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INADVERTENT INTRUDER ANALYSIS FOR THE PORTSMOUTH ON-SITE WASTE DISPOSAL FACILITY (OSWDF)

Frank G. Smith, III
Mark A. Phifer

December 2013

Savannah River National Laboratory
Savannah River Nuclear Solutions
Aiken, SC 29808

Prepared for the U.S. Department of Energy Under Contract Number DE-AC09-08SR22470

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REVIEWS AND APPROVALS

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D&D	Decontamination and Decommissioning
DCF	dose conversion factor
DOE	Department of Energy
EDE	effective dose equivalent
FBP	Fluor-B&W Portsmouth
EPA	Environmental Protection Agency
GCL	geosynthetic clay liner
HDPE	high density polyethylene
ICRP	International Commission on Radiological Protection
NRC	Nuclear Regulatory Commission
OSWDF	On-Site Waste Disposal Facility
PA	Performance Assessment
RI/FS	Remedial Investigation and Feasibility Study
SOF	Sum of Fractions
SRNL	Savannah River National Laboratory

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1.0 INTRODUCTION

An On-Site Alternative is being evaluated as part of the Remedial Investigation and Feasibility Study (RI/FS) process for evaluation of alternatives for the disposal of waste generated from decontamination and decommissioning (D&D) at Portsmouth. The On-Site Alternative involves construction of an On-Site Waste Disposal Facility (OSWDF). Figure 1 provides the anticipated cross-section for the final cover of the OSWDF (FBP 2013). As part of Department of Energy (DOE) Order 435.1, Radioactive Waste Management (DOE 1999a), an inadvertent intruder analysis must be conducted for the OSWDF.

The inadvertent intruder analysis considers the radiological impacts to hypothetical persons who are assumed to inadvertently intrude on the Portsmouth OSWDF site after institutional control ceases 100 years after site closure. For the purposes of this analysis, we assume that the waste disposal in the OSWDF occurs at time zero, the site is under institutional control for the next 100 years, and inadvertent intrusion can occur over the following 1,000 year time period. Disposal of low-level radioactive waste in the OSWDF must meet a requirement to assess impacts on such individuals, and demonstrate that the effective dose equivalent to an intruder would not likely exceed 100 mrem per year for scenarios involving continuous exposure (i.e. chronic) or 500 mrem for scenarios involving a single acute exposure (DOE 1999b). These dose limits apply to the sum of dose equivalents from all exposure pathways that are assumed to occur in a given exposure scenario for an inadvertent intruder. Analytical results for the first 1,000 years after assumed loss of active institutional control are used to evaluate performance of the OSWDF with respect to inadvertent intruders.

The focus in development of exposure scenarios for inadvertent intruders was on selecting reasonable events that may occur, giving consideration to regional customs and construction practices. An important assumption in all scenarios is that an intruder has no prior knowledge of the existence of a waste disposal facility at the site. Therefore, after active institutional control ceases, certain exposure scenarios are assumed to be precluded only by the physical state of the disposal facility, i.e., the integrity of the engineered barriers used in facility construction or the thickness of clean material above the waste. Passive institutional controls, such as permanent marker systems at the disposal site and public records of prior land use, also could prevent inadvertent intrusion after active institutional control ceases, but the efficacy of passive institutional controls is not assumed in this analysis.

Consistent with the DOE Manual 435.1 (DOE 1999b) intruder exposure scenarios are to exclude radon in air. Consistent with guidance for DOE Order 435.1 (DOE 1999c) intruder exposure scenarios need not include the consumption of contaminated groundwater or the irrigation of crops with contaminated groundwater. Groundwater consumption and crop irrigation are excluded because the impacts of groundwater contamination are evaluated separately in the all-pathways analysis, the water resource protection analysis, or both. These exclusions to the intruder exposure scenarios are consistent with the draft DOE Order 435.1A update (DOE 2013a) and the associated Technical Standard (DOE 2013b). The intruder analysis evaluates the potential dose to an inadvertent intruder that actually intrudes upon the waste disposal facility itself. The all-pathways analysis evaluates the potential dose to the public outside the bounds of the disposal facility and typically includes exposure pathways associated with groundwater use (e.g. consumption and irrigation). The water resource protection analysis evaluates potential impacts to groundwater and surface water relative to applicable water quality standards.

Results of the analysis show that a hypothetical inadvertent intruder at the OSWDF who, in the worst case scenario, resides on the site and consumes vegetables from a garden established on the site using contaminated soil (chronic agriculture scenario) would receive a maximum chronic dose of approximately 7.0 mrem/yr during the 1000 year period of assessment. This dose falls well below the DOE chronic dose limit of 100 mrem/yr. Results of the analysis also showed that a hypothetical inadvertent intruder at the OSWDF who, in the worst case scenario, excavates a basement in the soil that reaches the waste (acute basement construction scenario) would receive a maximum acute dose of approximately 0.25 mrem/yr during the 1000 year period of assessment. This dose falls well below the DOE acute dose limit of 500 mrem/yr. Disposal inventory constraints based on the intruder analysis are well above conservative estimates of the OSWDF inventory and, based on intruder disposal limits; about 7% of the disposal capacity is reached with the estimated OSWDF inventory.

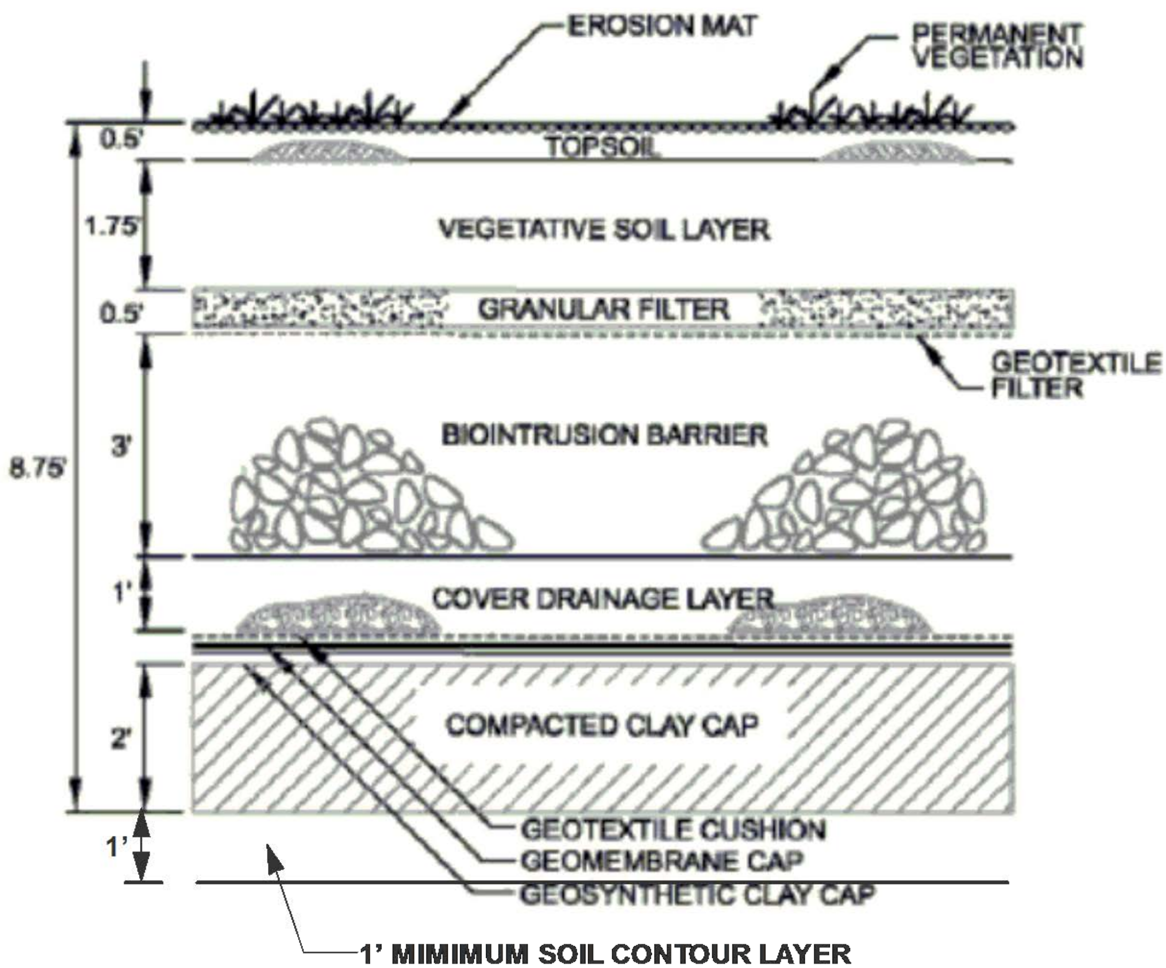

Figure 1. Portsmouth OSWDF Final Cover Cross-Section (FBP 2013)

2.0 INADVERTENT INTRUDER SCENARIOS AND DOSE EQUATIONS

This section describes the following exposure scenarios and their associated dose equations considered for inadvertent intruders in the OSWDF:

- Acute basement construction
- Acute well drilling
- Acute discovery
- Chronic agriculture
- Chronic post-drilling
- Chronic residential

2.1 ACUTE EXPOSURE SCENARIOS

Three distinct scenarios resulting in acute exposure of inadvertent intruders are considered in the dose analysis for the OSWDF. These scenarios are referred to as the basement construction, well drilling, and discovery scenarios (DOE 1999c; DOE 2013b). As noted previously, all acute exposure scenarios for inadvertent intruders are subject to a dose limit of 500 mrem. The following sections describe these three acute exposure scenarios and provide their associated dose equations. The equations implemented in the analysis are essentially the same equations for calculating intruder dose documented by McDowell-Boyer et al. (2000) and also documented in the Lee (2004) report.

2.1.1 Acute Basement Construction Scenario

The acute basement construction scenario is based on the assumption that after active institutional control ceases an intruder builds a home on the disposal site, with the basement extending into the waste. Direct intrusion into the waste over the 1,000 year assessment period is assumed to be precluded when the thickness of clean cover material over the waste is greater than the depth of a typical basement (3 meters (~10 feet)), or when the integrity of engineered barriers such as reinforced concrete prevents it. The basement construction scenario considers exposures during the short period of time required to dig the basement and build the home. During construction, the following relevant exposure pathways are assumed:

- External exposure photon-emitting radionuclides in the unshielded waste,
- Inhalation of radionuclides suspended in air from uncovered waste, and
- Ingestion of soil containing radionuclides from the uncovered waste.

The importance of the basement construction scenario arises primarily from the assumption that construction activities result in airborne concentrations of radionuclides that are substantially higher than would occur during other potential activities at the site. Direct intrusion into the waste over the 1,000 year assessment period is assumed for the OSWDF because the thickness of clean cover material over the waste is less than 3 meters (~10 feet) (see Figure 1) and because it cannot be assumed that the biointrusion barrier would prevent excavation into the waste, therefore this scenario will be considered.

The acute basement construction scenario dose (D_{bc}) is estimated by summing the dose for each radionuclide *i* at each time step:

$$D_{bc} = \sum_i (DC_{ibc} \times C_{iw}) \tag{1}$$

where

DC_{ibc} .... *basement construction scenario dose coefficient for radionuclide i (rem/year)/(μCi/m³)*
C_{iw}............. *average waste concentration of radionuclide i (μCi/m³)*

The basement construction scenario dose coefficient for radionuclide *i* (DC_{ibc}) is estimated by summing the following exposure pathway dose coefficients:

$$DC_{ibc} = DC_{ie}(bc) + DC_{ia}(bc) + DC_{is}(bc) \tag{2}$$

where

$DC_{ie}(bc)$ ..... *basement construction external exposure dose coefficient (rem/year)/(μCi/m³)*
$DC_{ia}(bc)$ ..... *basement construction inhalation dose coefficient (rem/year)/(μCi/m³)*
$DC_{is}(bc)$ ..... *basement construction soil ingestion dose coefficient (rem/year)/(μCi/m³)*

The basement construction external exposure dose coefficient for radionuclide *i* ($DC_{ie}(bc)$) is estimated by:

$$DC_{ie}(bc) = U_y(bc) \times DCF_{ie\,\mathrm{inf}} \tag{3}$$

where

$U_y(bc)$ .... *fraction of a year exposed to waste while constructing the basement*
DCF_{ieinf} ...... *dose conversion factor (DCF) for external exposure to infinite depth of soil uniformly contaminated with radionuclide i (rem/year)/(μCi/m³)*

The basement construction soil inhalation dose coefficient for radionuclide *i* ($DC_{ia}(bc)$) is estimated by:

$$DC_{ia}(bc) = \frac{U_y(bc) \times I_{acw} \times L_a(bc) \times DCF_{ia}}{\rho_s} \tag{4}$$

where

$U_y(bc)$ .... *fraction of a year exposed to waste while constructing the basement*
I_{acw} .... *annual air intake for construction worker (m³/year)*
$L_a(bc)$ .... *basement construction air mass loading (kg/m³)*
DCF_{ia} .... *inhalation dose conversion factor of radionuclide i (rem/μCi)*

ρ_s...............*bulk density of soil (kg/m^3)*

The basement construction soil ingestion dose coefficient for radionuclide *i* ($DC_{is}(bc)$) is estimated by:

$$DC_{is}(bc) = \frac{U_y(bc) \times C_s(bc) \times DCF_{ii}}{\rho_s} \quad (5)$$

where

$U_y(bc)$ ....*fraction of a year exposed to waste while constructing the basement*
$C_s(bc)$.........*basement construction annual consumption of soil (kg/year)*
DCF_{ii} ....*ingestion dose conversion factor for radionuclide i (rem/μCi)*
ρ_s...............*bulk density of soil (kg/m^3)*

2.1.2 Acute Well Drilling Scenario

The acute well drilling scenario is based on the assumption that after active institutional control ceases an intruder drills a well directly through a disposal unit. The acute drilling scenario considers exposures during the short period of time for drilling and construction of the well. During well drilling, the following relevant exposure pathways are assumed:

- External exposure photon-emitting radionuclides in the unshielded cuttings pile containing waste,
- Inhalation of radionuclides suspended in air from the uncovered cuttings pile containing waste, and
- Ingestion of soil containing radionuclides from the uncovered cuttings pile containing waste.

