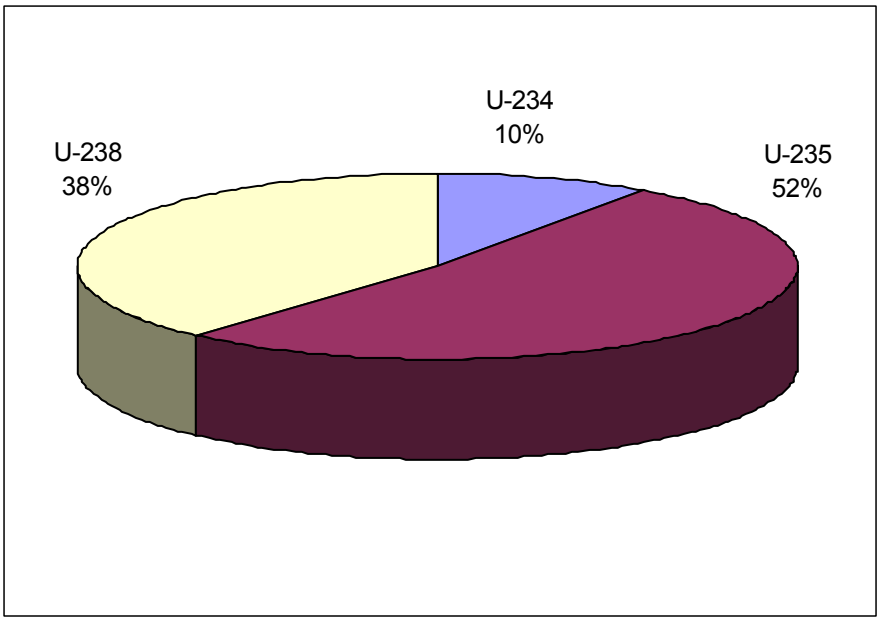

Figure 5–5 Construction Worker—Isotopic Contributions to TEDE—Enriched Uranium

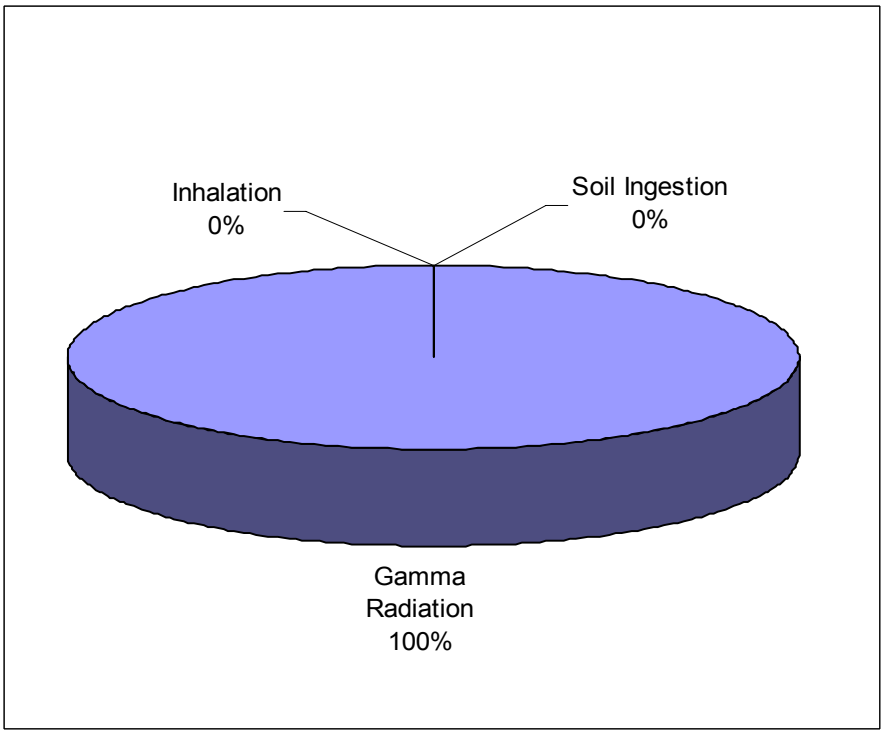

Figure 5–6 Construction Worker—Pathway Contributions to TEDE—Byproduct

5.1.3 Recreational Visitor / User

The recreational visitor (user) scenario evaluates the potential exposure to receptors that could be expected to frequent the property to use recreational facilities that might be made available in the future. The critical exposure group evaluated in this assessment is defined

by the recreational visitor receptor that is assumed to be an adolescent to middle-aged adult who lives in the area, but not on-Site, and who makes frequent use of the facilities[12].

Table 5–3 summarizes the results of modeling the projected future exposure potential for a scenario involving recreational uses of the Site after development. The isotope mixtures used are typical of, and consistent with, the isotopic mixture in soil at the Site.

Table 5-3 Recreational Visitor/User Scenario

Public Health Limit	Average Residual Radioactivity Concentration in Soil (pCi/g)	
	Total Uranium	*Co-60*
Annual Dose (25 mrem/y)	25,284	129.6
Annual Dose (19 mrem/y)	19,216	98.5
Computer printouts showing source term, dose, and radionuclide contribution distributions are in Appendix C. The soil concentration corresponding to an annual dose of 25 mrem is also presented for comparison purposes.		

It is notable that the dose for the recreational visitor with a given concentration of radioactivity in soil is smaller than for the occupational worker by approximately a factor of six. A review of the computer modeling printouts for the enriched uranium source term (Appendix C) reveals that exposure from gamma radiation is again the most significant exposure pathway for the recreational visitor scenario and that the uranium 235 isotope is the most significant contributor to total effective annual dose. For the byproduct materials source term, exposure from direct penetrating gamma radiation is by far the principal exposure pathway. Figures 5–7 through 5–9 illustrate the relative pathway and isotopic contributions to total effective dose equivalent for the recreational visitor scenario.

