DERIVATION OF THE SITE-SPECIFIC SOIL DCGLS

ADDENDUM

SOIL DCGLS FOR THORIUM AND RADIUM

CE WINDSOR SITE

Windsor, Connecticut

US NRC License Number 06-00217-06

Docket Number 030-03754

August 2010

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ABB	ABB Inc.
ABB-ES	ABB Environmental Services
AEC	Atomic Energy Commission
bgs	below ground surface
CE	Combustion Engineering, Inc.
CFR	Code of Federal Regulations
cm	centimeter
cm3/g	cubic centimeters per gram
CT	Connecticut
CTAG	Connecticut Transfer Act
CTDEP	Connecticut Department of Environmental Protection
DCF	Dose Conversion Factor
DCGL	derived concentration guideline level
$DCGL_W$	derived concentration guideline level, survey unit average (median) concentration corresponding to the permissible limit
DOE	(United States) Department of Energy (See USDOE)
DP	Decommissioning Plan
ENSR	ENSR Corporation
EPA	(United States) Environmental Protection Agency (See USEPA)
FGR	Federal Guidance Report
FR	Federal Register
FUSRAP	Formerly Utilized Site Remedial Action Program
g/cm3	grams per cubic centimeter
g/y	grams per year
g/m3	grams per cubic meter
g/Kg-day	grams per kilogram per day
GI	gastro-intestinal
h	hour(s)
hr	hour(s)
HRR	Historical Review Report
HSA	Historical Site Assessment
ICRP	International Commission on Radiological Protection
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
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
MCL	maximum contaminant level
min	minimum
μg/g	micro-grams per gram
μg/m^3	micro-grams per cubic meter
mg	milli-gram(s)
mg/d	milli-grams per day
mg/kg	milli-grams per kilo-gram
mph	miles per hour
mrem	milli-Roentgen equivalent man
mrem/pCi	mrem per pico-Currie (See mrem)
mrem/y	mrem per year (See mrem)
NCRP	National Council on Radiation Protection and Measurements
NOAA	National Oceanographic and Aeronautic Administration
NRC	(United States) Nuclear Regulatory Commission (See USNRC)
ORISE	Oak Ridge Institute for Science and Engineering
pCi/g	pico-Curies per gram
PRA	Probabilistic Risk Assessment
Ra-226	Radium 226
RCRA	Resource Conservation and Recovery Act
RSR	Remediation Standard Regulation
SAIC	Science Applications International Corporation
Sb-125	antimony 125
TEDE	Total Effective Dose Equivalent
Th-232	Thorium 232
USACE	United States Army Corps of Engineers
USDOE	United States Department of Energy
USEPA	United States Environmental Protection Agency
USNRC	United States Nuclear Regulatory Commission
VCA	Voluntary Corrective Action
WWTP	wastewater treatment plant
y	year
yrs	years

EXECUTIVE SUMMARY

This report presents an addendum to the Derivation of the Site-Specific Soil Derived Concentration Guidance Levels (DCGLs) (ABB, 2003) for the Combustion Engineering, Inc. (CE) Site located at 2000 Day Hill Road in Windsor, Connecticut. The Site is owned by ABB Inc. (ABB) and ABB is currently licensed by the Nuclear Regulatory Commission (NRC) to possess radioactive materials at the site and to engage in the decontamination and decommissioning of the Site (NRC, 2009).

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 NRC and Connecticut Department of Environmental Protection (CTDEP).

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 testing of nuclear reactor plant components, testing of materials, and servicing of radiologically contaminated reactor plant components. Because of these past activities, areas of radiologically impacted soil at the Site may have residual radioactivity concentrations from enriched uranium (principally) and reactor byproduct materials (minimally). In addition, some portions of the Site were involved with processing thoriated waste materials. These thoriated waste materials were incinerated at an area identified as the Burning Grounds. This area was previously remediated and released by the NRC.

The objective of ABB 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 and the land and buildings at the Site can be returned to unrestricted use.

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. Future residential use of the land is considered possible given the current community growth, planning and development strategies of the local municipality.

Decommissioning activities at the CE Windsor site have identified additional radiological constituents of concern. Initially, these additional radiological constituents of concern were found at the Burning Grounds area and later in the adjacent Woods area and Drum Burial Pit area. This addendum specifically addresses thorium and radium as additional radiological constituents of concern and presents dose modeling for each consistent with the model, parameters and scenario previously accepted for uranium and byproduct materials in soil at the CE Windsor site.

These addendum DCGLs for the CE Windsor Site have been calculated using the RESRAD 6.4 modeling code. The previous soil DCGLs were determined by the scenario that resulted in the smallest concentration yielding 19 mrem/y, which was the Residential Farm scenario. Based on these results, the proposed thorium soil DCGL is 4.0 pCi/g thorium 232 (Th-232) and the proposed radium DCGL is 4.5 pCi/g radium 226 (Ra-226) in soil.

Conservatism has been built into the prospective dose modeling (and thus the proposed DCGLs) 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 DCGLs proposed have been derived using appropriate techniques in accordance with governing guidance, standards, and regulations. In addition, model parameter selection and scenario derivation was the same as the previously approved soil DCGLs for the CE Windsor site. Therefore, it is recommended that these soil concentration values be approved and adopted as additional Site-specific permissible soil concentrations for the entire CE Windsor Site.

1.0 INTRODUCTION

1.1 BACKGROUND

The U.S. Nuclear Regulatory Commission (NRC) regulates sites where radioactive materials are possessed or stored. The NRC manages its authority to regulate users of radioactive materials via a licensing system whereby it grants limited authority to a licensee and imposes certain restrictions and responsibilities on the licensee. In order to terminate such a license, the licensee must demonstrate that residual radioactivity remaining at the site following cessation of licensed activities is within applicable dose-based limits defined in regulation (NRC 1997).

From the mid-1950's, the Combustion Engineering (CE) Site in Windsor Connecticut has been involved in research, development, engineering, production, and servicing of nuclear fuels, systems and services (Harding ESE 2002). ABB Inc. (ABB) has prepared a site-wide Decommissioning Plan (DP) Revision 1, to allow for decommissioning that will lead to license termination and unrestricted release in accordance with the requirements of the License Termination Rule at 10 CFR Part 20, Subpart E (NRC 1997).