The importance of the well drilling scenario arises primarily from the assumption that an intruder could be located near an unshielded cutting pile for a substantial period of time. This scenario can be excluded from consideration over the 1,000 year assessment period, if drilling into the waste is precluded by the inability of typical site-specific drilling techniques from drilling through an engineered barrier such as reinforced concrete. The well drilling scenario applies to the OSWDF because it cannot be assumed that the biointrusion barrier would preclude drilling into the waste since typical well drilling in the Portsmouth area utilizes drilling techniques suitable to drilling through rock.

The acute well drilling scenario dose (D_{wd}) is estimated by summing the dose for each radionuclide *i* at each time step:

$$D_{wd} = \sum_i (DC_{iwd} \times C_{iw}) \quad (6)$$

where

DC_{iwd}..........*well drilling scenario dose coefficient for radionuclide i (rem/year)/(μCi/m^3)*

C_{iw}.............average waste concentration of radionuclide i (μCi/m^3)

The well drilling scenario dose coefficient for radionuclide *i* (DC_{iwd}) is estimated by summing the following exposure pathway dose coefficients:

$$DC_{iwd} = DC_{ie}(wd) + DC_{ia}(wd) + DC_{is}(wd) \tag{7}$$

where

$DC_{ie}(wd)$ ....well drilling external exposure dose coefficient (rem/year)/(μCi/m^3)
$DC_{ia}(wd)$ ....well drilling inhalation dose coefficient (rem/year)/(μCi/m^3)
$DC_{is}(wd)$ ....well drilling soil ingestion dose coefficient (rem/year)/(μCi/m^3)

The well drilling external exposure dose coefficient for radionuclide *i* ($DC_{ie}(wd)$) is estimated by:

$$DC_{ie}(wd) = f_c \times U_y(wd) \times DCF_{ie15} \tag{8}$$

where

f_c................dilution factor for mixture of waste and geologic cuttings
$U_y(wd)$........fraction of a year exposed to cutting pile while drilling the well
DCF_{ie15}.......dose conversion factor for external exposure to 15 cm of soil uniformly contaminated with radionuclide i (rem/year)/(μCi/m^3)

The well drilling soil inhalation dose coefficient for radionuclide *i* ($DC_{ia}(wd)$) is estimated by:

$$DC_{ia}(wd) = \frac{f_c \times U_y(wd) \times I_{aw} \times L_a(wd) \times DCF_{ia}}{\rho_s} \tag{9}$$

where

f_c................dilution factor for mixture of waste and geologic cuttings
$U_y(wd)$........fraction of a year exposed to cutting pile while drilling the well
I_{aw}..............annual air intake for worker (m^3/year)
$L_a(wd)$ ....well drilling air mass loading (kg/m^3)
DCF_{ia}.........inhalation dose conversion factor of radionuclide i (rem/μCi)
ρ_s...............bulk density of soil (kg/m^3)

The well drilling soil ingestion dose coefficient for radionuclide *i* ($DC_{is}(wd)$) is estimated by:

$$DC_{is}(wd) = \frac{f_c \times U_y(wd) \times C_s(wd) \times DCF_{ii}}{\rho_s} \tag{10}$$

where

f_c................*dilution factor for mixture of waste and geologic cuttings*
$U_y(wd)$........*fraction of a year exposed to cutting pile while drilling the well*
$C_s(wd)$........*well drilling annual consumption of soil (kg/year)*
DCF_{ii} ....*ingestion dose conversion factor for radionuclide i (rem/μCi)*
ρ_s................*bulk density of soil (kg/m^3)*

2.1.3 Acute Discovery Scenario

The acute discovery scenario is based on the assumption that after active institutional control ceases an intruder attempts to excavate a basement for a home on the disposal site but stops prior to excavating into the waste and moves elsewhere because of the unusual nature of the materials being excavated (see Figure 1). The primary exposure pathway for this scenario is external exposure to photon-emitting radionuclides in the disposal facility during the time the intruder digs at the site. Because the intruder does not excavate into the waste it is assumed that any significant inhalation or ingestion exposures are precluded. This intruder scenario is applicable to the Portsmouth OSWDF and it will be assumed that the intruder stops upon reaching the geotextile cushion, high density polyethylene geomembrane (HDPE), and geosynthetic clay layer (GCL) below the 1-foot drainage layer (see Figure 1). The Kocher shielding DCFs are utilized as outlined below to account for the shielding provided by the compacted clay cap and soil contour layer (see Figure 1), which are assumed to remain intact in this scenario.

The acute discovery scenario dose (D_d) is estimated by summing the dose for each radionuclide *i* at each time step:

$$D_d = \sum_i (DC_{id} \times C_{iw}) \tag{11}$$

where

DC_{id} ....*discovery scenario dose coefficient for radionuclide i (rem/year)/(μCi/m^3)*
C_{iw}..............*average waste concentration of radionuclide i (μCi/m^3)*

The discovery scenario dose coefficient for radionuclide *i* (DC_{id}) consists only of the discovery external exposure dose coefficient:

$$DC_{id} = DC_{ie}(d) \tag{12}$$

where

$DC_{ie}(d)$.......*discovery external exposure dose coefficient (rem/year)/(μCi/m^3)*

Discovery external exposure dose coefficient for radionuclide *i* ($DC_{ie}(d)$) is estimated by:

$$DC_{ie}(d) = U_y(d) \times DCF_{it}(t) \tag{13}$$

where

$U_y(d)$ .... fraction of a year spent digging at waste site
$DCF_{it}(t)$ ..... dose conversion factor for external exposure to waste containing radionuclide i with a known amount of shielding (t) (rem/year)/(μCi/m^3) (Kocher shielding DCFs)

2.2 CHRONIC EXPOSURE SCENARIOS

Three distinct scenarios resulting in chronic exposure of inadvertent intruders are considered in the dose analysis for the OSWDF. These scenarios are referred to as agriculture (or homesteader), post-drilling, and residential (DOE 1999c; DOE 2013b). As noted previously, all chronic exposure scenarios for inadvertent intruders are subject to a dose limit of 100 mrem/year. The following sections describe these three chronic exposure scenarios and provide their associated dose equations.

2.2.1 Chronic Agriculture Scenario

The chronic agriculture scenario is based on the assumption that after active institutional control ceases an intruder comes onto the site and establishes a permanent homestead. Waste in the disposal facility is assumed to be accessed when an intruder constructs a home directly on top of a disposal facility and the basement of the home extends into the waste itself. All waste in the disposal facility at the time the basement is dug is assumed to be physically indistinguishable from native soil. Some of the waste exhumed from the disposal facility is assumed to be mixed with native soil in the intruder's vegetable garden. Direct intrusion into the waste is assumed to be precluded when the thickness of clean cover material over the waste is greater than the depth of a typical basement (3 meters (~10 feet)), or when the integrity of engineered barriers such as reinforced concrete prevents it. The following exposure pathways involving exhumed waste or waste remaining in the exposed disposal facility on which the intruder's home is located are assumed to occur:

- Internal exposure from ingestion of vegetables grown in contaminated garden soil.
- Internal exposure from direct ingestion of contaminated soil, primarily in conjunction with intakes of vegetables from the garden.
- External exposure to contaminated soil while working in the garden.
- External exposure to contaminated soil while residing in the home on top of the disposal facility.
- Internal exposure from inhalation of radionuclides attached to soil particles that are suspended into air from contaminated soil while working in the garden.
- Internal exposure from inhalation of contaminated particulates while residing in the home.

Direct intrusion into the waste over the 1,000 year assessment period is assumed for the OSWDF because the thickness of clean cover material over the waste is less than 3 meters (~10 feet) (see Figure 1) and because it cannot be assumed that the biointrusion barrier would prevent excavation into the waste, therefore this scenario will be considered. As outlined in

Section 1.0, the agriculture scenario does not include radon in air, groundwater consumption, and crop irrigation.

The chronic agriculture scenario dose (D_A) is estimated by summing the dose for each radionuclide *i* at each time step:

$$D_A = \sum_i (DC_{iA} \times C_{iw}) \tag{14}$$

where

DC_{iA} .... agriculture scenario dose coefficient for radionuclide i (rem/year)/(μCi/m³)
C_{iw} .... average waste concentration of radionuclide i (μCi/m³)

The agriculture scenario dose coefficient for radionuclide *i* is estimated by summing the following exposure pathway dose coefficients:

$$DC_{iA} = DC_{iv}(A) + DC_{is}(A) + DC_{ieg}(A) + DC_{ieh}(A) + DC_{iag}(A) + DC_{iah}(A) \tag{15}$$

where

$DC_{iv}(A)$ ...... agriculture vegetable consumption dose coefficient (rem/year)/(μCi/m³)
$DC_{is}(A)$....... agriculture soil ingestion dose coefficient (rem/year)/(μCi/m³)
$DC_{ieg}(A)$ ..... agriculture garden external exposure dose coefficient (rem/year)/(μCi/m³)
$DC_{ieh}(A)$ ..... agriculture home external exposure dose coefficient (rem/year)/(μCi/m³)
$DC_{iag}(A)$ ..... agriculture garden exposure inhalation dose coefficient (rem/year)/(μCi/m³)
$DC_{iah}(A)$ ..... agriculture home exposure inhalation dose coefficient (rem/year)/(μCi/m³)

The agriculture vegetable consumption dose coefficient for radionuclide *i ($DC_{iv}(A)$)* is estimated by:

$$DC_{iv}(A) = \frac{B_{iv} \times C_v \times f_{Ag} \times DCF_{ii}}{\rho_s} \tag{16}$$

where

B_{iv}............... plant-to-soil ratio for radionuclide i
C_v .... annual consumption of vegetables (kg/year)
f_{Ag} .... dilution factor for mixture of exhumed waste in vegetable garden
DCF_{ii} .... ingestion dose conversion factor for radionuclide i (rem/μCi)
ρ_s................ bulk density of soil (kg/m³)

The agriculture soil ingestion dose coefficient for radionuclide *i ($DC_{is}(A)$)* is estimated by:

$$DC_{is}(A) = \frac{C_s \times f_{Ag} \times DCF_{ii}}{\rho_s} \tag{17}$$

where

C_s ....annual consumption of soil (kg/year)
f_{Ag}..............dilution factor for mixture of exhumed waste in vegetable garden
DCF_{ii} ....ingestion dose conversion factor for radionuclide i (rem/μCi)
ρ_s...............bulk density of soil (kg/m^3)

The agriculture garden external exposure dose coefficient for radionuclide *i ($DC_{ie}(A)$)* is estimated by:

$$DC_{ieg}(A) = U_y(g) \times f_{Ag} \times DCF_{ie15} \tag{18}$$

where

$U_y(g)$ ....fraction of a year exposed to contaminated soil in vegetable garden
f_{Ag} ....dilution factor for mixture of exhumed waste in vegetable garden
DCF_{ie15}.......dose conversion factor for external exposure to 15 cm of soil uniformly contaminated with radionuclide i (rem/year)/(μCi/m^3)

The agriculture home external exposure dose coefficient for radionuclide *i ($DC_{ie}(A)$)* is estimated by:

$$DC_{ieh}(A) = U_y(h) \times DCF_{it}(0) \times S \tag{19}$$

where

$U_y(h)$ ....fraction of a year spent in home
$DCF_{it}(0)$ ....dose conversion factor for external exposure to waste containing radionuclide i with a known amount of shielding (t) (rem/year)/(μCi/m^3) (Kocher shielding DCFs)
S................additional shielding factor for radionuclides during indoor residence accounting for presence of basement floor

The analysis assumes that a resident inadvertent intruder builds a home having a basement that extends 3.0 m into the soil. From the calculation parameters specified in Table 2 below, the depth of the waste below the soil surface is 9.75 feet or 2.97 m. Because the basement extends into the waste zone, soil shielding for the residential exposer does not apply and the Kocher dose conversion factor with no shielding is used in Eq. (30) as indicated. In this case the basement concrete floor slab is located directly on top of the waste and that the only shielding is provided by the concrete floor slab. In essence the agriculture home external exposure pathway only considers external exposure to contaminated soil shielding only by a concrete floor slab (*S* parameter in above equation) while residing in the home on top of the disposal facility.

