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AIR AND RADON PATHWAY MODELING FOR THE H-AREA TANK FARM

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JUNE 2010

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

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LIST OF ACRONYMS

Ci	Curie
CFR	Code of Federal Regulations
DRF	Dose Release Factor
FMB	Fourmile Branch
GCL	Geosynthetic Clay Liner
GSA	General Separations Area
HDPE	High Density Polyethylene
HTF	H-Area Tank Farm
K_d	Partition Coefficient
K_s	Saturated Hydraulic Conductivity
MEI	Maximally Exposed Individual
NRC	Nuclear Regulatory Commission
PA	Performance Assessment
pCi	picoCurie
SRNL	Savannah River National Laboratory
SRR	Savannah River Remediation
SRNS	Savannah River Nuclear Solutions
SRS	Savannah River Site
USDOE	United States Department of Energy
UTR	Upper Three Runs

1.0 EXECUTIVE SUMMARY

An air and radon pathways analysis was conducted for the H-Area Tank Farm (HTF) to estimate the flux of volatile radionuclides and radon at the ground surface due to residual waste remaining in the tanks following closure. This analysis was used as the basis to estimate the dose to the maximally exposed individual (MEI) for the air pathway per Curie (Ci) of each radionuclide remaining in the combined HTF waste tanks.

For the air pathway analysis, several gaseous radionuclides were considered. These included carbon-14 (C-14), chlorine-36 (Cl-36), iodine-129 (I-129), selenium-79 (Se-79), antimony-125 (Sb-125), tin-126 (Sn-126), tritium (H-3), and technetium-99 (Tc-99). The dose to the MEI was estimated at the SRS Boundary during the 100 year institutional control period. For the 10,000 year post closure compliance period, the dose to the MEI was estimated at the 100 m compliance point. Additionally, the dose to the MEI was estimated at several seepage outcrops located various distances from the facility.

For the radon pathway analysis, five parent radionuclides and their progeny were analyzed. These parent radionuclides included uranium-238 (U-238), plutonium-238 (Pu-238), uranium-234 (U-234), thorium-230 (Th-230), and radium-226 (Ra-226). The peak flux of radon-222 due to each parent radionuclide was estimated for the simulation period of 10,100 years.

2.0 INTRODUCTION

The H-Area Tank Farm (HTF) is located within H-Area in the General Separations Area (GSA) of the Savannah River Site (SRS) as seen in Figure 1. The GSA contains the F and H-Area Separations Facilities, the S-Area Defense Waste Processing Facility, the Z-Area Saltstone Facility, and the E-Area Low-Level Waste Disposal Facilities. The HTF has approximate dimensions of 2,111 ft by 827 ft (643.4 m by 252.1 m) and comprises approximately 40 acres (162,190 m^2).

An air and radon pathway analysis is required to support the SRS HTF Performance Assessment (PA). Tank designs considered for this analysis include Type I and Type II waste tanks (SRR, 2010a and 2010b). The analysis will be used to evaluate the potential magnitude of gaseous release of radionuclides from the HTF over the 100-year institutional control period and 10,000-year post-closure compliance period. The results from the air pathway analysis will be used to estimate the dose to the maximally exposed individual (MEI) at the SRS boundary (during the institutional control period), several seepline locations (Fourmile Branch, Crouch Branch, McQueen Branch, and Upper Three Runs), and at the 100 m boundary (during the post closure compliance period). The sections that follow discuss the conceptual model for the air and radon pathways analysis, the numerical implementation of the conceptual model, and the dose calculations for the MEI based on the results of the modeling.

3.0 HTF AIR AND RADON PATHWAY ANALYSIS

The air and radon pathway analysis was divided into two time periods: 1) 100-year institutional control period and 2) 10,000 year post-closure compliance period. This results in a 10,100 year simulation period. During the operational period, wastes will be removed from the tanks and the tanks will be filled with grout. Therefore, the operational period was not considered in this analysis.

The method employed and the key aspects of the analysis performed are discussed in the sections that follow. For the radon pathway the peak flux at the ground surface of ^{222}Rn was calculated for five parent radionuclides for each time period. For the air pathway analysis, a list of eight radionuclides of interest was provided by Closure and Disposal Assessment. The dose to the MEI was also calculated for these radionuclides based on the gaseous flux of each at the land surface for each time period.