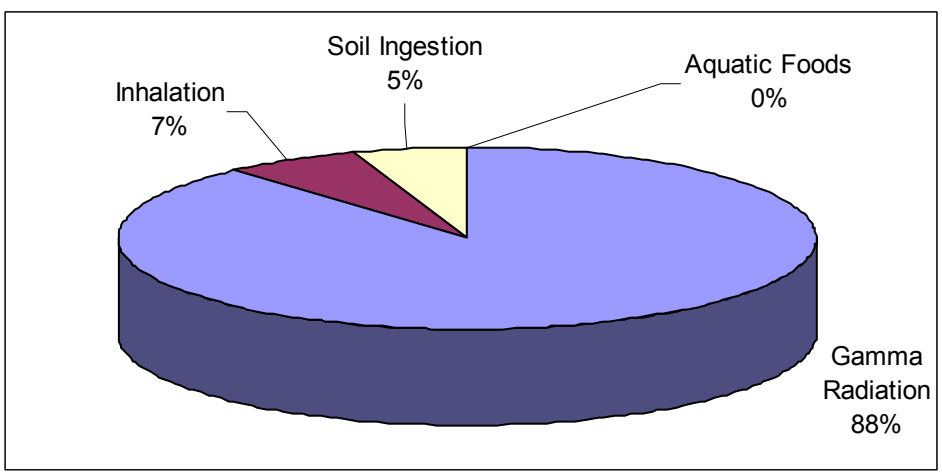

Figure 5–7 Recreational Visitor—Pathway Contributions to TEDE—Enriched Uranium

[12] This exposure group is protective for a passive recreational visitor who may use the property for more passive activities (e.g., reading, picnicking, sun-bathing).

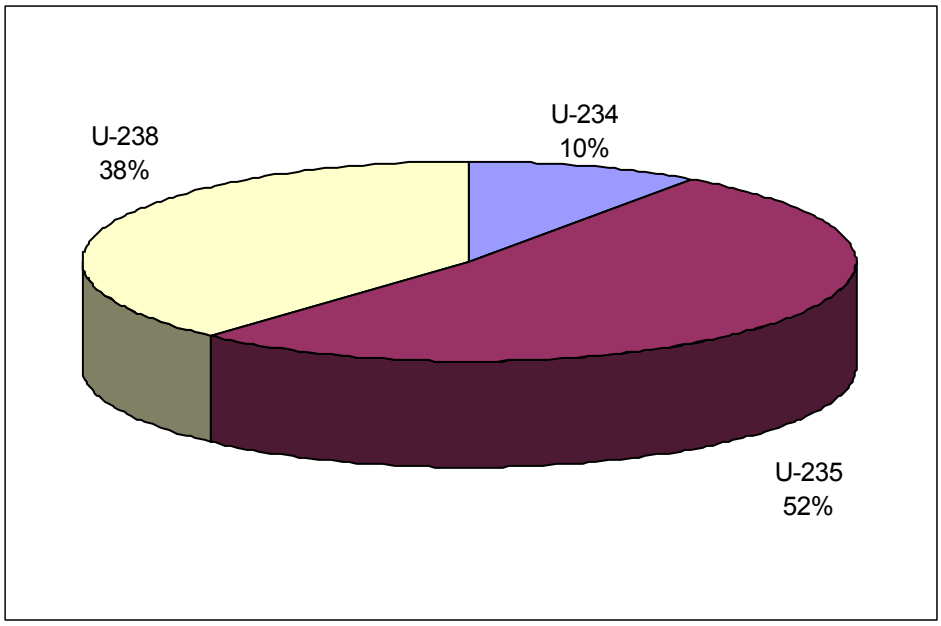

Figure 5–8 Recreational Visitor —Isotopic Contributions to TEDE—Enriched Uranium

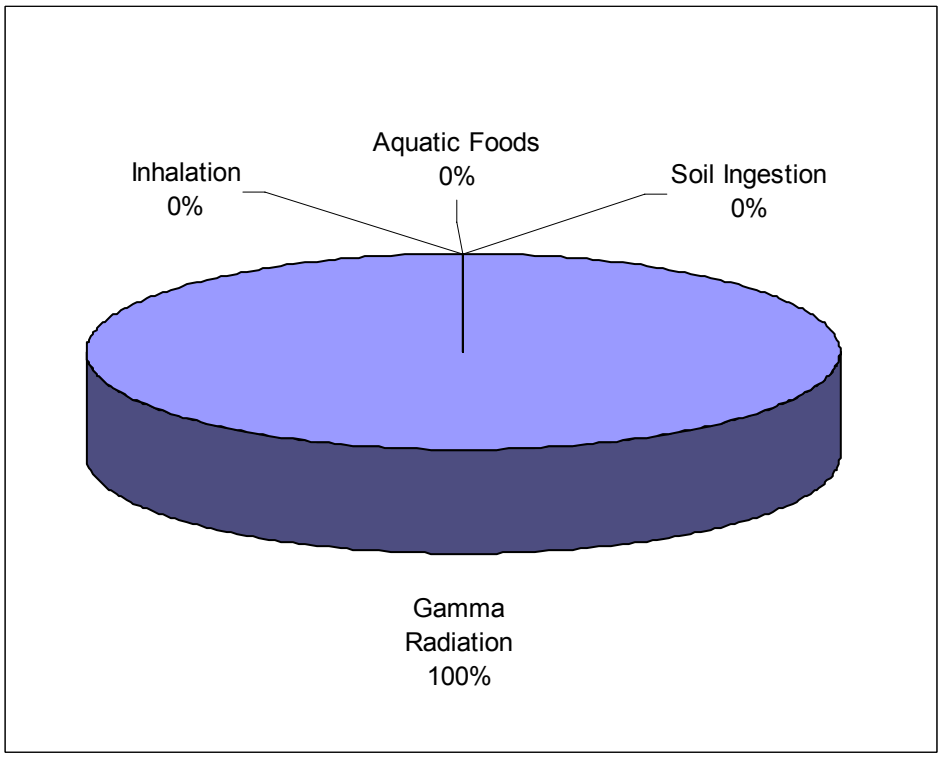

Figure 5–9 Recreational Visitor—Pathway Contributions to TEDE—Byproduct

5.1.4 Truck Farmer

While economic and societal factors make it unlikely that the CE property would be converted to commercial farming land, the presence of such farms in the near vicinity of the Site makes it plausible as a future use scenario. The critical exposure group for the commercial truck farmer scenario is an adult potentially exposed on a seasonal basis while engaging in activities related to the commercial farming of the land and through consumption of vegetables grown on the Site.