1.2 DECOMMISSIONING OBJECTIVE

ABB's objective is to decommission the entire Site such that it will meet the criteria for unrestricted use as specified by the License Termination Rule at Title 10, Code of Federal Regulations (CFR) Part 20 (NRC 1997), and to terminate NRC license No. 06-00217-06 (NRC 2009). In support of this objective, ABB has derived dose-based derived concentration guideline levels (DCGLs) for radiologically impacted soil in accordance with applicable requirements and regulations. This report documents the derivation of additional dose-based DCGLs for thorium and radium to be used in demonstrating that the criteria for unrestricted use have been met, and serves to support the regulatory decision to terminate the license.

1.3 SITE DESCRIPTION

Between 1956 and 2001, the 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, Connecticut (CT). An overview of the site layout is shown on Figure 1–2.

The Site is industrially zoned by the Town of Windsor, and is located in a Mixed Land Use area of Hartford County. 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; commercial development 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.

1.4 DEVELOPMENT OF THE DCGLS

The NRC has the regulatory licensing authority and federal responsibility to determine that the radiological criteria for release of this Site from NRC licensing have been achieved. In this capacity, the NRC 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), Connecticut Department of Environmental Protection (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.

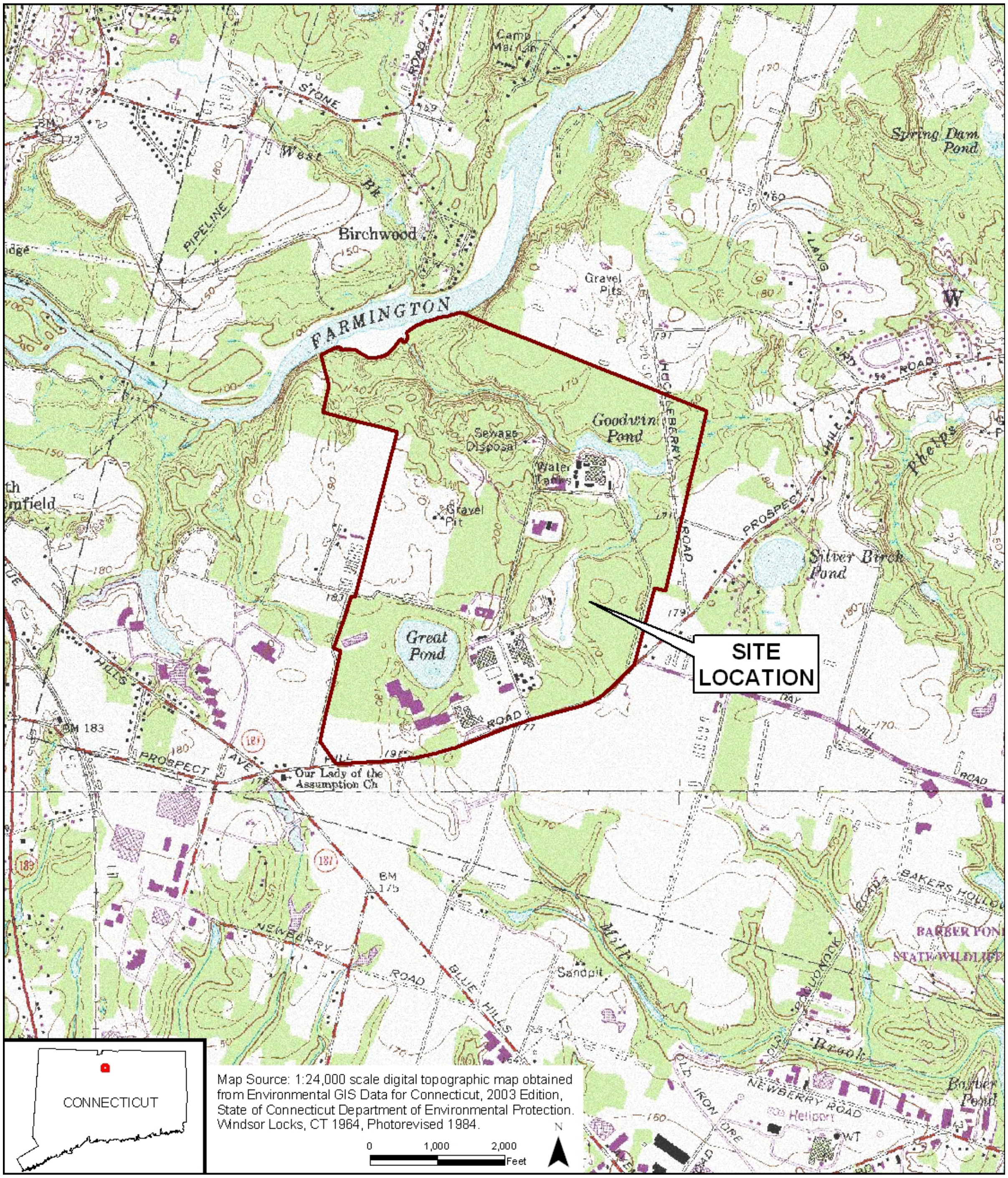

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Figure 1–1. Site Location Map