The agriculture garden exposure inhalation dose coefficient for radionuclide *i ($DC_{iag}(A)$)*is estimated by:

$$DC_{iag}(A) = \frac{U_y(g) \times f_{Ag} \times I_{arp} \times L_a(g) \times DCF_{ia}}{\rho_s} \tag{20}$$

where

$U_y(g)$ ....*fraction of a year exposed to contaminated soil in vegetable garden*
f_{Ag} ....*dilution factor for mixture of exhumed waste in vegetable garden*
I_{arp} ....*reference person annual air intake (m^3/year)*
$L_a(g)$...........*garden air mass loading (kg/cm^3)*
DCF_{ia}.........*inhalation dose conversion factor of radionuclide i (rem/µCi)*
ρ_s...............*bulk density of soil (kg/m^3)*

The agriculture home exposure inhalation dose coefficient for radionuclide *i* ($DC_{iah}(A)$)is estimated by:

$$DC_{iah}(A) = \frac{U_y(h) \times I_{arp} \times L_a(h) \times DCF_{ia}}{\rho_s} \tag{21}$$

where

$U_y(h)$ ....*fraction of a year spent in home*
I_{arp} ....*reference person annual air intake (m^3/year)*
$L_a(h)$...........*home air mass loading (kg/cm^3)*
DCF_{ia}.............*inhalation dose conversion factor of radionuclide i (rem/µCi)*
ρ_s...............*bulk density of soil (kg/cm^3)*

2.2.2 Chronic Post-Drilling Scenario

The chronic post-drilling scenario is based on the assumption that after active institutional control ceases an intruder who resides permanently near the disposal facility drills through the disposal facility while constructing a well for a domestic water supply. Following construction of the well, the contaminated material brought to the surface during drilling operations, which is assumed to be indistinguishable from native soil, is assumed to be mixed with native soil in the intruder's vegetable garden. This scenario can be excluded from consideration over the 1,000 year assessment period, if drilling into the waste is precluded by the inability of typical site-specific drilling techniques from drilling through an engineered barrier such as reinforced concrete. The following exposure pathways involving the contaminated material brought to the surface are then assumed to occur:

- Internal exposure from ingestion of vegetables grown in contaminated garden soil.
- Internal exposure from direct ingestion of contaminated soil, primarily in conjunction with intakes of vegetables from the garden.
- External exposure to contaminated soil while working in the garden.
- Internal exposure from inhalation of radionuclides attached to soil particles that are suspended into air from contaminated soil while working in the garden.

The post-drilling scenario applies to the OSWDF because it cannot be assumed that the biointrusion barrier would preclude drilling into the waste since typical well drilling in the Portsmouth area utilizes drilling techniques suitable to drilling through rock. As outlined in Section 1.0, the post-drilling scenario does not include radon in air, groundwater consumption, and crop irrigation.

The chronic post drilling scenario dose (D_{PD}) is estimated by summing the dose for each radionuclide *i* at each time step:

$$D_{PD} = \sum_i (DC_{iPD} \times C_{iw}) \tag{22}$$

where

DC_{iPD}.........post-drilling scenario dose coefficient for radionuclide i (rem/year)/(μCi/m^3)
C_{iw}.............average waste concentration of radionuclide i (μCi/m^3)

The post-drilling scenario dose coefficient for radionuclide *i* is estimated by summing the following exposure pathway dose coefficients:

$$DC_{iPD} = DC_{iv}(PD) + DC_{is}(PD) + DC_{ieg}(PD) + DC_{iag}(PD) \tag{23}$$

where

$DC_{iv}(PD)$....agriculture vegetable consumption dose coefficient (rem/year)/(μCi/m^3)
$DC_{is}(PD)$....agriculture soil ingestion dose coefficient (rem/year)/(μCi/m^3)
$DC_{ieg}(PD)$..agriculture garden external exposure dose coefficient (rem/year)/(μCi/m^3)
$DC_{iag}(PD)$..agriculture garden exposure inhalation dose coefficient (rem/year)/(μCi/m^3)

The post-drilling vegetable consumption dose coefficient for radionuclide *i* *($DC_{iv}(PD)$)* is estimated by:

$$DC_{iv}(PD) = \frac{B_{iv} \times C_v \times f_{PDg} \times DCF_{ii}}{\rho_s} \tag{24}$$

where

B_{iv}...............plant-to-soil ratio for radionuclide i
C_v...............annual consumption of vegetables (kg/year)
f_{PDg}.............dilution factor for mixture of drill cuttings in vegetable garden
DCF_{ii}.........ingestion dose conversion factor for radionuclide i (rem/μCi)
ρ_s................bulk density of soil (kg/m^3)

The post-drilling soil ingestion dose coefficient for radionuclide *i* *($DC_{is}(PD)$)* is estimated by:

$$DC_{is}(PD) = \frac{C_s \times f_{PDg} \times DCF_{ii}}{\rho_s} \tag{25}$$

where

C_s .... annual consumption of soil (kg/year)
f_{PDg} .... dilution factor for mixture of drill cuttings in vegetable garden
DCF_{ii} .... ingestion dose conversion factor for radionuclide i (rem/μCi)
ρ_s................ bulk density of soil (kg/m^3)

The post-drilling garden external exposure dose coefficient for radionuclide *i* ($DC_{ie}(PD)$) is estimated by:

$$DC_{ieg}(PD) = U_y(g) \times f_{PDg} \times DCF_{ie15} \tag{26}$$

where

$U_y(g)$ .... fraction of a year exposed to contaminated soil in vegetable garden
f_{PDg} .... dilution factor for mixture of drill cuttings in vegetable garden
DCF_{ie15}....... dose conversion factor for external exposure to 15 cm of soil uniformly contaminated with radionuclide i (rem/year)/(μCi/m^3)

The post-drilling garden exposure inhalation dose coefficient for radionuclide *i* ($DC_{iag}(PD)$)is estimated by:

$$DC_{iag}(PD) = \frac{U_y(g) \times f_{PDg} \times I_{arp} \times L_a(g) \times DCF_{ia}}{\rho_s} \tag{27}$$

where

$U_y(g)$ .... fraction of a year exposed to contaminated soil in vegetable garden
f_{PDg} .... dilution factor for mixture of drill cuttings in vegetable garden
I_{arp} .... reference person annual air intake (m^3/year)
$L_a(g)$........... garden air mass loading (kg/cm^3)
DCF_{ia}......... inhalation dose conversion factor of radionuclide i (rem/μCi)
ρ_s................ bulk density of soil (kg/m^3)

2.2.3 Chronic Residential Scenario

The residential scenario assumes that after active institutional control ceases an intruder lives in a home with a basement that is located directly on top of the disposal facility. It is further assumed that the basement concrete floor slab is located directly on top of the waste and that the only shielding is provided by the concrete floor slab. In essence the resident scenario only considers external exposure to contaminated soil shielded only by a concrete floor slab while residing in the home on top of the disposal facility.

The chronic residential scenario dose (D_R) is estimated by summing the dose for each radionuclide *i* at each time step:

$$D_R = \sum_i (DC_{iR} \times C_{iw}) \tag{28}$$

where

DC_{iR} ....residential scenario dose coefficient for radionuclide i (rem/year)/(µCi/m^3)
C_{iw}..............average waste concentration of radionuclide i (µCi/m^3)

The chronic residential scenario dose coefficient for radionuclide *i* (DC_{iR}) consists only of the residential external exposure dose coefficient:

$$DC_{iR} = DC_{ie}(R) \tag{29}$$

where

$DC_{ie}(R)$ ......residential external exposure dose coefficient (rem/year)/(µCi/m^3)

Residential external exposure dose coefficient for radionuclide *i (DC_{ie} (R))* is estimated by:

$$DC_{ie}(R) = U_y(h) \times DCF_{ie\inf} \times S \tag{30}$$

where

$U_y(h)$ ....fraction of a year spent in home
DCF_{ieinf} ......dose conversion factor for external exposure to infinite depth of soil uniformly contaminated with radionuclide i (rem/year)/(µCi/m^3)
S.................additional shielding factor for radionuclides during indoor residence accounting for presence of basement floor

3.0 INADVERTENT INTRUDER DOSE CALCULATIONS

The intruder analysis was performed by implementing the equation set shown in Section 2 using the GoldSim™ software (specifically GoldSim™ Version 10.50 SP 3 (GTC 2010)). GoldSim™ is a widely used commercial software package that has been employed previously at SRNL to model one-dimensional radionuclide transport and perform dose calculations (e.g. Smith, et al., 2009). GoldSim™ is a graphically based programming environment that allows a very modular approach to model construction. While not all aspects of implementing the intruder dose calculations in GoldSim™ will be described, a few parts of the model are shown below to give the reader some understanding of how the dose calculations were implemented.

Figure 2 shows a screen capture of the top level of the GoldSim™ model. This model is actually an extension of one developed previously to calculate the ingrowth of daughter radionuclides in the Portsmouth OSWDF (Phifer and Smith, 2013). The previous calculation conveniently provides concentrations for all parent and daughter radionuclides as a function of time. Intruder dose calculations are performed in the *Dose_Calculation* container shown in Figure 2. An expanded view of this container is shown in Figure 3 where other containers that store dose conversion factors, perform the intruder dose calculations, and collect results are located. Figure 4 shows an expanded view of the *Chronic_Intruder_Dose* container where dose calculations for the chronic intruder scenarios described in Section 2 are performed. At this level in the model we are performing the actual dose calculations using the functions shown. For example, function *Ag_Expose_Home* is an implementation of Eq. (21) which calculates the dose from exposure in a home for the agriculture chronic intruder scenario.

For each exposure pathway in a scenario of interest, an effective dose equivalent (EDE) in rem/yr for each radionuclide in the decay chain of a parent is calculated based on published dose conversion factors (DOE 2011). The analysis disregards leaching, such that radioactive decay alone determines the concentration within the waste unit for each radionuclide in the decay chain. This overestimates the radionuclide inventory in the waste at the time the intruder is assumed to be exposed. The decay process continually changes the amount of contaminant present in the waste zone that the intruder can encounter. While the amount of parent monotonically decreases, the amount of each progeny initially increases and ultimately decreases. A transient calculation is conducted which allows evaluation of when the maximum dose to the intruder occurs.

Radionuclide- and scenario-specific parameters within the software have been researched and independently verified (Lee, 2004 and Jannik 2013). As the decay process takes place, sediments and engineered materials can erode and degrade as well. A soil erosion rate of 0.0066 mm/yr was calculated for the OSWDF using the RUSLE2 average annual soil loss rate of 0.0471 ton/ac/yr based upon an assumed soil bulk density of 1.6 g/cm^3 (OSDC Calculation Package, D2 (Rev. F) Section I (page 34 of 128)). Over the 1,100 year period covered by the intruder analysis, erosion would reduce the initial soil depth of 2.97 m by less than 0.8 cm. Therefore, soil erosion was neglected in the dose calculations.

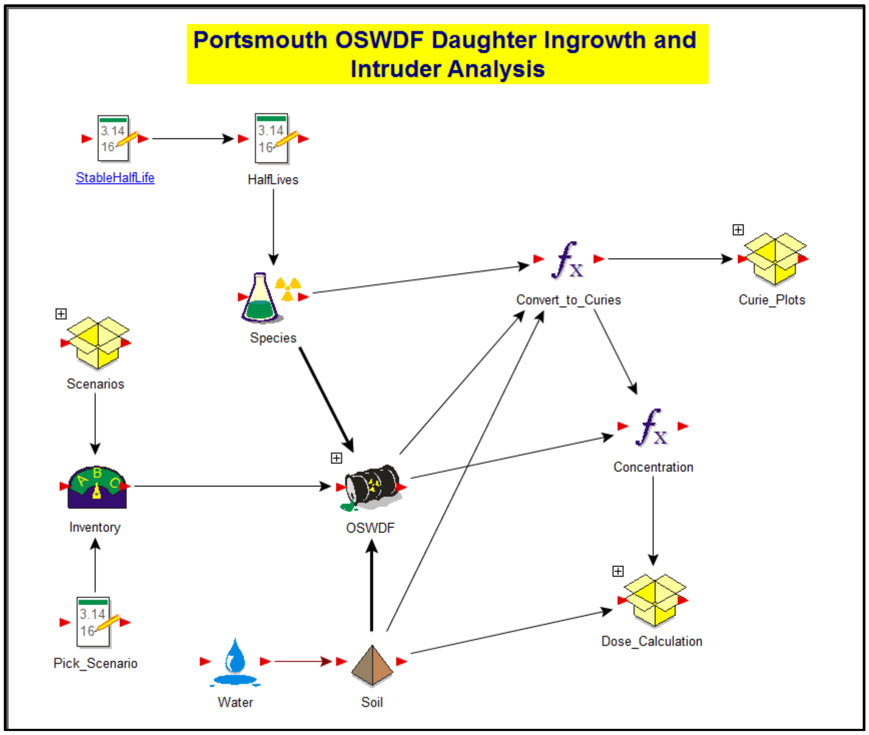

Figure 2. Top level of GoldSim model used to calculate daughter ingrowth and intruder doses for Portsmouth OSWDF.