Table 5–4 summarizes the results of modeling the projected future exposure potential for a scenario involving commercial farming uses of the Site. The isotope mixtures used are typical of, and consistent with, the isotopic mixture in soil at the Site.

Table 5-4 Commercial Truck Farmer Scenario

Public Health Limit	Average Residual Radioactivity Concentration in Soil (pCi/g)	
	Total Uranium	*Co-60*
Annual Dose (25 mrem/y)	7093	52.1
Annual Dose (19 mrem/y)	5390	39.6
Computer printouts showing source term, dose, and radionuclide contribution distributions are in Appendix D. The soil concentration corresponding to an annual dose of 19 mrem is also presented for comparison purposes.		

The commercial truck farmer scenario yields dose estimates higher than that observed with the recreational visitor scenario but lower than those observed in either the occupational worker or construction worker scenarios. A review of the computer modeling printouts for the enriched uranium source term (Appendix D) reveals that gamma radiation exposure is again the most significant pathway for exposure. However, exposure from plant ingestion is a significant exposure pathway for the commercial truck farmer scenario. This is attributed to the assignment of a rather substantial fraction of the farm worker's annual plant food diet to produce grown onsite. Each of the three uranium isotopes contribute nearly equally to total effective annual dose. For the byproduct materials source term, exposure from direct penetrating gamma radiation is by far the principal exposure pathway with contribution from plant ingestion accounting for only 1% of the annual TEDE. Figures 5–10 through 5–12 illustrate the relative pathway and isotopic contributions to total effective dose equivalent for the commercial truck farmer scenario.