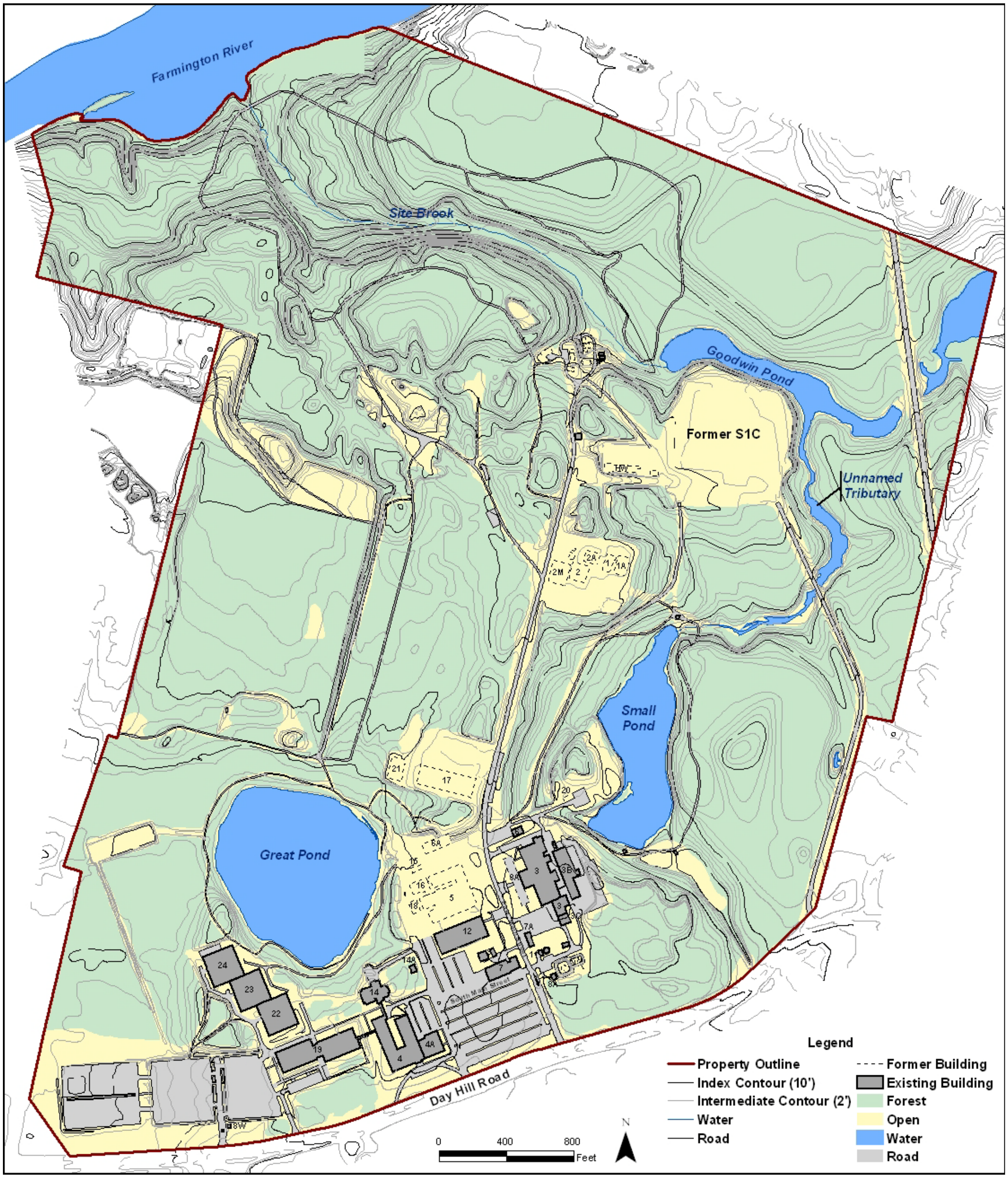

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Figure 1–2. Site Overview

2.0 SITE HISTORY

2.1 HISTORICAL SITE ACTIVITIES

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 and training center. 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 facilitate AEC activities. AEC manufacturing and research and development activities for naval nuclear fuel were terminated by AEC by 1962.

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 (beginning in 1968). Buildings 3 and 6 were designed and built (and initially used) for U.S. Navy nuclear fuel manufacturing at the Site. Subsequently (after 1962), large-scale fossil fuel boiler tests were conducted in Building 3. Nuclear wastewater pumping and dilution was conducted in Building 6.

The historical processes at the Site generated both low-level radioactive wastes (LLRW) as well as Resource Conservation and Recovery Act (RCRA) hazardous chemical wastes. The most common radioactive 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 ACTIVITIES

The CE Windsor Site is currently undergoing decontamination and decommissioning. Buildings and areas associated with commercial nuclear operations were remediated previously. This included decontamination and dismantlement of buildings, removal of associated systems and underground utilities and soil remediation as approved under Decommissioning Plan Revision 0. Decommissioning has begun on the remaining areas primarily impacted by AEC activities, as well as some later commercial operations at the Site, as approved under Decommissioning Plan Revision 1.

2.3 RESIDUAL RADIOACTIVITY PROFILE

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.

Thorium and radium were initially identified at the Burning Grounds area at the Site. During decommissioning activities, thorium and radium have been identified within some portions of the Woods area and Drum Burial Pit area as well.

The Burning Grounds were used from approximately 1956 to 1961. Zirconium tailings and turnings generated during fuel element assembly processes were transported in drums and burned at this location. By burning the tailings, the zirconium was stabilized and could then either remain in place or be transported off-site. After 1964, zirconium scrap was reportedly no longer burned on-site but was sent directly off-site to be reprocessed. However, some additional burning of miscellaneous materials may have continued through the late-1960s (Harding ESE, 2002).

The magnesium and thorium burning area was co-located with the zirconium burning ground. As mentioned earlier, CE was licensed under the AEC to burn the magnesium and thorium wastes during the late 1950s. During this time, CE also accepted thorium wastes from off-site sources for burning. The burning area consisted of a bermed concrete pad. After burning activities ceased in the early 1960's, the area was used as a storage area for drums of radiological waste.

This incineration practice with radiological waste was terminated by 1962. Materials from the burning grounds and woods area were probably included as part of those placed into the Drum Burial Pit in the 1950/60s. These three areas are adjacent to each other and these historical operations and processes provide an explanation for the origination of the thorium and radium source term at the Site and pathways for their migration.

2.3.1 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 Formerly Utilized Site Remedial Action Program (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 Corporation (ENSR), who completed a field program in December 2000 under contract to United States Army Corps of Engineers (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 Voluntary Corrective Action (VCA) Program under the Environmental Protection Agency (EPA). 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 Historical Site Assessment (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, thorium, radium 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 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.

2.3.2 Site Geologic and Hydrogeologic Features

As indicated in the original DCGL report (ABB, 2003) and the Decommissioning Plan (ABB, 2008), 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.