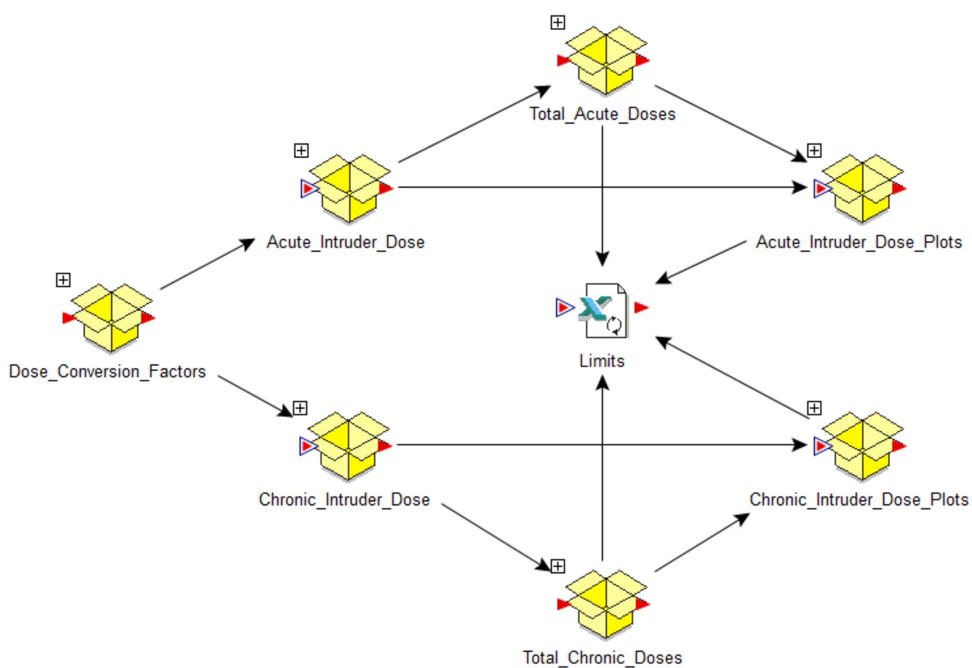

Figure 3. Expanded view of Dose_Calculation container.

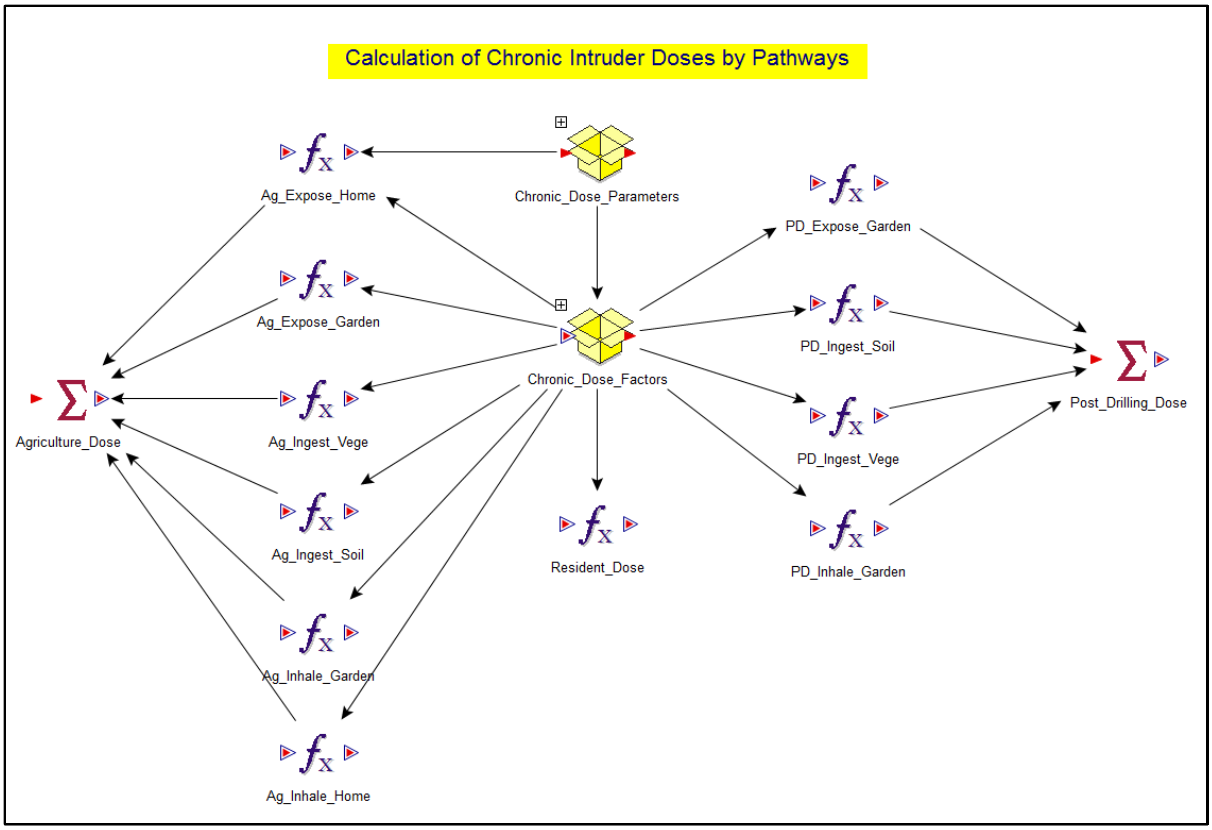

Figure 4. Expanded view of *Chronic_Intruder_Dose* container.

4.0 MODEL INPUT

Table 1 shows the radionuclide inventory assumed for the inadvertent intruder analysis. The assumed inventory is Inventory Scenario 4 from Appendix K, Attachment K.1 of the Portsmouth Waste Disposition RI/FS (FBP 2013), which is the greatest inventory of the four produced. The radionuclides Rn-218, Tl-210, and U-235m which appear as decay products from some of the radionuclides listed in Table 1 were not included in the intruder analysis. Rn-218 is a minor branching fraction in the decay of At-218 and there is very little in the OSWDF according to Table 8 and Figure 9 of the daughter in-growth report (Phifer and Smith, 2013). Tl-210 is a minor branching fraction in the decay of Bi-214 and there is very little in the OSWDF according to Table 8 and Figure 9 of the daughter in-growth report. As shown in Table 5 below, Rn-218 and Tl-210 do not have ingestion or inhalation dose coefficients and therefore would not contribute to the intruder dose. U-235m has a very short half-life and quickly decays to U-235, which is included in the intruder analysis, and there is very little U-235m compared to U-235 in the OSWDF according to Figure 10 of Phifer and Smith (2013). Also, as shown in Table 5, U-235m has very small dose coefficients and would contribute a negligible dose to an intruder.

Tables 2, 3 and 4 provide a list of inputs used in the inadvertent intruder analysis. In addition it was assumed that all intruder scenarios on an area basis intrude over only waste and not clean materials, which is the most conservative assumption in terms of dose.

Table 1. OSWDF Scenario 4 Inventory used for Inadvertent Intruder Analysis

Nuclide	Inventory (Ci)
Tc-99	3.86E+02
Ra-224	1.41E-02
Ra-228	1.41E-02
Ac-228	1.41E-02
Th-228	1.41E-02
Th-230	6.04E-01
Th-231	1.26E+01
Th-232	1.41E-02
Th-234	8.76E+01
Pa-233	1.48E-01
Pa-234m	8.76E+01
U-234	1.88E+02
U-235	1.26E+01
U-236	1.74E+00
U-238	8.76E+01
Np-237	1.48E-01
Pu-238	1.16E-02
Pu-239	2.92E-02
Am-241	1.79E-02

Table 2. Portsmouth OSWDF Intruder Analysis Geometry and DCF Data

Parameter	Value	Units	Reference
Waste Volume [1]	108,000,000 (3,058,560)	ft^3 (m^3)	FBP 2013 Section K.4.1 [1]
Initial Thickness of material above Biointrusion barrier [2]	2.75 (0.84)	Ft (m)	FBP 2013 Section K.4.3 and Figure K.9
Thickness of Biointrusion barrier [2]	3 (0.91)	Ft (m)	FBP 2013 Section K.4.3 and Figure K.9
Thickness of clean material between Biointrusion barrier and waste [2]	4 (1.22)	Ft (m)	FBP 2013 Section K.4.3 and Figure K.9
Soil Density, ρ_s [3]	1400	kg/m^3	Garden soil, drill cuttings, waste (Lee 2004) [3]
OSDC Inventory [1]	Radionuclide specific values from Scenario 4	Ci	FBP 2013 Appendix K, Attachment K.1 (see Table 1)
Ingestion Dose Conversion Factor, DCF_{ii}	Reference Person value by radionuclide	rem/µCi	DOE 2011 Table A-1 (see Table 5)
Inhalation Dose Conversion Factor, DCF_{ia}	Reference Person value by radionuclide	rem/µCi	DOE 2011 Table A-2 (see Table 5)
External Exposure in 15 cm of surface soil Dose Conversion Factor, DCF_{ie15}	Radionuclide specific value	rem/yr per $\mu Ci/m^3$	EPA 1993 and Lee 2004 (see Table 6)
External Exposure in infinite depth of soil Dose Conversion Factor, DCF_{ieinf}	Radionuclide specific value	rem/yr per $\mu Ci/m^3$	EPA 1993 and Lee 2004 (see Table 6)
Kocher Shielding Dose Conversion Factor, $DCF_{it}(t)$	Radionuclide specific value	rem/yr per $\mu Ci/m^3$	Kocher 2004 and Lee 2004
Soil-to-Vegetable Transfer factors, B_{iv}	Element specific value	Fraction	Baes et al. 1984 and Lee 2004 (see Table 6)
Radionuclide decay data [4]	Half-lives and branching fractions	-	ICRP 2008 and Phifer and Smith 2013 (see Table 7)

1. FBP 2013 Section K.4.1 assumes an OSWDF volume of 5 million cubic yards (135,000,000 ft^3) associated with an 11 cell OSWDF; a 9 cell OSWDF with a volume of 4 million cubic yards has been assumed for conservatism because it results in a greater modeled radionuclide concentration. Average waste concentration of radionuclide i (C_{iw}) calculated by dividing inventory by waste volume.
2. See Figure 1 for the OSWDF final cover cross-section.
3. A single bulk density of 1,400 kg/m3 has been utilized to represent the garden soil, drill cutting, and waste. This value is conservative relative to dose.
4. ICRP 2008 radionuclide decay data used to be consistent with DOE 2011 dose conversion factors.

Table 3. Portsmouth OSWDF Acute Intruder Analysis Parameters

Parameter	Value	Units	Reference
Fraction of year spent constructing basement, $U_y(bc)$	0.0183 (160 hrs/yr)	-	Jannik 2013 (see Appendix A)
Fraction of year spent drilling well, $U_y(wd)$	0.0034 (30 hrs/yr)	-	Jannik 2013 (see Appendix A)
Fraction of year spent digging, $U_y(d)$	0.0091 (80 hrs/yr)	-	Estimated as half of the time spent for basement construction
Thickness of clean material between intruder and waste, *t* [1]	3	ft	FBP 2013 Section K.4.3 and Figure K.9 [1]
Consumption of contaminated soil while constructing basement, $C_s(bc)$	0.0402 (110 mg/day)	kg/yr	Jannik 2013 (see Appendix A)
Consumption of contaminated soil while drilling well, $C_s(wd)$	0.0365 (100 mg/day)	kg/yr	Jannik 2013 (see Appendix A)
Dilution factor for mixing of waste with cuttings for drilling scenario, f_c	0.29	-	OSWDF specific value (see Appendix C)
Atmospheric mass loading of soil particles while constructing basement, $L_a(bc)$	6.0E-07	kg/m^3	Jannik 2013 (see Appendix A)
Atmospheric mass loading of soil particles while drilling well, $L_a(wd)$	1.0E-07	kg/m^3	Jannik 2013 (see Appendix A)
Construction worker air intake (breathing rate), I_{acw}	11400	m^3/yr	Jannik 2013 (see Appendix A)
Drilling worker air intake (breathing rate), I_{aw}	8400	m^3/yr	Jannik 2013 (see Appendix A)

[1] Assumes that after the discovery intruder digs through the 3-foot biointrusion barrier and the 1-foot drainage layer and reaches the geotextile cushion, HDPE geomembrane, and GCL layers that he quits digging because it becomes obvious that the cover isn't natural. This leaves 3 feet of clean material between the intruder and the waste.