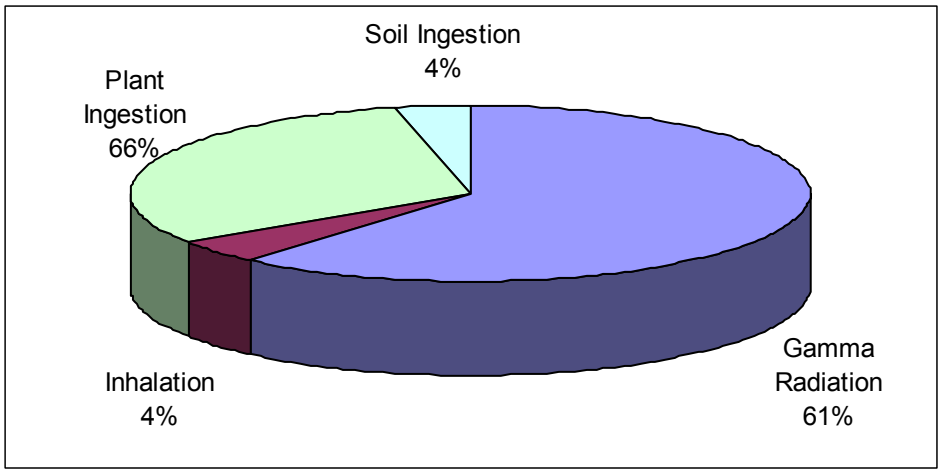

Figure 5–10 Truck Farmer—Pathway Contributions to TEDE—Enriched Uranium

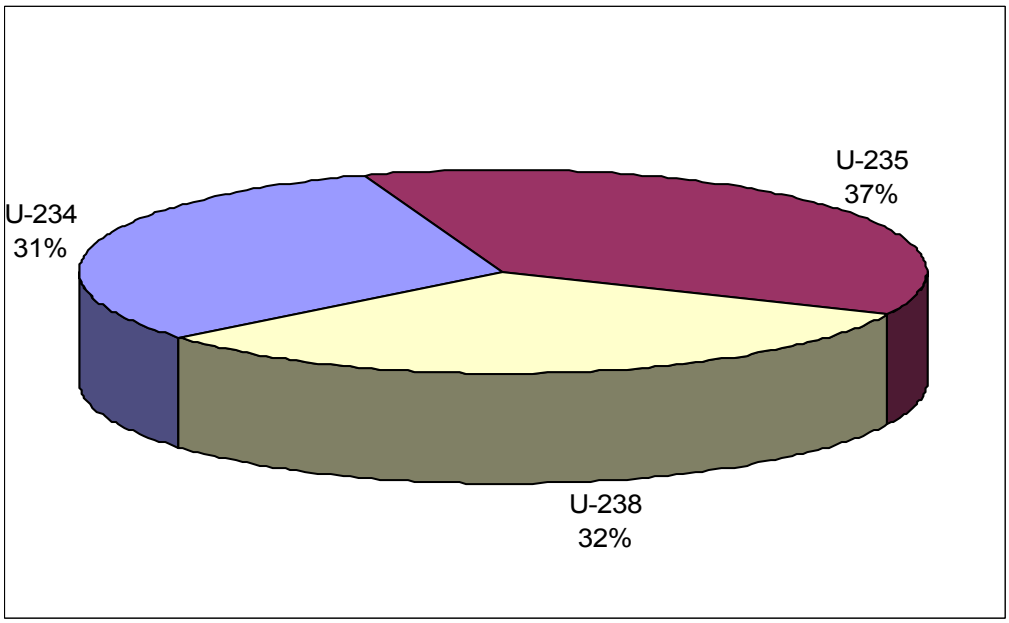

Figure 5–11 Truck Farmer —Isotopic Contributions to TEDE—Enriched Uranium

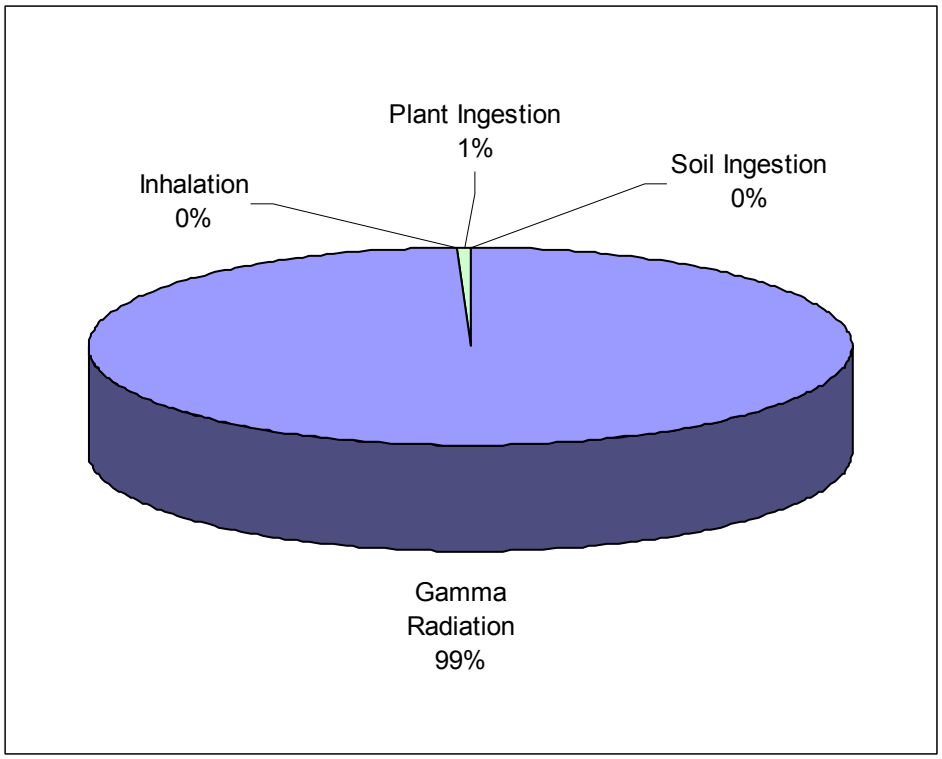

Figure 5–12 Truck Farmer —Pathway Contributions to TEDE—Byproduct

5.1.5 Suburban Resident

A suburban residential scenario (though less likely than some of the others evaluated) is within the realm of plausible and credible future use for the CE Windsor Site. The resident receptor is assumed to consume vegetables grown in a backyard garden. Table 5–5 summarizes the results of modeling the projected future exposure potential for a stay-at-home adult receptor exposed in the suburban residential setting. The isotope mixtures used are typical of, and consistent with, the isotopic mixture in soil at the Site.

Table 5-5 Suburban Residential Scenario

Public Health Limit	**Average Residual Radioactivity Concentration in Soil (pCi/g)**	
	Total Uranium	Co-60
Annual Dose (25 mrem/y)	1342	7.8
Annual Dose (19 mrem/y)	1020	5.9
Computer printouts showing source term, dose, and radionuclide contribution distributions are in Appendix E. The soil concentration corresponding to an annual dose of 25 mrem is also presented for comparison purposes.		

A review of the computer modeling printouts for the enriched uranium source term (Appendix E) reveals that direct gamma radiation exposure is the most significant exposure pathway for the suburban resident receptor. Uranium 235 is the most

significant isotope contributor to total effective annual dose, producing nearly 50% of the total projected annual dose. For the byproduct materials source term, exposure from direct penetrating gamma radiation is by far the principal exposure pathway. Figures 5–13 through 5–15 illustrate the relative pathway and isotopic contributions to total effective dose equivalent for the suburban resident scenario.