A radiological groundwater monitoring program has been implemented at the Site and there have been no radiological impacts to groundwater in excess of the EPA drinking water maximum contaminant level (MCL). ABB does not anticipate any cause that would lead to a need for groundwater remediation, and groundwater monitoring will continue post-remediation as required by the Connecticut Remediation Standard Regulation (RSR), but is not required under NRC regulations.

2.4 RADIOLOGICAL CHARACTERISTICS OF THORIUM AND RADIUM

Soil and waste characterization results from the Burning Grounds, Woods and Drum Burial Pit areas have indicated that the source term released during the processes described previously involved primarily natural thorium (almost 100% Th-232 plus decay progeny) with small amounts of radium (Ra-226 plus decay progeny) present as an impurity in the thorium separation process. In many cases thorium and radium are co-mingled with enriched uranium as well.

2.4.1 Radiological Characteristics of Thorium

Thorium is typically extracted from monazite ores, which also contain uranium and subsequently radium. Thorium has a series of decay progeny that reach secular equilibrium in approximately 40 years. Figure 2-1 below shows the Th-232 and associated progeny in the decay series. Given the amount of time that residual thorium materials have been present at the Site, it is expected that thorium will be in secular equilibrium.

The dose conversion factors (DCF) in the isotope library used in *RESRAD* assumes that progeny isotopes with radioactive half-lives less than 180 days are in secular equilibrium with their parent (an isotope with a half-life greater than 180 days). Consequently, the dose contributions from the short-lived progeny of the long-lived thorium nuclides (e.g., Ac-228, Pb-212, Bi-212, etc.) are automatically included in the calculations. In addition, *RESRAD* automatically calculates the ingrowth concentrations of the longer-lived progeny (e.g., Ra-228, Th-228, etc.) and accounts for the dose contributions from these nuclides.

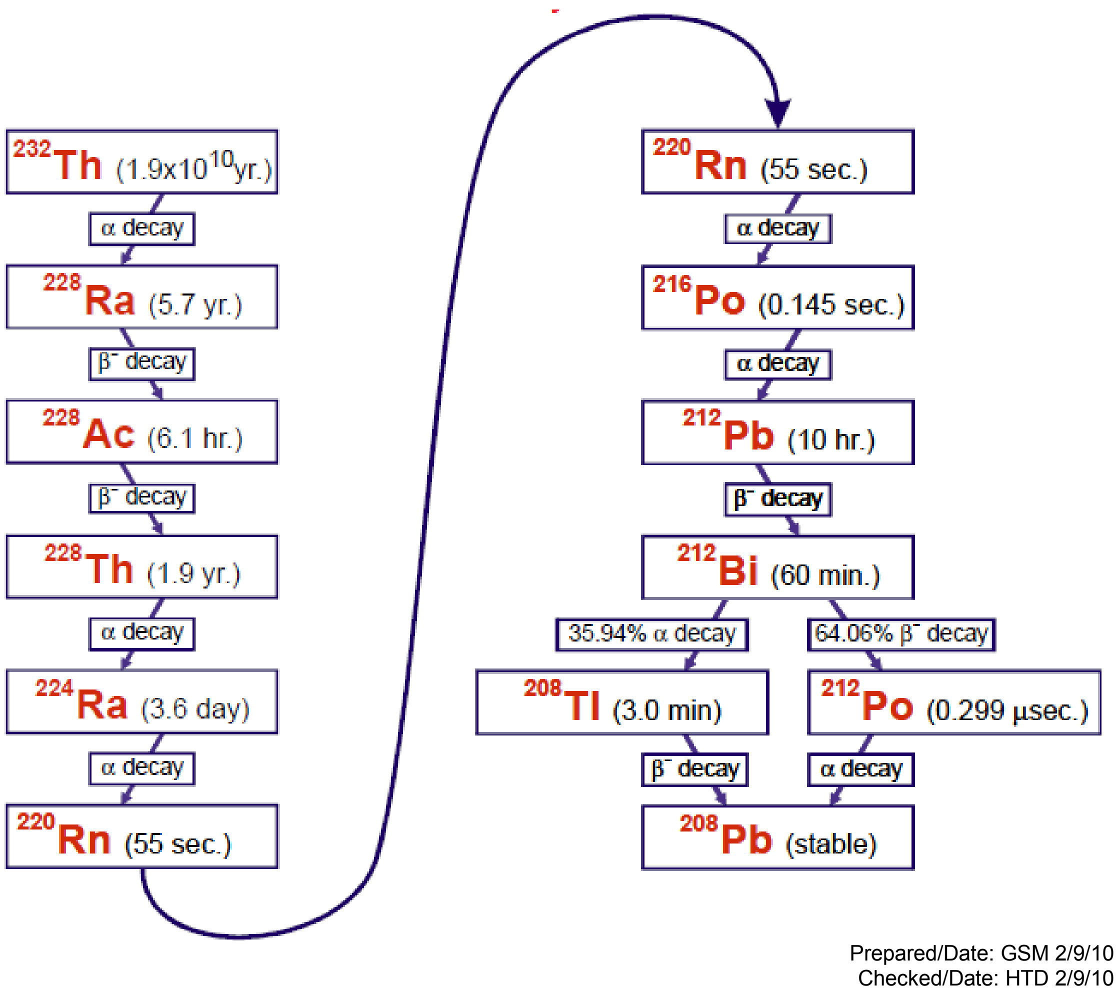

Figure 2-1 Thorium Series

2.4.2 Radiological Characteristics of Radium

Radium at the Site appears to be associated with impurities from thorium extraction. Figure 2-2 below shows the uranium 238 decay chain, which includes radium (beginning with Ra-226) and associated progeny in the decay series.

The DCF in the isotope library used in *RESRAD* assumes that progeny isotopes with radioactive half-lives less than 180 days are in secular equilibrium with their parent (an isotope with a half-life greater than 180 days). Consequently, the dose contributions from the short-lived progeny of the long-lived radium nuclides (e.g., Rn-222, Po-218, Pb-214, etc.) are automatically included in the calculations. In addition, *RESRAD* automatically calculates the ingrowth concentrations of the longer-lived progeny (e.g., Pb-210) and accounts for the dose contributions from these nuclides.