The method chosen is a hybrid approach where most parameters were set to their best estimate values (i.e., based on available site-specific measurements or engineering judgment), while other parameters were set to conservative/bounding values. The conceptual PORFLOW transport model used for the air and radon pathway analysis has imbedded within it biases that are intended to be conservative where possible. The conceptual model for both the air and radon pathway analysis is the same and the PORFLOW transport model used for both pathways utilizes essentially the same input files. Section 3.1 and its associated subsections discuss the conceptual model for the air and radon pathway analysis. Sections 3.2 and 3.3 discuss the details specific to each analysis.

This analysis considers Type I and Type II tanks and does not include any piping or ancillary equipment associated with the waste tanks. Some of the waste tanks are partially submerged below the water table aquifer. The simplified conceptual model used for this analysis did not try to account for partially submerged tanks. Schematics of the Type I and Type II tanks are given in Figure 2 and Figure 3. The minimum closure cap thickness over the tanks was assumed for conservatism. These assumptions should produce the maximum flux of gaseous radionuclides at the ground surface.

3.1 AIR AND RADON PATHWAY CONCEPTUAL MODEL

The approach taken focuses primarily on a baseline scenario where nominal settings for many of the input parameters have been conservatively chosen. The main analysis tool employed is the PORFLOW code which simulates the transport of radionuclide chains (i.e., parents and daughters) in porous media. The flux of radioactive gasses at the land surface above the HTF was evaluated for the closure configuration given by Phifer et al. (2008). Gaseous radionuclides within the waste zone diffuse outward into the air-filled pore space of the overlying materials. Ultimately, some of the radionuclides emanate at the land surface. As such, air is the medium through which they diffuse. It is assumed that fluctuations in atmospheric pressure at the land surface that could induce small pulses of air movement into and out of the shallow soil profile over relatively short periods of time will have a zero net effect when averaged over longer time periods. Thus, advective transport of radionuclides in

air-filled soil pores is not considered to be a significant process when compared to the rate of air diffusion.

The closure cap as described by Phifer et al. (2008) consists of a top soil layer, an upper backfill layer, an erosion barrier layer, middle backfill layer, lateral drainage layer, a high density polyethylene (HDPE) geomembrane, a geosynthetic clay liner (GCL), an upper foundation layer, and a lower foundation layer. The HDPE geomembrane and the GCL are excluded from this analysis. By excluding these materials, the baseline analysis will be more conservative as these materials would be expected to significantly reduce gaseous flux at the land surface. The HDPE geomembrane would have very low gaseous diffusion coefficients and the GCL would have very little air-filled porosity, since it would be at or near saturation. The top soil layer and the upper backfill layer are also excluded from the baseline analysis, since they are located above the erosion barrier and are therefore subject to erosion. For the purposes of this analysis, it is assumed that those components situated below the top of the erosion barrier remain intact for the duration of the simulation (10,100 years).

The Type I and Type II waste tanks include primary and secondary steel liners situated above a layer of base mat concrete as shown in Figure 2 and Figure 3. The top of each tank is covered with a concrete roof. For the each analysis, the model domain begins at the top surface of the lower primary liner and extends through the waste material to the top of the erosion barrier. The model excludes the upper primary steel liner. As with the exclusion of the geomembrane and GCL, this should make the model more conservative because including the steel liner would be expected to significantly reduce gaseous flux at the land surface.

For the Type I tank, the total thickness of the waste, tank, and cover materials (excluding the top soil, upper backfill, geomembrane, GCL, and steel liner) is 36.33 ft (11.07 m), with a contamination zone thickness of 1.0 ft (0.30 m). For the Type II tank, the total thickness of the waste, tank, and cover materials (excluding the top soil, upper backfill, geomembrane, GCL, and steel liner) is 41.75 ft (12.73 m), with a waste layer thickness of 1.0 ft (0.30 m). Table 1 lists the individual components of the tanks and closure cap included in the analysis. Materials are indicated with the associated thickness of each component, in inches, feet, and meters.

3.1.1 Air and Radon Pathway Diffusive Transport Model

A 1-dimensional PORFLOW based diffusive transport model was created for the HTF Type I and Type II tanks. PC-based PORFLOW Version 6.10.3 was used to conduct the simulations (ACRI, 2007). PORFLOW has been widely used at the SRS and in the USDOE complex to address major issues related to the groundwater and nuclear waste management.

The governing equation for mass transport of species *k* in the fluid phase is given by

$$\frac{\partial C_k}{\partial t} + \frac{\partial}{\partial x_i}\left(\frac{V_i}{R_f} C_k\right) = \frac{\partial}{\partial x_i}\left(\frac{D_{ij}}{R_f}\frac{\partial C_k}{\partial x_j}\right) + \gamma_k \qquad (1)$$

Where:

C_k	concentration of species *k*, Ci/m^3
V_i	fluid velocity in the ith direction, m/yr
D_{ij}	molecular diffusion coefficient for the species, m^2/yr
R_f	retardation factor
γ_k	net decay of species *k*, Ci/m^3 yr
i, j	direction index
t	time, yr
x	distance coordinate, m

This equation is solved within PORFLOW to evaluate transient radionuclide transport above the tank and to calculate gaseous radionuclide flux at the land surface over time. For this analysis, the advection term was disabled within PORFLOW and only the diffusive and net decay terms were evaluated.