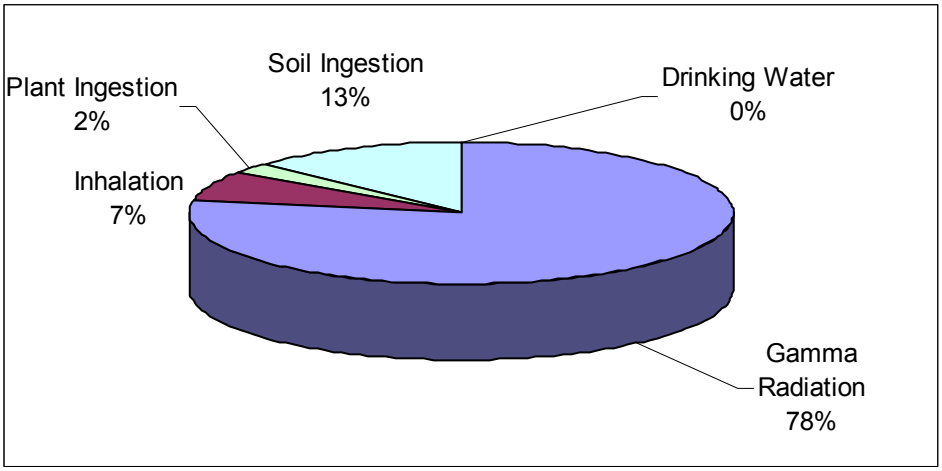

Figure 5–13 Suburban Resident—Pathway Contributions to TEDE—Enriched Uranium

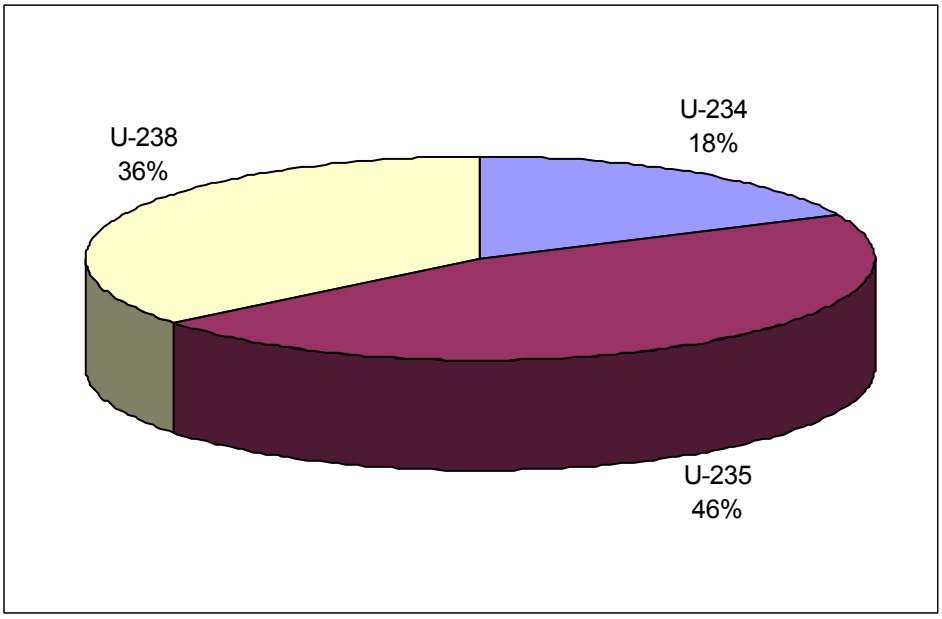

Figure 5–14 Suburban Resident—Isotopic Contributions to TEDE—Enriched Uranium

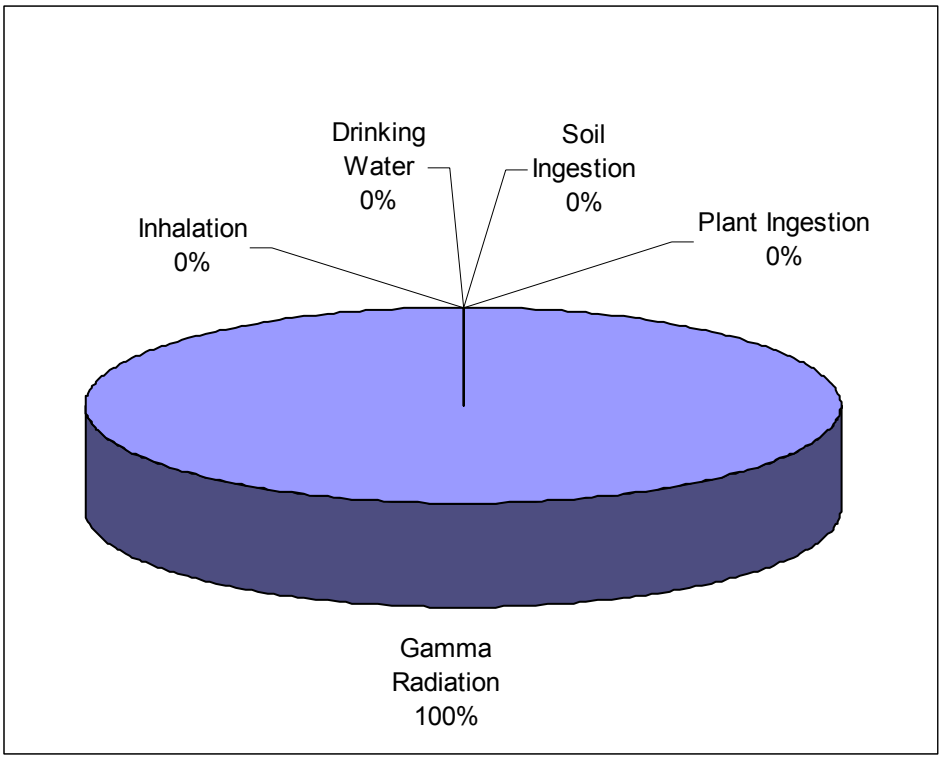

Figure 5–15 Suburban Resident—Pathway Contributions to TEDE—Byproduct

5.1.6 Resident Farmer

The resident farmer scenario, while thought to be improbable, is evaluated as a gauge of the extent of potential annual dose that might be accrued by a receptor in the event that more likely projected and anticipated future land uses (those listed in the above sections) prove inaccurate. The resident farmer scenario is essentially a screening level analysis with most of the exposure parameters used in the modeling conservatively set to default values. The resident farmer receptor is assumed to live on the site, consume produce grown on the site, derive his drinking and irrigation water from potentially contaminated sources onsite, and to raise livestock onsite to supply the annual dietary intake of milk and meat products. While considered highly improbable, this scenario serves well to gauge to *maximum* exposure potential at the Site.

Table 5–6 summarizes the results of modeling the projected future exposure potential for the residential farmer setting. The isotope mixtures used are typical of, and consistent with, the isotopic mixture in soil at the Site.

The resident farmer scenario yields dose estimates higher than all other scenarios evaluated and is, therefore, the scenario that constrains the selection of the dose-based soil DCGL. A review of the computer modeling printouts for the enriched uranium source term (Appendix F) reveals that exposure from direct gamma radiation is the most significant exposure pathway, producing approximately 50% of the total annual effective

dose. It is notable, however, that in the farming scenario, the consumption of significant fractions of the annual diet derived from foodstuffs produced onsite results in substantial contributions to annual dose from both the plant food and milk ingestion pathways. Again, each of the three uranium isotopes contribute nearly equally to total effective annual dose. For the byproduct materials source term, exposure from direct penetrating gamma radiation is by far the principal exposure pathway. Figures 5–16 through 5–18 illustrate the relative pathway and isotopic contributions to total effective dose equivalent for the resident farmer scenario.