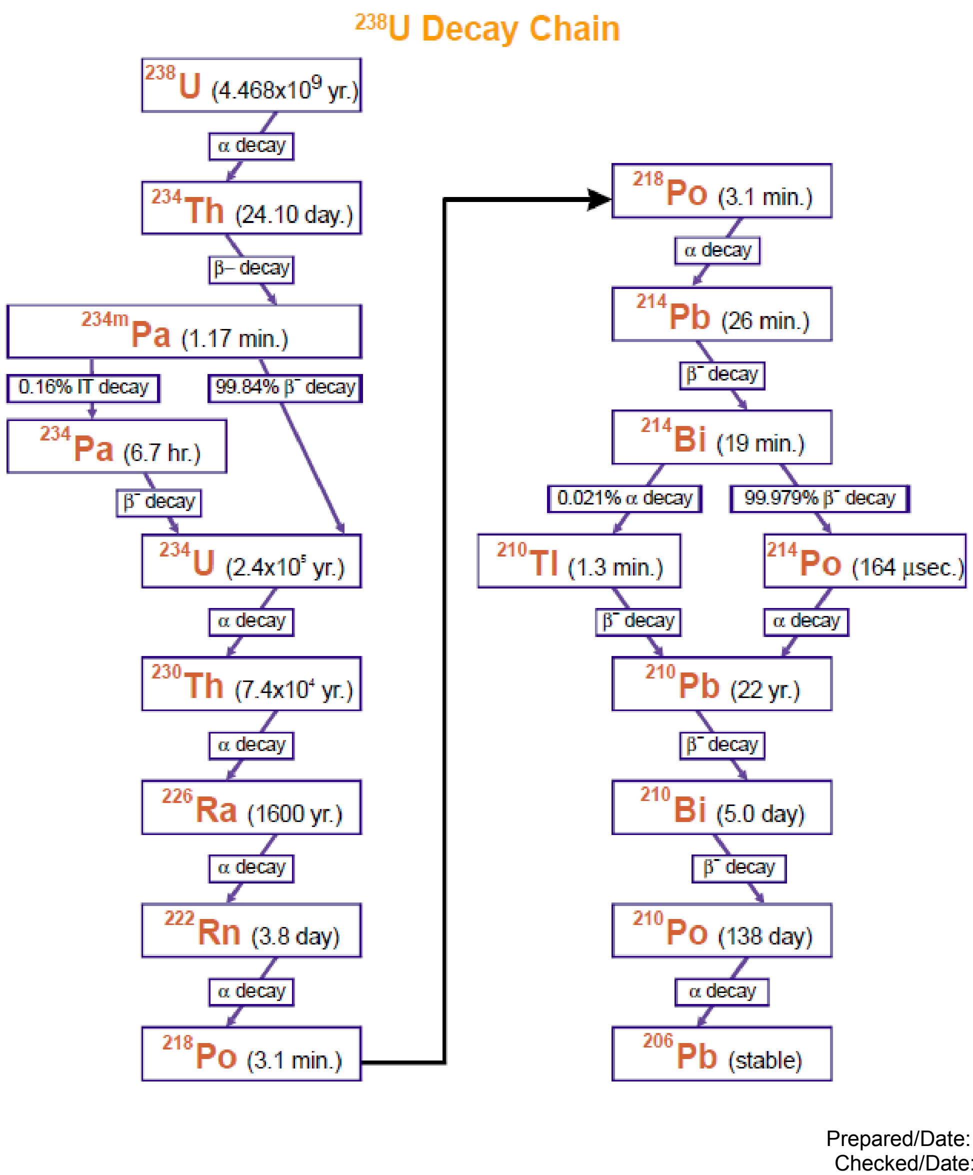

Figure 2-2 Uranium 238 (Radium) Series

3.0 DEVELOPMENT OF THE DERIVED CONCENTRATION GUIDELINE LEVEL

3.1 SELECTION OF THE ANNUAL PUBLIC DOSE LIMIT

The NRC's governing decommissioning and license termination regulation, 10 CFR 20.1402 (NRC 1997), limits radiation dose contribution to the average member of the critical exposure group (members of the exposed public) to no more than 25 millirem (mrem) in any single year following license termination. This criterion requires that all non-background sources of radiation and all credible and complete exposure pathways be considered in demonstrating compliance with the decommissioning dose limit.

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. The State of Connecticut has stipulated that post-decommissioning annual radiation doses should be limited to 19 millirem per year.

In deference to the more conservative Connecticut limit, ABB has selected an annual public dose limit of 19 millirem total effective dose equivalent (TEDE) as the dose basis for deriving the soil DCGLs. By such, both the NRC and State dose limits are satisfied with a single set of soil DCGLs.

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 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.