Table 4. Portsmouth OSWDF Chronic Intruder Analysis Parameters

Parameter	Value	Units	Reference
Fraction of year spent in garden, $U_y(g)$	0.01	-	Oztunali et al. 1981
Fraction of year spent in home, $U_h(h)$	0.5	-	Oztunali et al., 1981
Shielding factor in home, S	0.7	-	NRC 1977
Reference Person Consumption of contaminated vegetables, C_v	100	kg/yr	EPA 2011 and Stone and Jannik 2013
Consumption of contaminated soil while in garden, C_s	0.037 (100 mg/day)	kg/yr	EPA 1989
Dilution factor for mixing of waste with garden soil, f_{Ag}	0.2	-	Napier et al. 1984
Dilution factor for mixing of drill cuttings with garden soil, f_{PDg}	0.02	-	Lee 2004 (Estimated as 10% of agriculture value)
Atmospheric mass loading of soil particles in home, $L_a(h)$	1.0E-08	kg/m^3	Lee 2004
Atmospheric mass loading of soil particles in garden, $L_a(g)$	1.0E-07	kg/m^3	Lee 2004
Reference person air intake (breathing rate), I_{arp}	6642	m^3/yr	Derived from DOE 2011 Table 3 (see Appendix B)

Table 5. Ingestion and Inhalation Dose Coefficients

Radionuclide	Ingestion DCF		Inhalation DCF [1]	
	Sv/Bq	***(rem/µCi)***	***Sv/Bq***	***(rem/µCi)***
Ac-225	5.23E-08	1.94E-01	9.18E-06	3.40E+01
Ac-227	3.92E-07	1.45E+00	5.91E-05	2.19E+02
Ac-228	5.14E-10	1.90E-03	1.61E-08	5.96E-02
Am-241	2.38E-07	8.81E-01	4.21E-05	1.56E+02
At-217				
At-218				
Bi-210	1.80E-09	6.66E-03	1.46E-07	5.40E-01
Bi-211				
Bi-212	3.52E-10	1.30E-03	3.67E-08	1.36E-01
Bi-213	2.68E-10	9.92E-04	3.55E-08	1.31E-01
Bi-214	1.49E-10	5.51E-04	1.72E-08	6.36E-02
Fr-221				
Fr-223	3.23E-09	1.20E-02	1.33E-08	4.92E-02
Np-237	1.25E-07	4.63E-01	2.30E-05	8.51E+01
Pa-231	5.59E-07	2.07E+00	2.99E-05	1.11E+02
Pa-233	1.32E-09	4.88E-03	4.56E-09	1.69E-02
Pa-234	5.57E-10	2.06E-03	3.98E-10	1.47E-03
Pa-234m				
Pb-209	7.46E-11	2.76E-04	6.46E-11	2.39E-04
Pb-210	1.02E-06	3.77E+00	1.21E-06	4.48E+00
Pb-211	2.62E-10	9.69E-04	1.26E-08	4.66E-02
Pb-212	1.03E-08	3.81E-02	1.86E-07	6.88E-01
Pb-214	1.99E-10	7.36E-04	1.47E-08	5.44E-02
Po-210	3.56E-07	1.32E+00	3.60E-06	1.33E+01
Po-211				
Po-212				
Po-213				
Po-214				
Po-215				
Po-216				
Po-218				
Pu-238	2.63E-07	9.73E-01	4.65E-05	1.72E+02
Pu-239	2.88E-07	1.07E+00	5.04E-05	1.86E+02
Pu-240	2.88E-07	1.07E+00	5.04E-05	1.86E+02
Ra-223	2.17E-07	8.03E-01	8.05E-06	2.98E+01
Ra-224	1.26E-07	4.66E-01	3.22E-06	1.19E+01

Radionuclide	Ingestion DCF		Inhalation DCF [1]	
	Sv/Bq	*(rem/µCi)*	*Sv/Bq*	*(rem/µCi)*
Ra-225	2.38E-07	8.81E-01	6.83E-06	2.53E+01
Ra-226	4.54E-07	1.68E+00	3.82E-06	1.41E+01
Ra-228	1.60E-06	5.92E+00	3.08E-06	1.14E+01
Rn-218				
Rn-219				
Rn-220				
Rn-222				
Tc-99	9.00E-10	3.33E-03	4.42E-09	1.64E-02
Th-227	1.47E-08	5.44E-02	1.12E-05	4.14E+01
Th-228	1.16E-07	4.29E-01	4.35E-05	1.61E+02
Th-229	6.08E-07	2.25E+00	7.55E-05	2.79E+02
Th-230	2.53E-07	9.36E-01	1.47E-05	5.44E+01
Th-231	4.62E-10	1.71E-03	3.78E-10	1.40E-03
Th-232	2.78E-07	1.03E+00	2.56E-05	9.47E+01
Th-234	4.68E-09	1.73E-02	8.60E-09	3.18E-02
Tl-207				
Tl-208				
Tl-209				
Tl-210				
U-233	6.02E-08	2.23E-01	3.89E-06	1.44E+01
U-234	5.81E-08	2.15E-01	3.81E-06	1.41E+01
U-235	5.49E-08	2.03E-01	3.38E-06	1.25E+01
U-235m	5.82E-15	2.15E-08	9.01E-16	3.33E-09
U-236	5.47E-08	2.02E-01	3.49E-06	1.29E+01
U-238	5.24E-08	1.94E-01	3.14E-06	1.16E+01

- All data obtained from DOE 2011

[1] Utilized recommended default absorption type from DOE 2011 where available and slow absorption type otherwise.

Table 6. External Soil Exposure and Soil Transfer Factors

Radionuclide	External 15cm Soil (rem/yr) per (µCi/m^3)	External Infinite Soil (rem/yr) per (µCi/m^3)	Soil-Vegetable Transfer Ratio
Ac-225	3.90E-05	3.98E-05	1.51E-04
Ac-227	3.06E-07	3.10E-07	1.51E-04
Ac-228	3.22E-03	3.74E-03	1.51E-04
Am-241	2.73E-05	2.73E-05	1.08E-04
At-217	1.01E-06	1.11E-06	6.45E-02
At-218	3.65E-06	3.65E-06	6.45E-02
Bi-210	2.17E-06	2.25E-06	2.15E-03
Bi-211	1.49E-04	1.60E-04	2.15E-03
Bi-212	6.26E-04	7.32E-04	2.15E-03
Bi-213	4.38E-04	4.79E-04	2.15E-03
Bi-214	5.09E-03	6.13E-03	2.15E-03
Fr-221	9.23E-05	9.60E-05	1.29E-02
Fr-223	1.18E-04	1.24E-04	1.29E-02
Np-237	4.86E-05	4.87E-05	4.30E-03
Pa-231	1.12E-04	1.19E-04	1.08E-04
Pa-233	6.03E-04	6.38E-04	1.08E-04
Pa-234	6.28E-03	7.22E-03	1.08E-04
Pa-234m	4.90E-05	5.61E-05	1.08E-04
Pb-209	4.76E-07	4.83E-07	3.87E-03
Pb-210	1.53E-06	1.53E-06	3.87E-03
Pb-211	1.70E-04	1.91E-04	3.87E-03
Pb-212	4.23E-04	4.40E-04	3.87E-03
Pb-214	7.83E-04	8.39E-04	3.87E-03
Po-210	2.86E-08	3.27E-08	1.72E-04
Po-211	2.62E-05	2.98E-05	1.72E-04
Po-212			1.72E-04
Po-213			1.72E-04
Po-214	2.80E-07	3.21E-07	1.72E-04
Po-215	5.82E-07	6.35E-07	1.72E-04
Po-216	5.69E-08	6.52E-08	1.72E-04
Po-218	3.07E-08	3.53E-08	1.72E-04
Pu-238	9.43E-08	9.46E-08	1.94E-05
Pu-239	1.78E-07	1.85E-07	1.94E-05
Pu-240	9.16E-08	9.17E-08	1.94E-05

Radionuclide	**External 15cm Soil (rem/yr) per (µCi/m^3)**	**External Infinite Soil (rem/yr) per (µCi/m^3)**	**Soil-Vegetable Transfer Ratio**
Ra-223	3.62E-04	3.77E-04	6.45E-03
Ra-224	3.06E-05	3.20E-05	6.45E-03
Ra-225	6.89E-06	6.89E-06	6.45E-03
Ra-226	1.93E-05	1.99E-05	6.45E-03
Ra-228			6.45E-03
Rn-218			
Rn-219	1.80E-04	1.93E-04	
Rn-220	1.28E-06	1.44E-06	
Rn-222	1.33E-06	1.47E-06	
Tc-99	7.82E-08	7.85E-08	6.45E-01
Th-227	3.10E-04	3.26E-04	3.66E-05
Th-228	4.87E-06	4.96E-06	3.66E-05
Th-229	1.99E-04	2.01E-04	3.66E-05
Th-230	7.46E-07	7.56E-07	3.66E-05
Th-231	2.27E-05	2.28E-05	3.66E-05
Th-232	3.25E-07	3.26E-07	3.66E-05
Th-234	1.51E-05	1.51E-05	3.66E-05
Tl-207	1.11E-05	1.24E-05	1.72E-04
Tl-208	1.13E-02	1.44E-02	1.72E-04
Tl-209	6.76E-03	8.08E-03	1.72E-04
Tl-210			1.72E-04
U-233	8.46E-07	8.74E-07	1.72E-03
U-234	2.50E-07	2.51E-07	1.72E-03
U-235	4.38E-04	4.51E-04	1.72E-03
U-235m			1.72E-03
U-236	1.33E-07	1.34E-07	1.72E-03
U-238	6.45E-08	6.45E-08	1.72E-03

- External Soil Exposure Factors obtained from EPA 1993 and Lee 2004
- Soil-to-Vegetable Transfer Ratio obtained from Baes et al. (1984) and Lee 2004

Table 7. Portsmouth OSWDF Radionuclides, Half-lives, and Branching Fractions

Radionuclide	Half-life (years)	Daughter 1 Branching Fraction	Daughter 1	Daughter 2 Branching Fraction	Daughter 2
Ac-225	2.74E-02	1	Fr-221		
Ac-227	2.18E+01	0.9862	Th-227	0.0138	Fr223
Ac-228	7.02E-04	1	Th-228		
Am-241	4.32E+02	1	Np-237		
At-217	1.02E-09	0.99988	Bi-213		
At-218	4.75E-08	0.999	Bi-214	0.001	Rn218
Bi-210	1.37E-02	1[1]	Po-210		
Bi-211	4.07E-06	0.99724	Tl-207	0.00276	Po211
Bi-212	1.33E-05	0.6406	Po-212	0.3594	Tl208
Bi-213	8.67E-05	0.9791	Po-213	0.0209	Tl209
Bi-214	3.78E-05	0.99979	Po-214	0.00021	Tl210
Fr-221	9.32E-06	1	At-217		
Fr-223	4.18E-05	1[1]	Ra-223		
Np-237	2.14E+06	1	Pa-233		
Pa-231	3.28E+04	1	Ac-227		
Pa-233	7.38E-02	1	U-233		
Pa-234	7.64E-04	1	U-234		
Pa-234m	2.22E-06	0.9984	U-234	0.0016	Pa234
Pb-209	3.71E-04	1	*Bi*		
Pb-210	2.22E+01	1[1]	Bi-210		
Pb-211	6.86E-05	1	Bi-211		
Pb-212	1.21E-03	1	Bi-212		
Pb-214	5.10E-05	1	Bi-214		
Po-210	3.79E-01	1	*Pb*		
Po-211	1.64E-08	1	*Pb*		
Po-212 [2]	9.47E-15 (2.00E-10)	1	*Pb*		
Po-213 [2]	1.33E-13 (2.00E-10)	1	Pb-209		
Po-214 [2]	5.21E-12 (2.00E-10)	1	Pb-210		
Po-215 [2]	5.64E-11 (2.00E-10)	1	Pb-211		
Po-216	4.59E-09	1	Pb-212		
Po-218	5.89E-06	0.9998	Pb-214	0.0002	At218
Pu-238	8.77E+01	1	U-234		
Pu-239	2.41E+04	0.9994	U-235m	0.0006	U235
Pu-240	6.56E+03	1	U-236		

Radionuclide	Half-life (years)	Daughter 1 Branching Fraction	Daughter 1	Daughter 2 Branching Fraction	Daughter 2
Ra-223	3.13E-02	1	Rn-219		
Ra-224	1.00E-02	1	Rn-220		
Ra-225	4.08E-02	1	Ac-225		
Ra-226	1.60E+03	1	Rn-222		
Ra-228	5.75E+00	1	Ac-228		
Rn-218	1.11E-09	1	Po-214		
Rn-219	1.25E-07	1	Po-215		
Rn-220	1.76E-06	1	Po-216		
Rn-222	1.05E-02	1	Po-218		
Tc-99	2.11E+05	1	*Ru*		
Th-227	5.11E-02	1	Ra-223		
Th-228	1.91E+00	1	Ra-224		
Th-229	7.34E+03	1	Ra-225		
Th-230	7.54E+04	1	Ra-226		
Th-231	2.91E-03	1	Pa-231		
Th-232	1.41E+10	1	Ra-228		
Th-234	6.60E-02	1	Pa-234m		
Tl-207	9.07E-06	1	*Pb*		
Tl-208	5.80E-06	1	*Pb*		
Tl-209	4.11E-06	1	Pb-209		
Tl-210	2.47E-06	1	Pb-210		
U-233	1.59E+05	1	Th-229		
U-234	2.46E+05	1	Th-230		
U-235	7.04E+08	1	Th-231		
U-235m	4.94E-05	1	U-235		
U-236	2.34E+07	1	Th-232		
U-238	4.47E+09	1	Th-234		

- All data obtained from ICRP 2008

[1] Rounded to 1 from value greater than 0.9999; radionuclide dose from other branch insignificant (minor branching fraction less than 0.0001)

[2] GoldSim (GTG 2010) does not allow the use of half-lives less than 2.00E-10 years; therefore radionuclides with half-lives less than 2.00E-10 years were set to 2.00E-10 years.