The boundary conditions imposed on the entire model domain included:

- No-flux specified for all radionuclides along sides and bottom
  ($\partial C/\partial X = 0$ at x=0, x=1 and $\partial C/\partial Y = 0$ at y=0)
- Species concentration set to 0 at land surface (top of erosion barrier)
  ($C = 0$ at $y=y_{max}$)

These boundary conditions force all of the gaseous radionuclides to move upward from the waste disposal zone to the land surface. In reality, some lateral and downward diffusion occurs in the air-filled pores surrounding the waste zone; hence ignoring this lateral and downward movement has the effect of increasing the flux at the land surface. This should introduce some conservatism in the calculated results. Simulations were conducted in transient mode for diffusive transport in air, with results being obtained over 10,100 years which includes both the institutional control and post-closure compliance periods.

The initial condition imposed on the domain, except for the waste zone, included:

- Species concentration set to 0 at time = 0
  ($C=0$ for $0 \le x \le 1$ at t=0 and $C=0$ for $0 \le y \le y_{max}$ at t=0)

For the air pathway analysis, the initial conditions for the model assumed a 1 Ci inventory of each radionuclide uniformly spread over the waste zone. For the radon pathway analysis, an emanation factor of 0.25 was applied resulting in an initial inventory of 0.25 Ci for each

parent radionuclide uniformly spread over the waste zone. This is discussed in more detail in Section 3.3.

3.1.1.1 Type I and Type II Tank Grid Construction

The model grid for the tanks and overlying cover materials was constructed as a node mesh 3 nodes wide by 80 nodes high. This mesh creates a vertical stack of 78 model elements. Figure 4 and Figure 5 show a schematic of the PORFLOW model grid used for the Type I and Type II tanks. The grid extends upward to the top of the erosion barrier, since this is the minimum possible cover thickness that could exist during the simulation period. A set of consistent units was employed in the simulations for length, mass and time, these being meters, grams and years, respectively.

3.1.1.2 Material Zone Properties and Other Input Parameters

Material properties for both tank models were specified for 8 material zones. The properties used in each model were identical. Each material zone was assigned values of particle density, total porosity, average saturation, air-filled porosity, air density, and an effective air-diffusion coefficient for each source element or compound. An effective air-diffusion coefficient was used for each radionuclide and material layer. Therefore, tortuosity was assigned a unit value in each material zone. An air fluid density of 1.24E+03 g/m^3 at standard atmospheric conditions was used in the transport simulations (Bolz et al., 1973).

The waste layer was assumed to be 1 ft thick and confined to the bottom of the tank. The waste tanks are to be filled with a reducing grout from the site concrete specification (OPDEXE-X-P-0-BS) and it was assumed that the waste layer would have similar properties. The hydraulic and physical properties of this mix have been determined by Dixon and Phifer (2007). Based on the results of this testing, the waste layer and the reducing grout layer was assigned a particle density of 2.51 g/cm^3 and a total and air-filled porosity of 0.266. The concrete roof layer was assumed to be similar to the base mat surrogate tested by Dixon and Phifer (2007). This layer was assigned a particle density of 2.51 g/cm^3 and a total porosity of 0.168.

At the time of this analysis, saturation values for the waste layer, reducing grout, and concrete roof were unavailable. Although these layers will likely be at or near saturation, for this analysis a saturation value of 50 percent was conservatively assumed. Thus, the air-filled porosity was set equal to 50 percent of the total porosity for the waste layer, reducing grout, and concrete roof.

The foundation layer is divided into the upper and lower foundation layers (Phifer et al. 2007). It is anticipated that the lower foundation layer will need to promote drainage of infiltrating water away from and around the tanks, requiring a relatively high saturated conductivity such as 1.0E-03 cm/s. It is anticipated that the upper foundation layer will consist of soil with a moderately low permeability (i.e., ≤1.0E-06 cm/s) produced by blending typical SRS backfill with a small weight percent bentonite. The particle density of

the lower and upper foundation layers was assigned that of control compacted backfill from Phifer et al., 2006 (i.e., 2.63 g/cm^3).