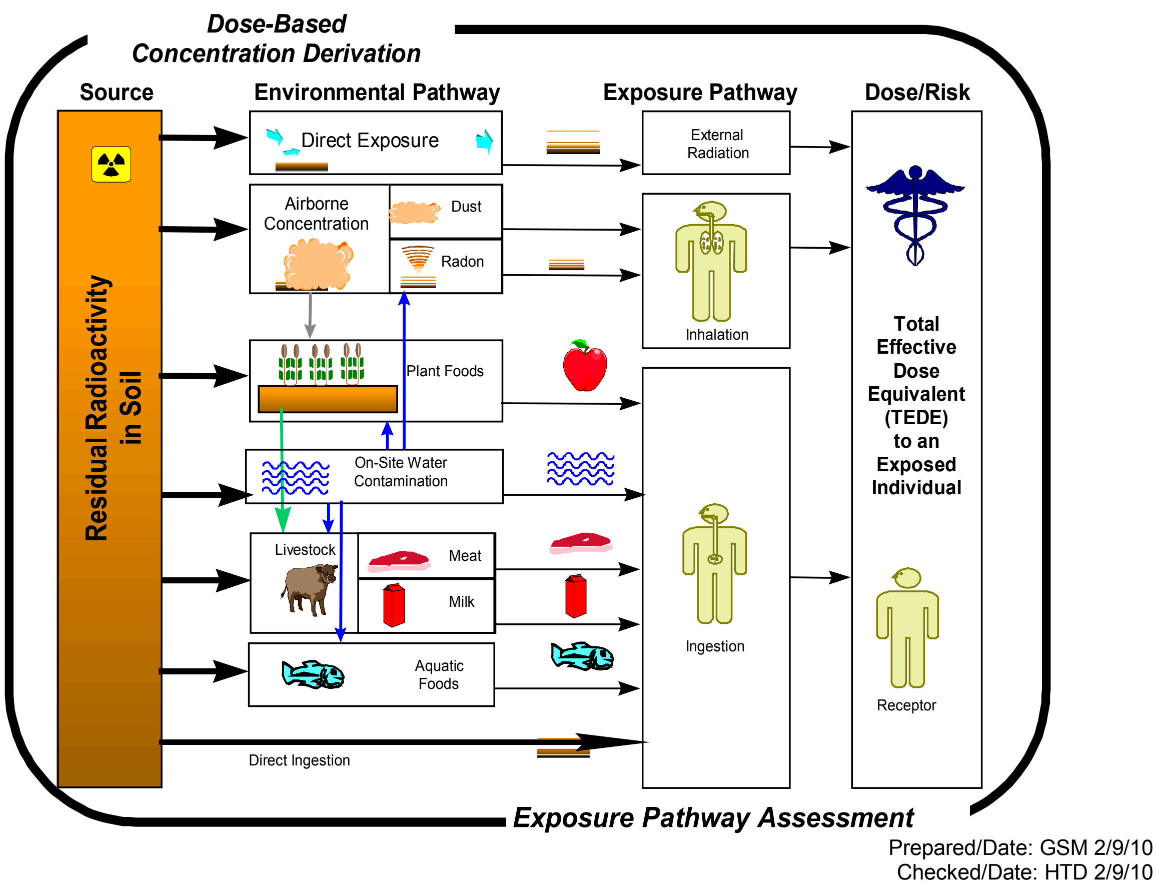

Figure 3–1 Conceptual Human Exposure Assessment Model

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.

3.2.1 RESRAD Computer Modeling Code

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 calculations and algorithms in RESRAD have been extensively verified and validated. 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 Department of Energy (DOE) to implement DOE requirements (DOE Order 5400.5) for developing Site-specific guidelines for allowable residual concentrations of radionuclides in soil. RESRAD for Windows, Version 6.4 (Yu, 2007) has been used to evaluate the exposure scenarios described above and to calculate the additional DCGLs for the Site.

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 DCFs used in RESRAD 6.4 are taken from Federal Guidance Report (FGR) #11 (EPA, 1988) and FGR #12 (EPA, 1993), and are derived using the International Commission on Radiological Protection (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 gastro-intestinal (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 POTENTIAL FUTURE EXPOSURE SCENARIO

As part of the original soil DCGL report, a suite of six separate future use scenarios were considered in the development of the site-specific soil DCGLs (ABB, 2003). Ultimately, the scenario yielding the smallest activity concentration corresponding to the dose criterion was selected as the limiting scenario, which was resident farming. For this addendum, only the limiting exposure scenario, resident farmer, will be evaluated for the calculation of thorium and radium soil DCGLs.

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.

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 additional Site-specific DCGLs, 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. This is the same approach used in the original accepted soil DCGLs (ABB, 2003).

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. This is the same geophysical model utilized in the original accepted soil DCGLs (ABB, 2003).

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 centimeters [cm]) with few screening results indicating the presence of detectable radioactivity at depths of 6" below ground surface (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 Site. In reality, several smaller areas of land surface located within the Site 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 DCGLs for the thorium and radium source terms.

3.3.2.2 Unsaturated Layer #1

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.

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.

3.3.2.4 Saturated Layer

The saturated soil layer is described, essentially, with RESRAD deterministic default parameters. 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 Residential Farming Exposure Scenario

As discussed in the original DCGL report (ABB, 2003), the circumstances in place at the Site make it exceedingly unlikely that any form of 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.

3.3.3.1 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 3–2 illustrates the conceptual description of the Site conditions that could be expected with a residential farming exposure scenario.

3.3.3.2 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 3–1 identifies the pathways that have been retained for the analysis and provides explanation for the single pathway that is not retained (radon).

3.3.3.3 Exposure Factor Parameters

This scenario is identical to that used in development of the original accepted DCGLs with only radionuclide specific parameter changes. These include the isotope and associated DCF and K_d values. 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 3-2 below along with specific remarks explaining the values selection.

The results of the probabilistic calculations of the DCGLs for thorium and radium in soil using RESRAD 6.4 are summarized in Section 4.0 of this report. Complete reports detailing the calculations of dose for the resident farmer scenario from RESRAD are contained in Appendix A (thorium and radium) while probabilistic evaluation summaries are provided in Appendix B.