5.0 MODEL RESULTS

Figure 5 shows a plot of results from the inadvertent intruder analysis for chronic exposure scenarios over a 1,000 year period of assessment beginning 100 years after site closure. We assume that the waste inventory specified in Table 2 applies at time zero and that for 100 years from the time of waste disposal the site is under institutional control and no inadvertent intrusion would occur. Therefore, the period of assessment is from 100 years to 1,100 years. It is seen that the doses to an inadvertent intruder remain relatively constant over the 1,000 year period of assessment. Maximum doses over the period of assessment occur at 1,100 years after waste burial and are approximately 7 mrem/yr for the agricultural scenario, 2.1 mrem/yr for the resident scenario, and 0.5 mrem/yr for the post-drilling scenario. The largest dose of 7.0 mrem/yr is well below the DOE limit of 100 mrem/yr for the chronic dose to an inadvertent intruder.

Contributions to the chronic intruder dose from the various dose pathways considered in the agriculture scenario are plotted in Figure 6. As Figure 6 shows, the largest contribution to the agriculture dose is from the vegetable ingestion pathway which accounts approximately 64% of the total dose at 1,100 years in this scenario. The next largest contribution to total agriculture dose is from exposure to external radiation in the home which is approximately 34% of the total dose at 1,100 years. All other pathways contribute relatively small doses to the agriculture scenario.

The resident scenario consists of only one exposure pathway (i.e. external exposure to contaminated soil while residing in the home on top of the disposal facility). Therefore a breakdown by exposure pathway is not required.

Contributions to the chronic intruder dose from the various dose pathways considered in the post drilling scenario are plotted in Figure 7. As Figure 7 shows, the largest contribution to the post drilling dose is from the vegetable ingestion pathway which accounts for 97% of total dose at 1,100 years. All other pathways contribute relatively small doses to the post drilling scenario.

The most significant contributions to the chronic intruder dose in the agriculture scenario from individual radionuclides are plotted in Figure 8. To make the plot readable, only those radionuclides contributing a dose greater than 0.01 mrem/yr during the 1,000 year period of assessment are plotted. We find that Tc-99 contributes approximately 56% of the total agriculture scenario dose at 1,100 years. U-235 is the only other radionuclide that contributes greater than 10% of the total agriculture dose at 1,100 years. From the results shown in Figures 6 and 8 we conclude that consumption of vegetables contaminated with Tc-99 is the greatest source of chronic dose to an inadvertent intruder.

Table 8 at the end of this section provides numerical values of the chronic intruder dose at 100 year intervals for the three scenarios considered.

Figure 9 shows a plot of results from the inadvertent intruder analysis for acute exposure scenarios over a 1,000 year period of assessment beginning 100 years after waste disposal. It is seen that the acute doses to an inadvertent intruder also remain relatively constant over the

1,000 year period of assessment. Maximum doses over the period of assessment occur at 1,100 years after waste burial and are approximately 0.25 mrem/yr for the basement construction scenario, 7.0E-03 mrem/yr for the well drilling scenario, and only 9.0E-06 mrem/yr for the discovery scenario. The largest dose of 0.25 mrem/yr is substantially below the DOE limit of 500 mrem/yr for the acute dose to an inadvertent intruder.

Contributions to the acute intruder dose from the various dose pathways considered in the basement construction scenario are plotted in Figure 10. As Figure 10 shows, the largest contributions to the basement construction dose are from the air inhalation and external exposure pathways. Together these two pathways account for approximately 95% of the total dose at 1,100 years in this scenario. The soil ingestion pathway contributes a relatively small dose to the basement construction scenario.

Contributions to the acute intruder dose from the various dose pathways considered in the well drilling scenario are plotted in Figure 11. As Figure 11 shows, the largest contribution to the post drilling dose is from the external exposure pathway which accounts for about 79% of total dose at 1,100 years. The other two pathways contribute relatively small doses to the well drilling scenario.

The most significant contributions to the acute intruder dose in the basement construction scenario from individual radionuclides are plotted in Figure 12. To make the plot readable, only those radionuclides contributing a dose greater than 0.001 mrem/yr during the 1,000 year period of assessment are plotted. We find that U-234 contributes approximately 35% of the total basement construction scenario dose at 1100 years. Altogether the three uranium isotopes (U-234, U-235 and U-238) contribute about 65% of the basement construction dose at 1,100 years.

Table 9 provides numerical values of the acute intruder dose at 100 year intervals for the three scenarios considered. In summary, the acute dose to an inadvertent intruder was found to be essentially negligible. The maximum chronic dose to an inadvertent intruder is from the agriculture scenario and is primarily from consumption of vegetables contaminated with Tc-99. However, the maximum chronic dose to an inadvertent intruder from the proposed Portsmouth OSWDF is about 7% of the DOE chronic intruder limit.

Tables 10, 11 and 12 provide disposal constraints for the 19 nuclides that will be in the OSWDF. Disposal constraints were determined by performing the following analysis:

1. An inventory of one Curie for each nuclide was specified.
2. The intruder dose model was run for each nuclide individually.
3. Maximum doses between 100 and 1100 years resulting from disposal of one Curie and time of occurrence of the maximum doses were determined for the acute and chronic intruder scenarios.
4. Disposal constraints for each nuclide and for each scenario were calculated as the ratio of the allowed dose (100 mrem/yr for chronic intruder scenarios and 500 mrem/yr for acute intruder scenarios) to the observed maximum dose from the disposal of one Curie.
5. Absolute disposal constraints for each nuclide were determined as the minimum disposal constraint for any of the intruder scenarios.

Table 10 gives disposal constraints and the time of occurrence for the three acute intruder scenarios. Table 11 gives disposal constraints and the time of occurrence for the three chronic intruder scenarios. Finally, Table 12 gives overall disposal constraints for the 19 nuclides in the OSWDF. Intruder disposal constraints are all set by the chronic agriculture intruder scenario. From Table 12, we see that only 11 of the 19 nuclides have intruder disposal constraints less than 10^6 Curies. Ra-224 essentially is gone within the first 100 years after disposal and is hence considered not applicable (NA).

Intruder disposal constraints can be evaluated by calculating the fraction of the disposal constraint represented by the inventory and summing these fractions. The Scenario 4 OSWDF inventory used in the calculation (Table 1) is given in the third column of Table 12 and the fraction of the disposal limit that the inventory represents is given in the fourth column of the table. The Sum of Fractions (SOF) for this inventory is approximately 0.07 which implies that about 7% of the total disposal capacity based on intruder limits is reached. The 7% SOF is almost entirely from Tc-99 at 4% and U-238, U-234, and U-235 at about 1% each. An SOF of one indicates that the disposal inventory has reached full capacity. There are of course many different inventory combinations that will give an SOF of one. For example, an SOF of one is reached by assuming that the relative inventory composition remains the same but the absolute inventory of every nuclide is increased by a factor of 14.4. Alternatively Table 12 can be used to evaluate different compositions. The last column in Table 12 shows the factors that the inventories of individual nuclides can be increased to reach an SOF of one. For example, if the Tc-99 inventory alone is increased by a factor of 25.8 an SOF of one is reached. From this analysis, it is unlikely that the intruder scenarios will be the determining factor in setting OSWDF disposal limits.

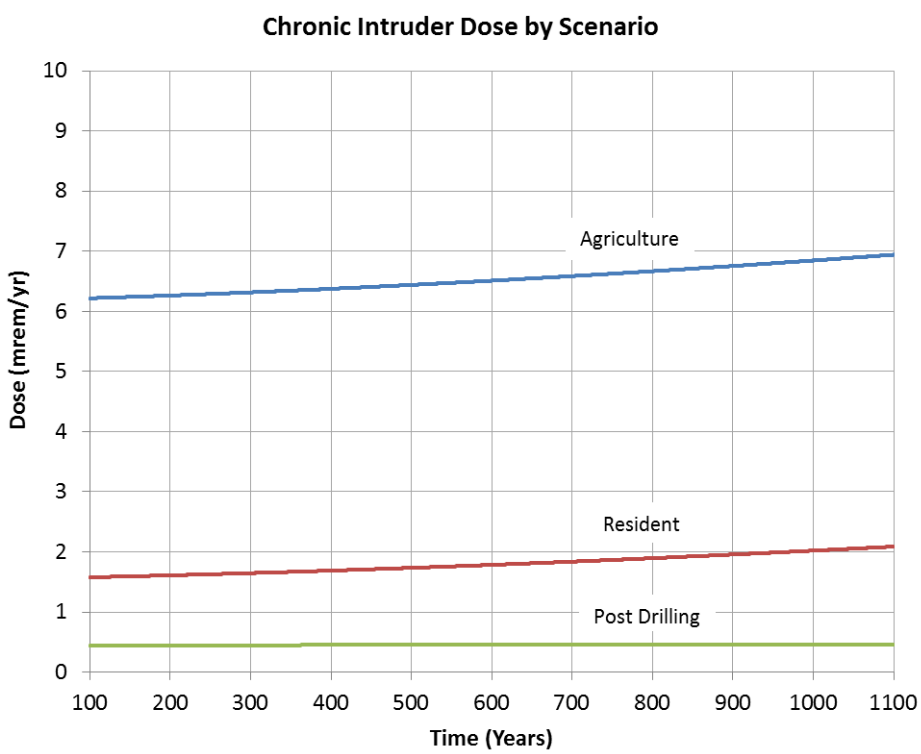

Figure 5. Chronic dose to intruder at OSWDF by scenario.

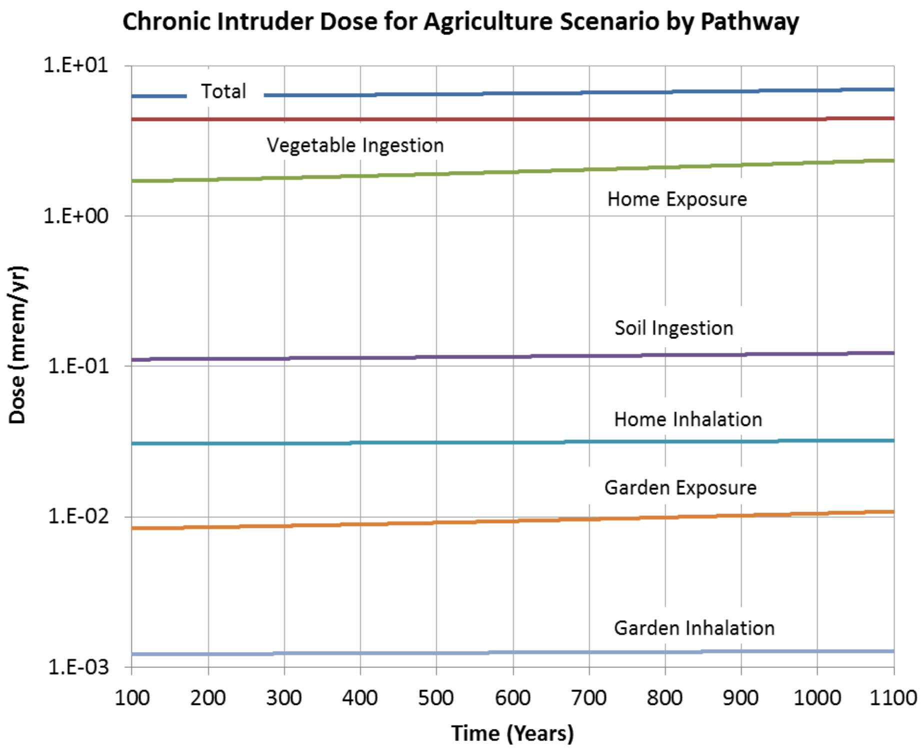

Figure 6. Chronic dose to intruder at OSWDF from agriculture scenario by pathway.