Table 5-6 Residential Farmer Scenario

Public Health Limit	**Average Residual Radioactivity Concentration in Soil** (pCi/g)	
	Total Uranium	Co-60
Annual Dose (25 mrem/y)	733	6.6
Annual Dose (19 mrem/y)	557	5.0
Computer printouts showing source term, dose, and radionuclide contribution distributions are in Appendix F. The soil concentration corresponding to an annual dose of 25 mrem is also presented for comparison purposes.		

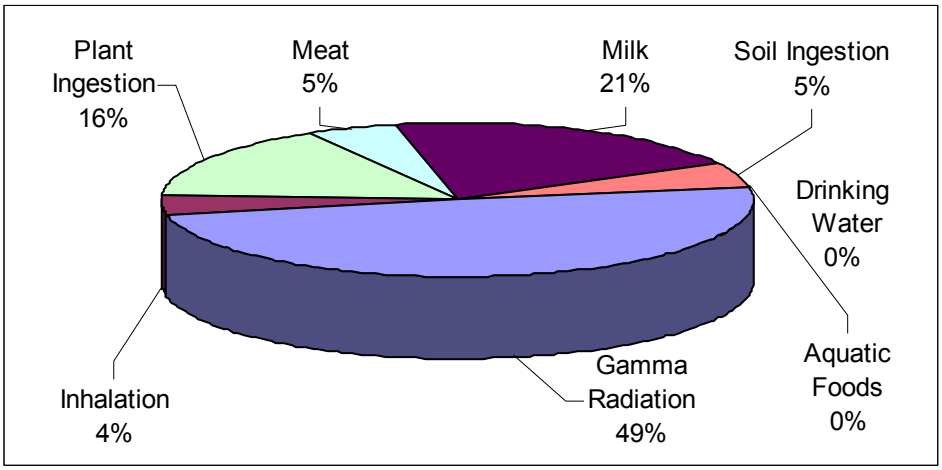

Figure 5–16 Resident Farmer—Pathway Contributions to TEDE—Enriched Uranium

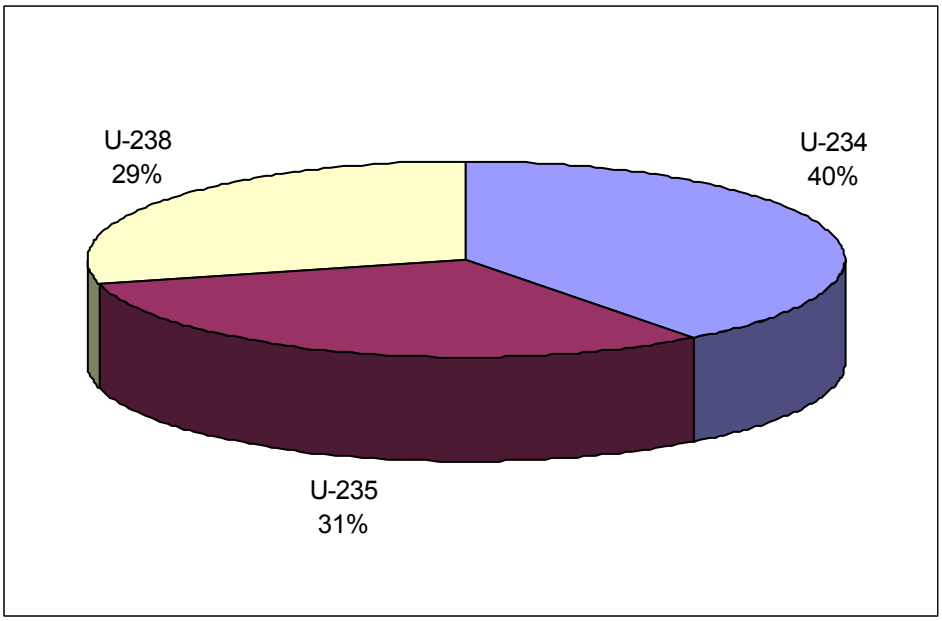

Figure 5–17 Resident Farmer—Isotopic Contributions to TEDE—Enriched Uranium

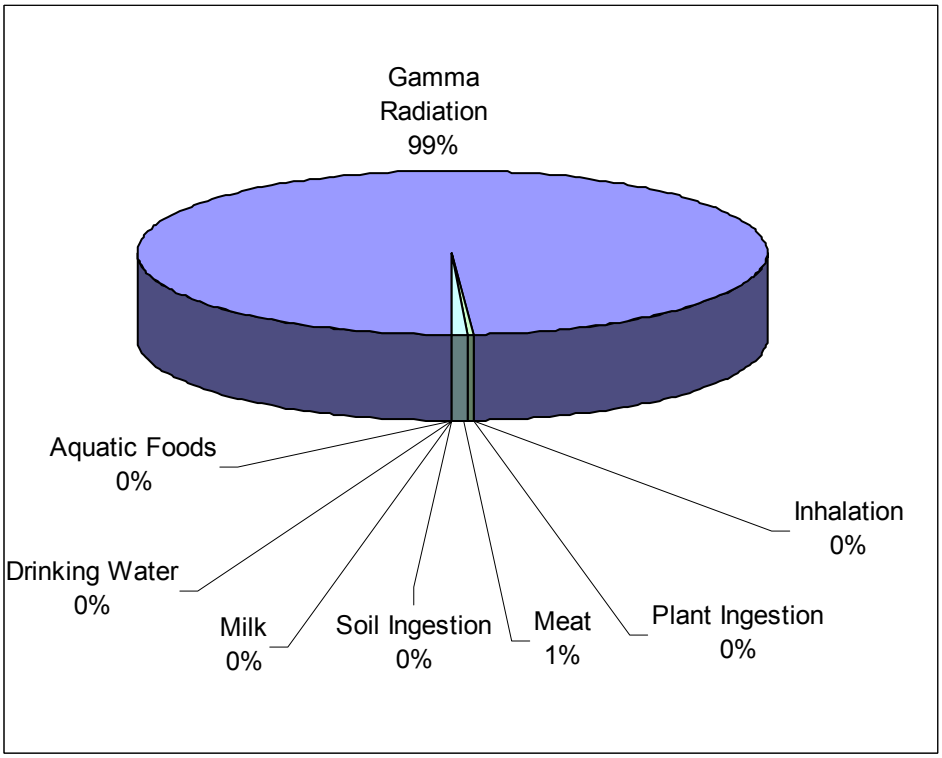

Figure 5–18 Resident Farmer—Pathway Contributions to TEDE—Byproduct

5.2 SUMMARY OF MODELING RESULTS

The results obtained above are compiled in Table 5–7, and are used to select the uranium and byproduct radioactivity in soil concentration that will be protective of all of the envisioned exposure scenarios. Based on annual public dose limits identified by the USNRC and the CTDEP, the limiting concentration for uranium in soil is 557 pCi/g total uranium, which yields 19 mrem/y to an exposed receptor who resides in a home constructed on the Site and produces a substantial portion of his annual diet on the site (the resident farmer). For byproduct radioactivity, the limiting concentration in soil is 5.0 pCi/g of Co-60, which, in the case of the residential farmer, yields an annual total effective dose equivalent of 19 mrem.

Table 5-7 Summary of Modeling Results

Exposure Scenario	**Average Residual Radioactivity Concentration in Soil (pCi/g)**			
	CTDEP 19 mrem/y		USNRC 25 mrem/y	
	Total Uranium	***Co-60***	***Total Uranium***	***Co-60***
Occupational Worker	3167	17.3	4167	22.8
Construction Worker	4620	23.8	6079	31.3
Recreational User / Visitor	19,216	98.5	25,284	129.6
Truck Farmer	5390	39.6	7093	52.1
Suburban Resident	1020	5.9	1342	7.8
Resident Farmer	557	5.0	733	6.6

6.0 SUMMARY AND RECOMMENDATIONS

6.1 PROPOSED SITE SPECIFIC DCGL VALUES

The dose evaluation described in this report provides the risk managers and decision makers with the substantive basis necessary to set and approve site-specific permissible concentration standards, the DCGLs, derived from the applicable regulatory limits for public dose. When approved, the proposed DCGLs will become the permissible soil concentration limits for unrestricted release of the CE Windsor Site from radiological controls.

The evaluation establishes a constrained public dose limit of 19 mrem/y from which the DCGLs are derived. Constraining the allowable dose to 19 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[13]. 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 uranium-in-soil concentration that ensures protection of human health. Table 5–7 (Section 5.0 of this report) presented the possible candidate DCGLs derived from the foregoing analysis.

Each of the scenarios modeled is considered credible and foreseeable and each results in an average total uranium in soil and average Co-60 in soil concentration corresponding to the CTDEP's 19 mrem/y TEDE dose limit (with additional uranium and Cobalt-60 soil concentrations corresponding to the USNRC's decommissioning standard of 25 mrem/y TEDE presented for comparison). Considering the potential future land-use scenarios, the limiting scenario (the one that results in the smallest soil concentration yielding 19 mrem/y) is the resident farmer scenario.

Therefore, ABB proposes and recommends the following soil DCGLs for the CE Windsor Site[14]:

- $DCGL_W$ for enriched uranium in soil — 557 pCi/g, total uranium
- $DCGL_W$ for byproduct material in soil — 5.0 pCi/g, Co-60

If the land use does evolve to the point where the conditions described by either the Suburban Residential or Resident Farmer scenarios are possible, the conditions described in the Construction Worker scenario will have already occurred. However, in selecting

[13] The basic public dose limit is 100 mrem/y considering all sources and all pathways. The USNRC'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 CE Windsor Site, will not produce a combined dose to a member of the public in excess of the basic public dose limit. CTDEP establishes an additional constrained site-specific value of 19 mrem/y.

[14] The uranium and Co-60 soil DCGLs do not apply independently of one another. In survey units where both uranium and byproduct source terms are present together, a summation of the fractions of the applicable DCGLs must not exceed unity (see Section 5.0 for a complete discussion of the unity summation rule for multiple concentration limits).

the Resident Farmer scenario as a basis for establishing the DCGL(s), the most conservative and protective concentration limits will have been chosen. Thus, ensuring that the Site is safe for any conceivable future receptor including a resident farmer also ensures that the Site is safe for suburban residents, occupational workers, workers involved in construction work at the Site, for visitors to and users of the recreation facilities at the Site, and for workers who may engage in commercial truck farming of the land.

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 USNRC, USDOE, and USEPA 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 4.0 and Appendix H).

The uncertainty analysis focused on the key exposure parameters in each scenario. Not all parameters in each scenario have been assigned distributions in order to evaluate their impact on overall uncertainty, recognizing that either they have little affect on the overall dose for the suite of radionuclides under consideration or they have a comparable effect in each of the scenarios. Considering the magnitude and range of candidate DCGLs that emerged from the individual scenarios in comparison with the 557 pCi/g total uranium soil DCGL and the 5.0 pCi/g Co-60 soil DCGL identified for the Resident Farmer scenario, it is evident that there is considerable additional conservatism for these other more likely exposure scenarios.

As described in Section 2.0 of this report, the exposure scenarios used to derive the soil DCGLs at the CE Windsor Site have been presented in the order that ABB believes is the most likely future use for the site. While qualitative in nature this “ranking” based on expected likelihood of occurrence, provides the risk managers and decision makers with an overall picture of the protectiveness of the selected soil DCGLs. By all accounts, the most likely future use of the Site is consistent with its current use: a light-industrial office, warehousing, and research complex. Thus, the occupational worker scenario is judged the most likely exposure scenario describing potential future dose to a member of the critical exposure group arising from residual radioactivity in soil at the Site. The peak mean annual dose to a member of the critical exposure group in the occupational worker

scenario with 557 pCi/g of total uranium in soil is 3.3 mrem/y. The peak mean annual dose to the occupational worker with 5.0 pCi/g of Co-60 in soil is 4.6 mrem/y.