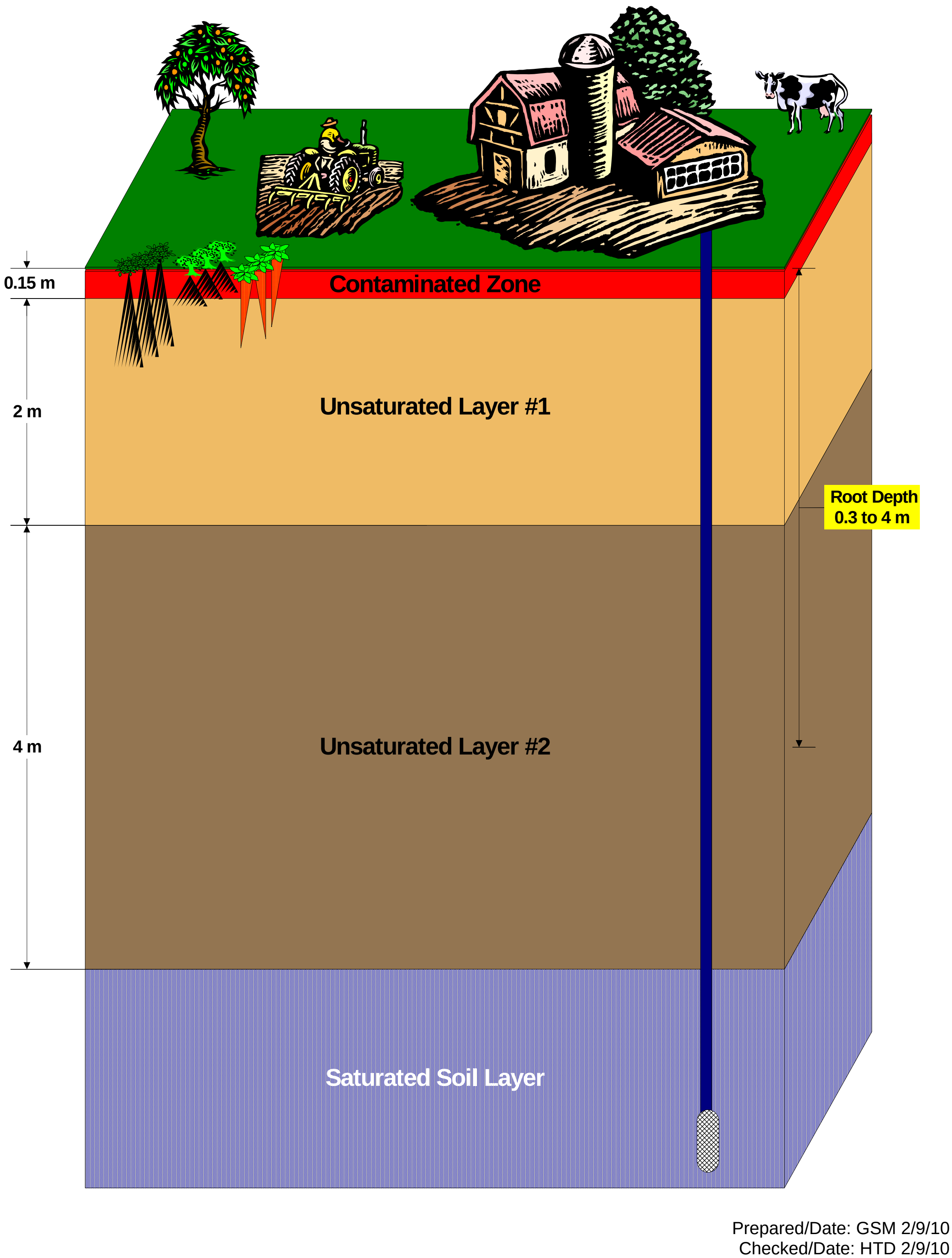

Figure 3–2. Conceptual Site Model Describing the Residential Farming Scenario

Table 3-1 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 the uranium series.
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.

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Table 3-2 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 3-2 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 (NRC, 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 3-2 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.
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 3-2 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 (EPA, 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 (EPA, 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 3-2 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 (EPA, 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) (EPA, 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.
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)

Table 3-2 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**	
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 Resident 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 (Thorium)	DCACT(n)	cm^3/g	60,000	Single point (deterministic) estimate used		RESRAD deterministic default.
K_d (Radium)	DCACT(n)	cm^3/g	70	Single point (deterministic) estimate used		RESRAD deterministic default.

Table 3-2 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 Term Factors						
Dose Conversion Factors	DCFX(n)	mrem/pCi	All DCFs used are RESRAD defaults			RESRAD defaults from FGR #11 (EPA, 1988) and FGR #12 (EPA, 1993) and are derived using ICRP 30 dosimetry model. Short-lived (<180 days) radioactive progeny isotopes are accounted for through the use of the “parent+D” DCFs.
Source Isotopes			Thorium Source Term			This thorium source term includes Th-232 and associated decay progeny.
Th-232	S1(1)	pCi/g	100%			
Source Isotopes			Radium Source Term			This radium source term includes Ra-226 and associated decay progeny.
Ra-226	S1(1)	pCi/g	100%			

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4.0 RESULTS OF COMPUTER MODELING

In order to evaluate the DCGLs, the computer modeling codes were run iteratively for each of the selected scenarios to arrive at the maximum uniform (average) concentrations 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.

The following sections present the results of the computer modeling relating both the thorium source concentrations in soil and radium source concentrations in soil with potential future doses for the one scenario 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 B.

4.1 MODEL RESULTS FOR RESIDENT FARMER SCENARIO

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 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 4–1 summarizes the results of modeling the projected future exposure potential for the residential farmer setting.

As mentioned previously, the resident farmer scenario yielded the lowest average residual radionuclide concentrations in soil compared with all other scenarios evaluated for uranium and byproducts as described in the original soil DCGL report (ABB, 2003), and is, therefore, the scenario that constrains the selection of the dose-based soil DCGL for this addendum.

A review of the computer modeling printouts for the thorium and radium source terms (Appendix A) 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 residential 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. For the radium-226 and Th-232 materials source term, exposure from direct penetrating gamma radiation is by far the principal exposure pathway. Figures 4–1 through 4–2 illustrate the relative pathway contributions to total effective dose equivalent for the resident farmer scenario for the radium and thorium source terms.

Table 4-1 Residential Farmer Scenario Results

Public Health Limit	**Average Residual Radioactivity Concentration in Soil** (pCi/g)	
	Thorium	Radium
Annual Dose (19 mrem/y)	4.0	4.5
Computer printouts showing source term, dose, and radionuclide contribution distributions are in Appendix A.		