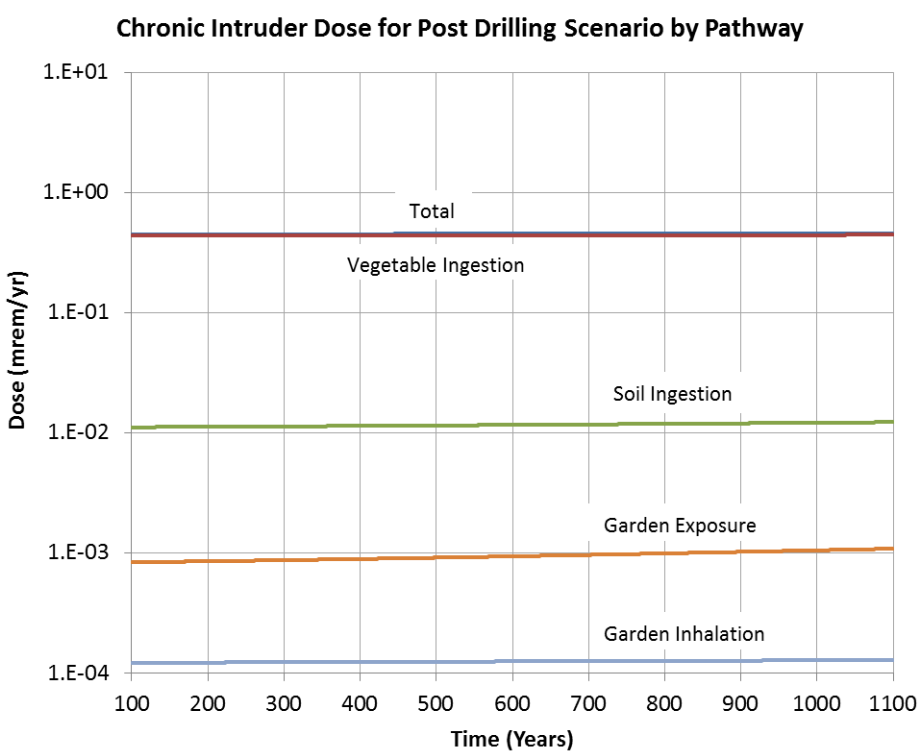

Figure 7. Chronic dose to intruder at OSWDF from post drilling scenario by pathway.

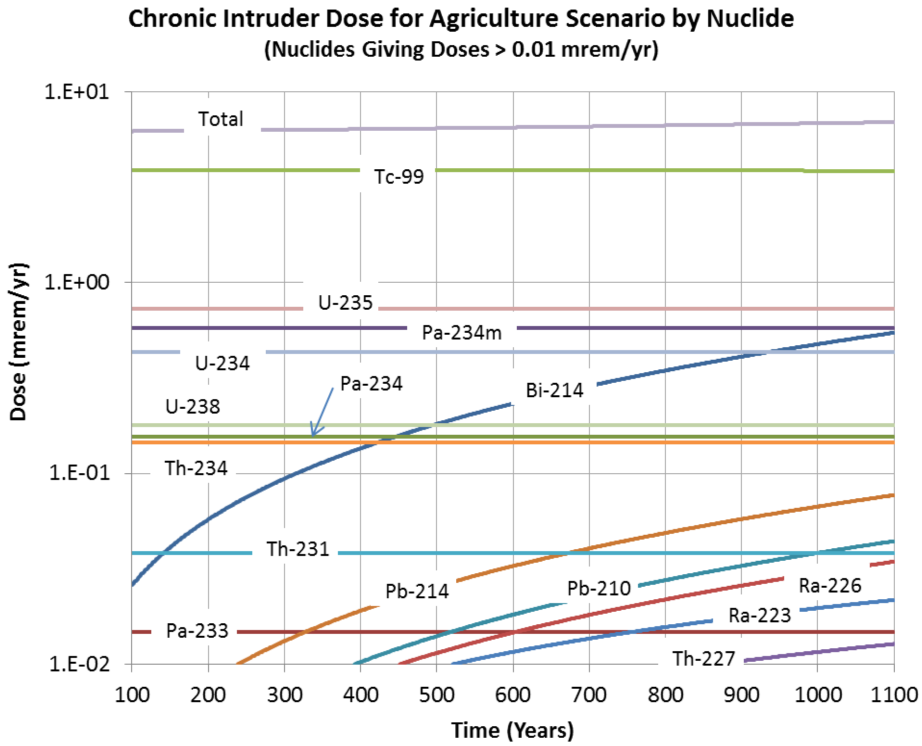

Figure 8. Chronic dose to intruder at OSWDF from agriculture scenario by nuclide.

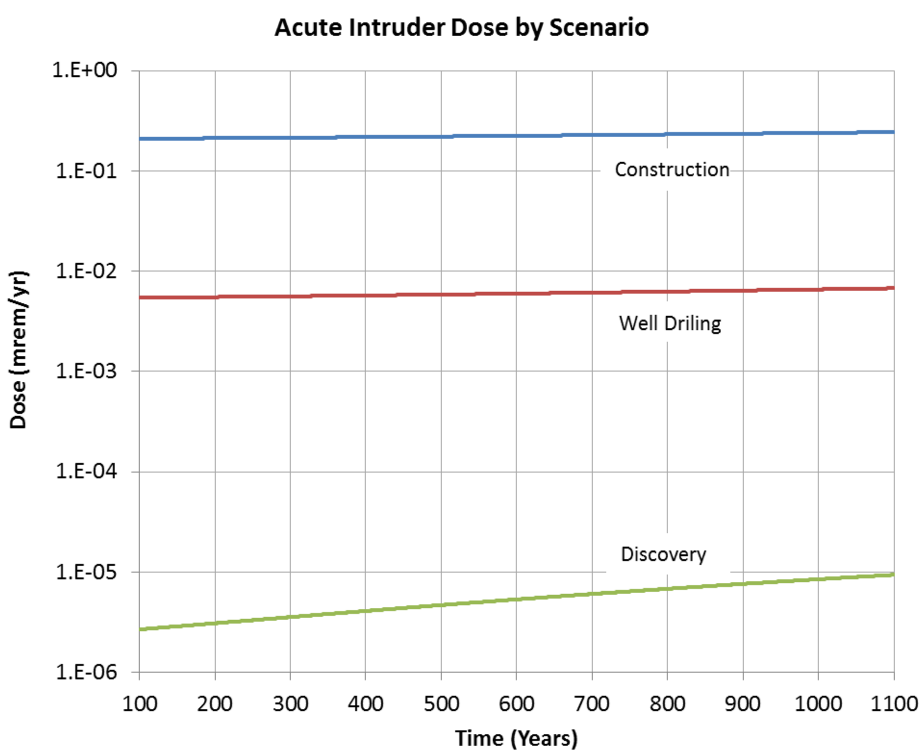

Figure 9. Acute dose to intruder at OSWDF by scenario.

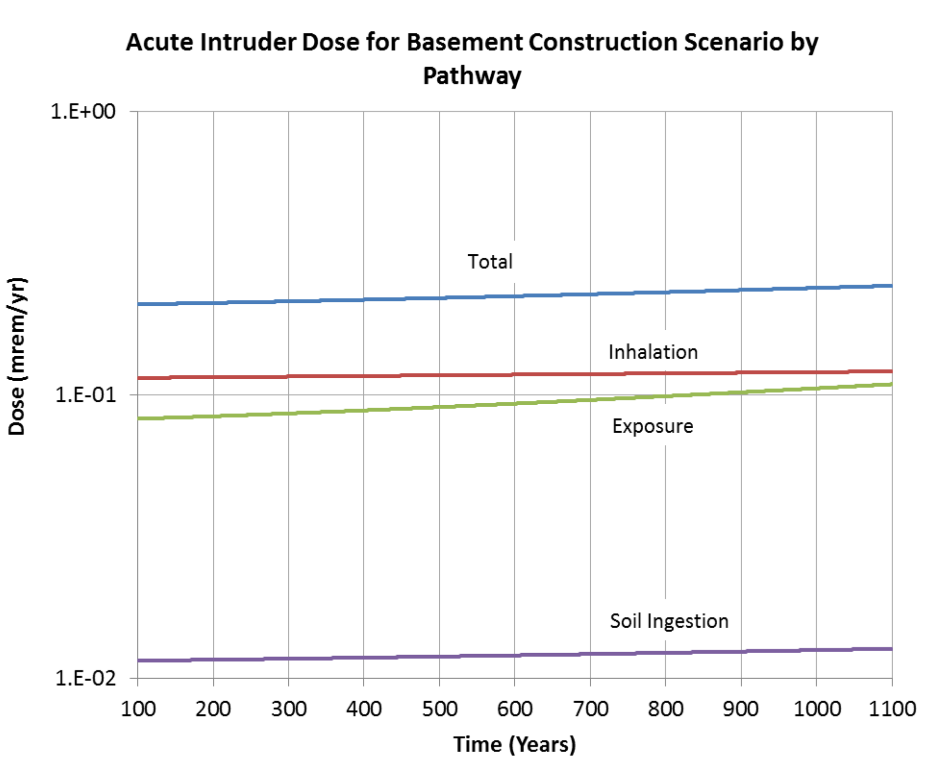

Figure 10. Acute dose to intruder at OSWDF from construction scenario by pathway.

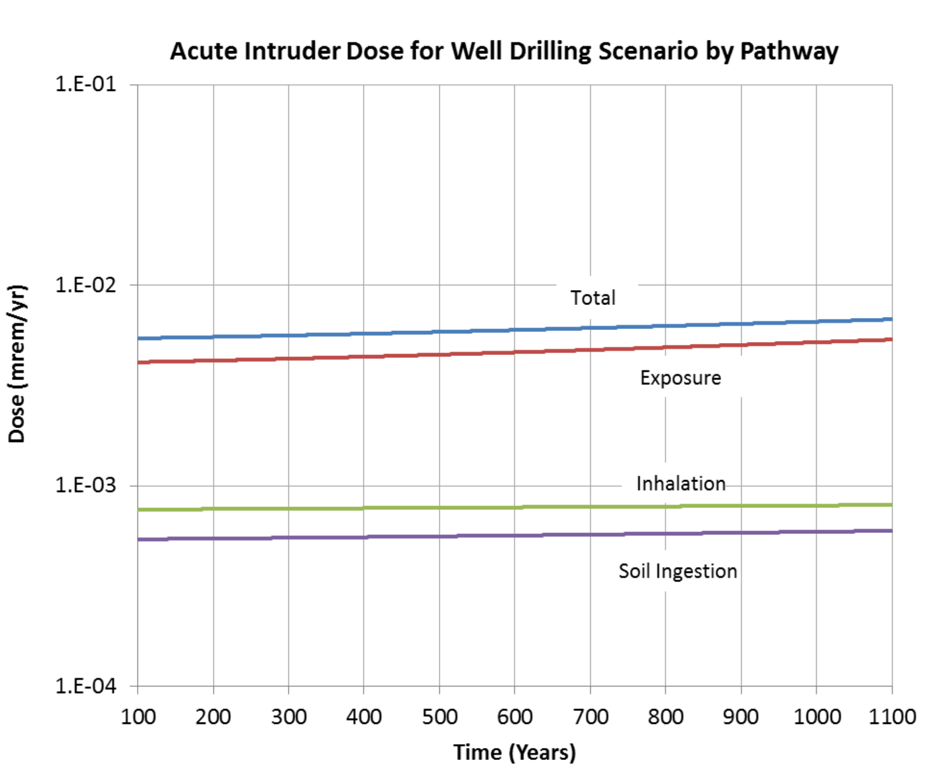

Figure 11. Acute dose to intruder at OSWDF from well drilling scenario by pathway.

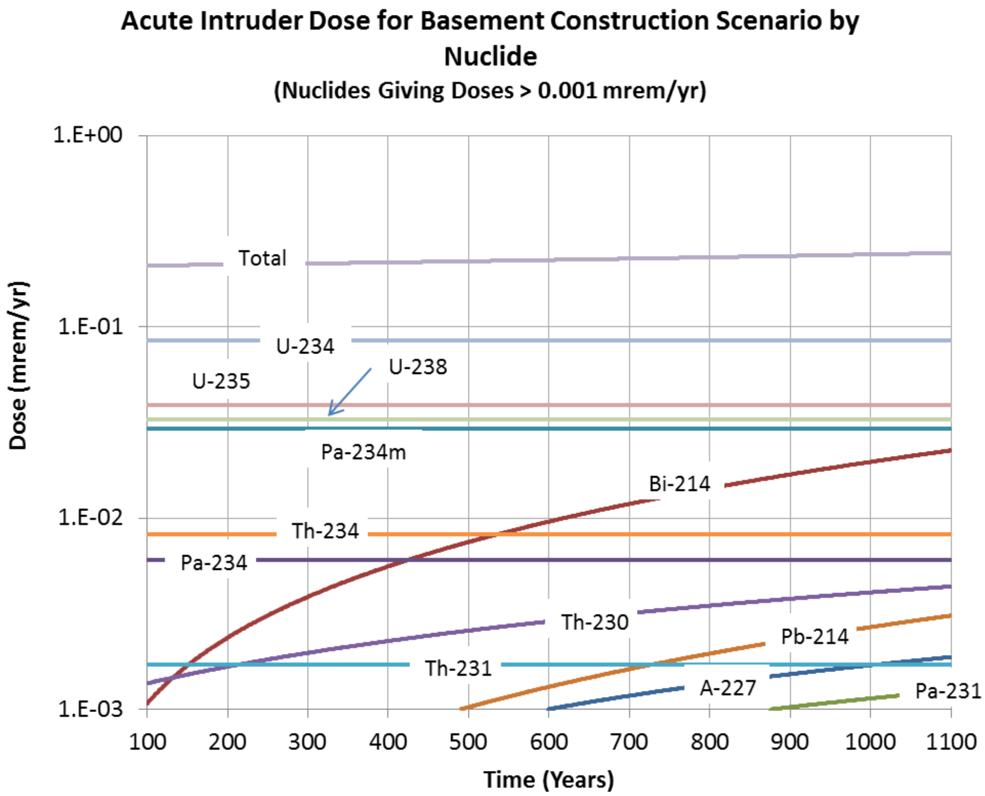

Figure 12. Acute dose to intruder at OSWDF from construction scenario by nuclide.