Table 6–1 provides a summary of the potential peak mean annual dose to the critical exposure group in each scenario with the DCGLs set at the limiting soil concentrations derived in the residential farming scenario.

Table 6-1. Estimate of Potential Dose at the Limiting Soil DCGLs

Exposure Scenario	**Potential Peak Mean Annual Dose (*mrem/y*)**	
	557 pCi/g Total Uranium	***5.0 pCi/g Co-60***
Occupational Worker	3.3	4.6
Construction Worker	2.3	4.0
Recreational User / Visitor	0.6	0.9
Truck Farmer	1.9	2.4
Suburban Resident	10.4	16.1
Resident Farmer	19	19

6.3 RECOMMENDATION

The soil DCGLs proposed have been conservatively derived using appropriate techniques in accordance with governing guidance, standards, and regulations. To assist the DCGL development process, input from stakeholders from ABB, USACE, the Town of Windsor, CT, CTDEP, and the USEPA was utilized. It is recommended that the proposed soil $DCGL_W$ values be approved and adopted as the Site-specific permissible mean soil concentrations.

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GLOSSARY OF TERMS, ACRONYMS, AND ABBREVIATIONS

ABB-ES .....ABB Environmental Services
AEC.....Atomic Energy Commission
ALARA.....As Low as Reasonably Achievable

bgs.....below ground surface

CE .....Combustion Engineering, Inc.
CERCLA.....Comprehensive Environmental Response, Compensation, and Liability Act
CFR.....Code of Federal Regulations
cm.....centimeter
cm^3/g .....cubic centimeters per gram
Co-60.....cobalt 60
Cs-137.....cesium 137
CT .....Connecticut
CTDEP.....Connecticut Department of Environmental Protection

DCF.....Dose Conversion Factor
DCGL.....derived concentration guideline level
$DCGL_{EMC}$.....derived concentration guideline level, elevated measurement comparison
$DCGL_W$ .....derived concentration guideline level, survey unit average (median) concentration corresponding to the permissible limit
DOE .....(United States) Department of Energy (See USDOE)
DQO.....Data Quality Objective
DU.....depleted uranium

ENSR .....ENSR Corporation
EPA.....(United States) Environmental Protection Agency (See USEPA)
ER_S.....exposure rate–shielded
ER_U .....exposure rate–unshielded
EU .....enriched uranium

Fe-55 .....iron 55
FGR.....Federal Guidance Report
FR.....Federal Register
FSS.....Final Status Survey (radiological)
FUSRAP .....Formerly Utilized Site Remedial Action Program

g/cm^3 .....grams per cubic centimeter
g/y .....grams per year
g/m^3 .....grams per cubic meter
g/Kg-day .....grams per kilogram per day
GI .....gastro-intestinal

h.....hour(s)
hr .....hour(s)
HEU .....highly-enriched uranium
HLA .....Harding Lawson Associates
HRR .....Historical Review Report
HSA.....Historical Site Assessment

ICRP.....International Commission on Radiological Protection

KAPL .....Knolls Atomic Power Laboratory
K_d .....distribution coefficient
kg.....kilo-gram(s)
kg/m^2 .....kilo-grams per square meter
kg/y .....kilo-grams per year

L/yr.....liters per year
L/day .....liters per day
LEU.....low-enriched uranium
LHS .....Latin hypercube sampling
LLRW .....low-level radioactive waste

m .....meter(s)
m/sec .....meters per second
m/y .....meters per year
m^2 .....meters squared
m^3/y .....cubic meters per year
MARSSIM .....Multi-Agency Radiation Survey and Site Investigation Manual
max.....maximum
MCA .....Monte Carlo Analysis
min .....minimum
µg/g .....micro-grams per gram
$\mu g/m^3$ .....micro-grams per cubic meter
mg .....milli-gram(s)
mg/d .....milli-grams per day
mg/kg .....milli-grams per kilo-gram
Mn-54.....manganese 54
mph .....miles per hour
mrem .....milli-Roentgen equivalent man
mrem/pCi .....mrem per pico-Currie (See mrem)
mrem/y .....mrem per year (See mrem)
MSL .....Mean Sea Level

NCRP .....National Council on Radiation Protection and Measurements
NED .....(Army Corps of Engineers) New England Division
NFM.....nuclear fuel manufacturing

NOAA .....National Oceanographic and Aeronautic Administration
NRC .....(United States) Nuclear Regulatory Commission (See USNRC)

ORISE .....Oak Ridge Institute for Science and Engineering

PAH.....polynuclear aromatic hydrocarbon(s)
pCi/g.....pico-Curies per gram
PDF .....Probability Density Function
PDU.....Process Development Unit
PRA.....Probabilistic Risk Assessment

RCRA.....Resource Conservation and Recovery Act
Rd. .....road
RME.....Reasonable Maximum Exposure

SAIC .....Science Applications International Corporation
SAP .....Sampling and Analysis Plan
Sb-125 .....antimony 125

TEDE .....Total Effective Dose Equivalent

U+d .....uranium plus daughters
U-234 .....uranium 234
U-235 .....uranium 235
U-238 .....uranium 238
UCL.....upper confidence level
UO_2 .....uranium dioxide
USACE .....United States Army Corps of Engineers
USDOE .....United States Department of Energy
USEPA.....United States Environmental Protection Agency
USGS .....United States Geologic Service
USNRC .....United States Nuclear Regulatory Commission

VCA .....Voluntary Corrective Action

WWTP .....wastewater treatment plant

y.....year
yrs.....years