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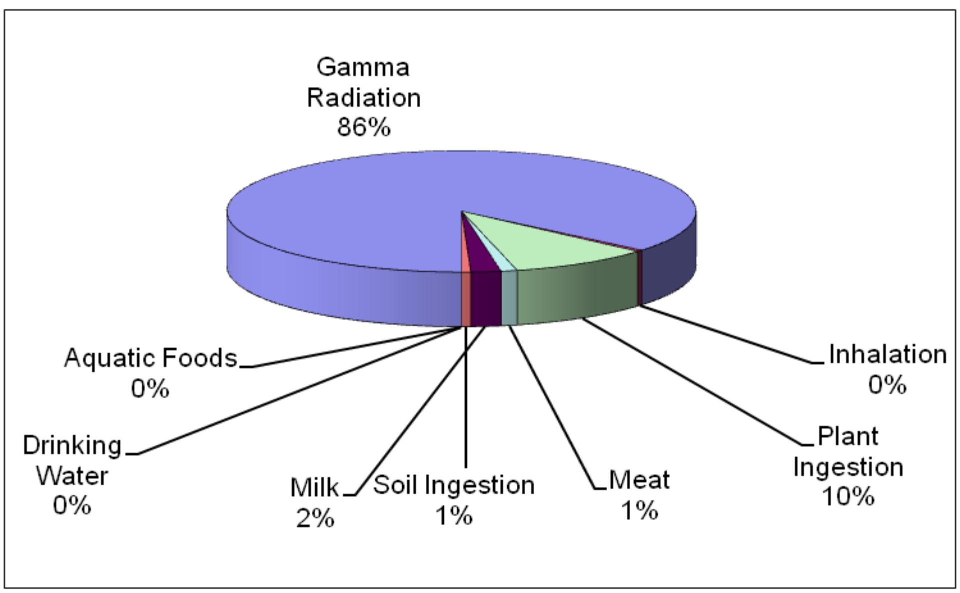

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Figure 4–1 Resident Farmer—Pathway Contributions to TEDE—Thorium

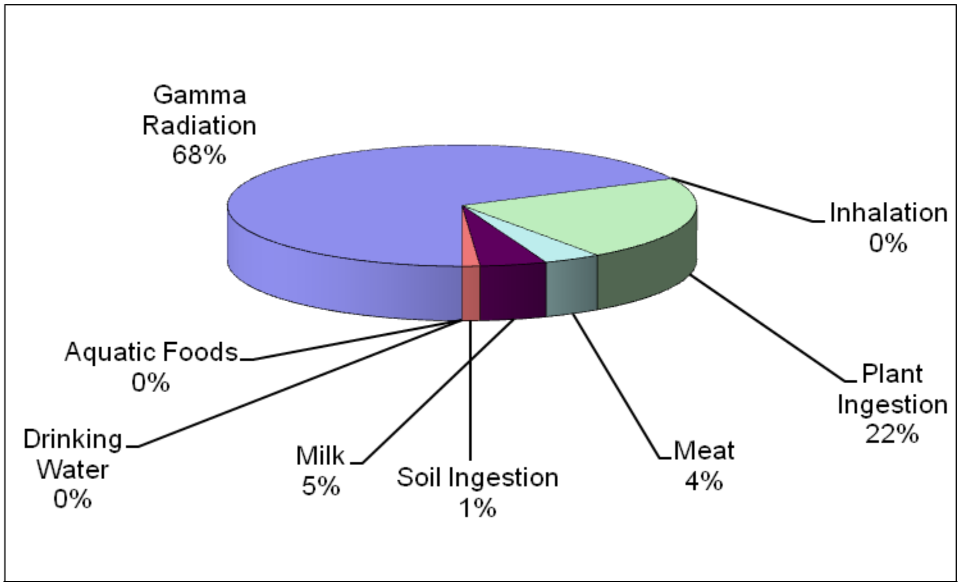

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Figure 4–2 Resident Farmer—Pathway Contributions to TEDE—Radium

Based on annual public dose limits identified by the NRC and the CTDEP, the limiting concentration for thorium in soil is 4.0 pCi/g Th-232, 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 radium in soil, the limiting concentration in soil is 4.5 pCi/g of Ra-226, which, in the case of the residential farmer, yields an annual total effective dose equivalent of 19 mrem.

5.0 SUMMARY AND RECOMMENDATIONS

5.1 PROPOSED SITE SPECIFIC DCGL VALUES

The dose evaluation described in this addendum 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 additional DCGLs will be included with 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[1]. Additionally, the proposed additional 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 additional DCGL(s) provide the risk managers with a very conservatively derived permissible thorium and radium-in-soil concentrations that ensure protection of human health. Table 5–1 (Section 5.0 of this report) presented the resident farmer scenario DCGLs derived from the foregoing analysis.

The resident farmer scenario modeled is considered credible and foreseeable and results in an average Ra-226 and an average Th-232 in soil concentration corresponding to the CTDEP's 19 mrem/y TEDE dose limit. 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 additional soil DCGLs to be included for the CE Windsor Site:

- $DCGL_W$ for thorium in soil — 4.0 pCi/g, Th-232
- $DCGL_W$ for radium in soil — 4.5 pCi/g, Ra-226

1 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.

5.2 SUMMARY OF THE UNCERTAINTY AND CONSERVATISM IN THE PROPOSED DCGL

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

Conservatism has been built into the modeling by conscientiously selecting exposure factor values that err on the side of safety when confronted with uncertainty in the selection of input parameters. In order to provide the risk managers and decision makers with insight as to the degree of conservatism associated with the proposed DCGLs, a quantitative uncertainty analysis addressing the key variables and their effect on the relationship between dose and concentration was performed (See Appendix B).

The uncertainty analysis focused on the key exposure parameters in the Resident Farmer scenario. Not all parameters in the scenario have been assigned distributions in order to evaluate their impact on overall uncertainty, recognizing that either they have little effect on the overall dose for the radionuclides under consideration or they have a comparable effect in the scenario. Considering the magnitude and range of candidate DCGLs that emerged from the individual scenarios that were evaluated previously (ABB, 2003) identifying the Resident Farmer scenario as the limiting scenario, it is evident that there would have been considerable additional conservatism for other more likely exposure scenarios had they been evaluated for this addendum.

Table 5–1 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 5-1. Estimate of Potential Dose at the Limiting Soil DCGLs

Exposure Scenario	Potential Peak Mean Annual Dose (*mrem/y*)	
	4.5 pCi/g Ra-226	***4.0 pCi/g Th-232***
Resident Farmer	19	19

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5.3 RECOMMENDATION

The soil DCGLs proposed have been conservatively derived using appropriate techniques in accordance with governing guidance, standards, and regulations. In selecting the Resident Farmer scenario as a basis for establishing the DCGLs, the most conservative and protective concentration limits have likely 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. It is recommended that the proposed additional soil $DCGL_W$ values in this addendum be approved and adopted as the Site-specific permissible mean soil concentrations for thorium and radium.

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