Table 8. Summary of Chronic Intruder Doses from OSWDF

Time (years)	Agriculture Scenario Dose (mrem/yr)	Resident Scenario Dose (mrem/yr)	Post Drilling Scenario Dose (mrem/yr)
100	6.22	1.58	0.448
200	6.26	1.61	0.449
300	6.31	1.65	0.450
400	6.37	1.69	0.450
500	6.44	1.73	0.451
600	6.51	1.78	0.452
700	6.58	1.84	0.452
800	6.67	1.89	0.453
900	6.75	1.96	0.454
1000	6.84	2.02	0.455
1100	6.94	2.09	0.456

Table 9. Summary of Acute Intruder Doses from OSWDF

Time (years)	Basement Construction Scenario Dose (mrem/yr)	Well Drilling Scenario Dose (mrem/yr)	Discovery Scenario Dose (mrem/yr)
100	0.209	5.43E-03	2.68E-06
200	0.211	5.51E-03	3.08E-06
300	0.214	5.61E-03	3.55E-06
400	0.217	5.72E-03	4.09E-06
500	0.220	5.84E-03	4.68E-06
600	0.223	5.97E-03	5.33E-06
700	0.227	6.11E-03	6.04E-06
800	0.231	6.25E-03	6.80E-06
900	0.235	6.41E-03	7.61E-06
1000	0.239	6.57E-03	8.47E-06
1100	0.243	6.75E-03	9.37E-06

Table 10. Disposal Constraints for Acute Intruder Scenarios

	Acute Scenarios					
	Construction		Drilling		Discovery	
Nuclide	Inventory (Ci)	Time (yr)	Inventory (Ci)	Time (yr)	Inventory (Ci)	Time (yr)
Ac-228	4.38E+22	100	1.12E+24	100	5.76E+25	100
Am-241	1.20E+05	100	1.27E+07	100	1.25E+15	1100
Np-237	7.48E+04	1100	2.17E+06	1100	2.07E+11	1100
Pa-233	5.19E+11	1100	2.49E+13	1100	3.78E+16	1100
Pa-234m	1.03E+17	1100	6.51E+18	1100	2.45E+21	1100
Pu-238	2.12E+05	100	2.66E+07	100	7.39E+13	1100
Pu-239	8.92E+04	100	1.11E+07	100	9.39E+17	1100
Ra-224	NA	0	NA	0	NA	0
Ra-228	8.23E+08	100	2.01E+10	100	1.42E+12	100
Tc-99	3.29E+08	100	8.87E+09	100	2.47E+22	100
Th-228	1.61E+19	100	4.11E+20	100	2.12E+22	100
Th-230	2.73E+04	1100	6.59E+05	1100	1.16E+08	1100
Th-231	2.74E+11	224	1.07E+13	226	1.84E+17	231
Th-232	7.13E+03	184	1.77E+05	184	1.42E+07	185
Th-234	3.34E+12	1100	2.11E+14	1100	7.93E+16	1100
U-234	8.97E+05	1100	5.66E+07	1100	2.13E+10	1100
U-235	1.35E+05	1100	3.04E+06	1100	7.06E+11	1100
U-236	1.21E+06	100	1.18E+08	1100	2.66E+14	1100
U-238	5.72E+05	1100	1.79E+07	1100	2.37E+10	1100

Table 11. Disposal Constraints for Chronic Intruder Scenarios

	Chronic Scenarios					
	Agriculture		Post Drilling		Resident	
Nuclide	Inventory (Ci)	Time (yr)	Inventory (Ci)	Time (yr)	Inventory (Ci)	Time (yr)
Ac-228	4.27E+20	100	1.92E+23	100	5.21E+20	100
Am-241	1.85E+04	100	5.77E+05	100	3.75E+04	100
Np-237	8.58E+02	1100	9.45E+04	1100	1.27E+03	1100
Pa-233	1.08E+10	1100	3.94E+11	1100	1.91E+10	1100
Pa-234m	2.46E+15	1100	4.82E+16	1100	6.85E+15	1100
Pu-238	6.78E+04	100	1.21E+06	100	2.03E+07	100
Pu-239	2.87E+04	100	5.00E+05	100	4.74E+06	100
Ra-224	NA	0	NA	0	NA	0
Ra-228	7.11E+06	100	6.64E+08	100	9.60E+06	100
Tc-99	9.96E+03	100	9.96E+04	100	1.11E+07	100
Th-228	1.57E+17	100	7.06E+19	100	1.91E+17	100
Th-230	2.30E+02	1100	1.92E+04	1100	3.31E+02	1100
Th-231	4.87E+09	228	3.25E+11	226	7.19E+09	228
Th-232	6.18E+01	184	4.70E+03	182	8.63E+01	184
Th-234	7.96E+10	1100	1.56E+12	1100	2.22E+11	1100
U-234	2.14E+04	1100	4.19E+05	1100	5.96E+04	1100
U-235	1.52E+03	1100	3.26E+05	1100	1.73E+03	1100
U-236	4.64E+04	1100	5.06E+05	100	6.49E+06	1100
U-238	8.26E+03	1100	5.04E+05	1100	1.05E+04	1100

Table 12. Constraining Disposal Inventories for Intruder Scenarios

Nuclide	Inventory Constraint (Ci)	Table 1 Inventory (Ci)	Fraction of Constraint (-)	Inventory Factor[1]
Ac-228	4.27E+20	1.41E-02	3.30E-23	> 1.0E+06
Am-241	1.85E+04	1.79E-02	9.66E-07	> 1.0E+06
Np-237	8.58E+02	1.48E-01	1.72E-04	5.80E+03
Pa-233	1.08E+10	1.48E-01	1.37E-11	> 1.0E+06
Pa-234m	2.46E+15	8.76E+01	3.57E-14	> 1.0E+06
Pu-238	6.78E+04	1.16E-02	1.71E-07	> 1.0E+06
Pu-239	2.87E+04	2.92E-02	1.02E-06	9.83E+05
Ra-224	NA	1.41E-02	NA	NA
Ra-228	7.11E+06	1.41E-02	1.98E-09	> 1.0E+06
Tc-99	9.96E+03	3.86E+02	3.87E-02	2.58E+01
Th-228	1.57E+17	1.41E-02	8.97E-20	> 1.0E+06
Th-230	2.30E+02	6.04E-01	2.63E-03	3.81E+02
Th-231	4.87E+09	1.26E+01	2.59E-09	> 1.0E+06
Th-232	6.18E+01	1.41E-02	2.28E-04	4.39E+03
Th-234	7.96E+10	8.76E+01	1.10E-09	> 1.0E+06
U-234	2.14E+04	1.88E+02	8.80E-03	1.14E+02
U-235	1.52E+03	1.26E+01	8.32E-03	1.20E+02
U-236	4.64E+04	1.74E+00	3.75E-05	2.67E+04
U-238	8.26E+03	8.76E+01	1.06E-02	9.42E+01
		Sum of Fractions	**6.95E-02**	**1.44E+01**

[1]The Inventory Factor is defined as the factor that when multiplied by the Table 1 radionuclide inventory results in an inventory that will produce a chronic agriculture intruder scenario dose of 100 mrem/yr (i.e. chronic intruder performance measure).

6.0 REFERENCES

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7.0 APPENDIX A –ACUTE EXPOSURE PARAMETERS

Recommended exposure factors for the acute intruder scenarios were obtained by G. T. Jannik of SRNL through a review of several sources as documented in the memorandum copied below.

SRNL-L4310-2013-00016

SRNL
SAVANNAH RIVER NATIONAL LABORATORY

August 6, 2013

TO: F.G. Smith, III, 703-41A
Computational Sciences

M.A. Phifer, 773-42A
Radiological Performance Assessment

FROM: G.T. Jannik, 773–42A
Environmental Sciences

cc: J.J. Mayer, 773–42A
E.B. Farfan, 773–42A
K.L. Dixon, 773–42A
A. Murray, 773-A
EDG Files, 773–42A

Recommended Exposure Parameters for Acute Intruder Scenarios at the Portsmith OH Disposal Facility (U)

At your request, Environmental Sciences has recommended selected exposure parameters for the "Well Driller" and "Home/Basement Builder" acute intruder scenarios at the Portsmith, OH Disposal Facility.

Table 1 shows the range of referenced values and the recommended values for Exposure Time, Soil Ingestion Rate, Inhalation Rate, and Mass Loading.

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SRNL-L4310-2013-00016
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Table 1. Recommended Exposure Values for Portsmith, OH Disposal Facility

	Exposure Time	Soil Ingestion	Air Inhalation	Mass Loading	Ref.
	hours/year	milligrams/day	m^3/year	kg/m^3	
Well Drilling					
ResRad	N/A	100	11,400	1.00E-07	1,2
EPA (PRG)	N/A	100	21,900	N/A	3
Hanford 1999 PA	40	500 mg (total)	10,500	1.00E-07	4
SRR HTF PA	20	100	8,400	1.00E-07	5
Idaho	160	50	?	1.00E-06	6
BDOSE	160	110	8,400	N/A	7
Recommended	**30**	**100**	**8,400**	**1.00E-07**	
Basement Construction					
ResRad	N/A	100	11,400	6.00E-07	1,2
EPA (PRG)	N/A	100	21,900	N/A	3
Hanford 1999 PA	N/A	500 mg (total)	10,500	1.00E-07	4
SRR HTF PA	N/A	100	8,400	1.00E-07	5
Idaho	N/A	50	?	1.00E-06	6
BDOSE	N/A	110	8,400	N/A	7
Recommended	**160**	**110**	**11,400**	**6.00E-07**	

References:

1) Yu, et al, *Users Manual for RESRAD Version 6*, Argonne National Laboratory Report: ANL/EAD/4, Argonne, IL. July, 2001.
2) Yu, et al, *Data Collection Handbook to Support Modeling Impacts of Radioactive Material in Soil*, Argonne National Laboratory, April, 2001.
3) Risk Assessment Information System, http://epa-prgs.ornl.gov/radionuclides/
4) Rittman, P.D., *Exposure Scenarios and Unit Dose Factors for the Hanford Immobilized Low-Activity Tank Waste Performance Assessment*, HNF-5636, Rev. 0, Appendix O, Hanford, WA, December 1999.
5) SRR HTF PA, *Performance Assessment for the H-Area Tank Farm at the Savannah River Site*, SRR-CWDA-2010-00128, Rev. 0. SRR, Aiken, SC, March 2011.
6) DOE–Idaho. DOE/ID–10966, *"Performance Assessment for the Tank Farm Facility at the Idaho National Engineering and Environmental Laboratory."* Rev. 1. Vol. 1. Idaho Falls, Idaho: 2003.
7) Simpkins, et al. *Description of Methodology for Biosphere Dose Model BDOSE*, USNRC Contract #NRC-02-07-006, San Antonio, TX, November 2008.

8.0 APPENDIX B –AIR INTAKE CALCULATION

Calculation of the air inhalation rate for a reference person is based on Table 3 of DOE-STD-1196-2011 (DOE 2011) as shown below.

Table 3 of DOE-STD-1196-2011 to produce Reference Person Air Intake

Reference Age Groups	Population Fraction		Daily Air Intake (m3)		Reference Person Fraction Daily Intake (m3)		Reference Person Total Intake (m3)	
	Male	Female	Male	Female	Male	Female	Total	
Newborn	0.00693	0.00660	4.15	4.15	0.0288	0.0274		
1-y	0.01383	0.01321	5.89	5.89	0.0815	0.0778		
5-y	0.02864	0.02731	9.00	9.08	0.2578	0.2480		
10-y	0.03814	0.03632	15.20	15.00	0.5797	0.5448		
15-y	0.03672	0.03482	20.00	15.80	0.7344	0.5502		
Adult	0.36630	0.39118	22.20	17.70	8.1319	6.9239		
				Total	9.8140	8.3720	18.2	Daily
							6642.4	Annual

9.0 APPENDIX C –DILUTION OF WELL DRILLING CUTTINGS

The value of parameter f_c , the dilution factor for mixing of waste and geologic cuttings, used in the acute well drilling scenario was obtained through the following process.

Geologic Layers from Surface to Groundwater	**Layer Thickness (ft)**
OSWDF cover	9.75
Waste zone	50
Liner	5
Upper Cuyahoga	20
Lower Cuyahoga	50
Sunbury	20
Berea	20
Total	174.75

This results in a site specific waste concentration dilution factor of 0.29 (50 ft waste thickness / 174.75 ft total thickness = 0.29). This should be considered a conservative estimate because cuttings from the waste would be overlain by cuttings from the underlying liner and geologic material while the estimate assumes the material is well mixed.