The particle density of the middle backfill layer was also assigned that of control compacted backfill from Phifer et al., 2006 (i.e., 2.63 g/cm^3). The lateral drainage layer and erosion barrier layer were assigned a particle density typical of quartz (i.e., 2.65 g/cm^3 (Hillel, 1982)).

Phifer et al. (2007) evaluated infiltration through the closure cap materials over time as the closure cap degraded using the HELP model. Values for total porosity and volumetric moisture content for the closure cap materials and foundation layers were taken from this analysis. These values were used to calculate the average saturation and the air-filled porosity for the closure cap materials (Table 2). The maximum air-filled porosity for each material layer over the 10,000-year simulation was utilized, since this represented the greatest air filled porosity in which a gas could diffuse.

Table 2 provides the values of particle density, total porosity, average saturation, and air-filled porosity utilized for all the layers for the simulation period (Type I and Type II models).

3.1.2 Summary of Key Air and Radon Pathway Assumptions

The following are the key air and radon pathway analysis assumptions associated with the HTF Type I and Type II tank models:

- The waste layer may be represented as a 1 ft thick layer of material located at the bottom of the tank.
- The waste layer, reducing grout, and concrete roof are assumed to be 50 percent saturated.
- The waste layer is assumed to have properties similar to reducing grout.
- Exclusion of the top soil, upper backfill, HDPE geomembrane, geosynthetic clay liner, and primary steel liner of the waste tank make the model more conservative.
- The final closure cap (not including layers above the erosion barrier) as outlined in Table 1 is assumed to remain intact for the duration of the simulation (10,100 years).

3.1.2.1 Measures Implemented to Ensure Conservative Results

In this analysis, several conditions introduce conservatism into the calculations. These include:

- The use of boundary conditions that force all of the gaseous radionuclides to move upward from the waste disposal zone to the land surface. In reality, some of the gaseous radionuclides diffuse sideways and downward in the air-filled pores surrounding the waste zone, hence ignoring this has the effect of increasing the flux at the land surface.
- Not taking credit for the removal of radionuclides by pore water moving vertically downward through the model domain. This mechanism would likely remove some

dissolved radionuclides, and therefore its omission has the effect of increasing the estimate of instantaneous radionuclide flux at the land surface in simulations conducted as a part of this investigation.

- Exclusion of the HDPE geomembrane, the geosynthetic clay liner, and the primary steel liner of the waste tank. Inclusion of these materials in the model would significantly reduce the gaseous flux at the land surface due to their material properties (i.e., low air-filled porosity).
- Exclusion of the cover materials above the erosion barrier (i.e., top soil and upper backfill layers). Excluding these materials shortens the diffusion pathway and could increase the flux at the land surface.
- Assuming the waste layer, the reducing grout, and concrete roof are only 50 percent saturated. These materials are most likely to be at or near saturation. Therefore, this assumption produces what should be the maximum diffusive transport through these materials since gaseous flux is through the air-filled porosity.

3.2 HTF AIR PATHWAY MODEL

For the air pathway analysis, a list of radionuclides of interest was provided by Closure and Disposal Assessment. These radionuclides included carbon-14 (C-14), chlorine-36 (Cl-36), iodine-129 (I-129), selenium-79 (Se-79), antimony-125 (Sb-125), tin-126 (Sn-126), tritium (H-3), and technetium-99 (Tc-99). A summary of the radionuclides and compounds of interest is presented in Table 3.

3.2.1 Source Term Development

The source term for the simulations was assumed to be 1 Ci of each radionuclide which was distributed uniformly throughout the liquid filled porosity of the waste layer. The radionuclides were then allowed to partition between the pore fluid and the air filled porosity. Partition coefficients equivalent to apparent Henry's Law constants were estimated by Denham (2010). Denham (2010) estimated apparent Henry's Law coefficients for each radionuclide for several possible pore fluids for both submerged and non-submerged tanks. These coefficients are presented in Table 4. The minimum apparent Henry's Law coefficient for all possible conditions for a particular radionuclide was used to calculate the partition coefficient used in the air pathway modeling.

3.2.2 Implementation of Partition Coefficients in PORFLOW

PORFLOW has the capability of partitioning radionuclides between the solid and liquid phases through a distribution coefficient. However, PORFLOW does not directly have the capability of partitioning radionuclides between the liquid and gas phases through Henry's law. Therefore, in order to use PORFLOW to represent the transport of radionuclides through the gas phase while considering liquid-gas partitioning, Henry's Law constants must be converted to equivalent distribution coefficients. This section outlines the method used to make the conversion.

The minimum apparent Henry's Law constant (Section 3.2.1) for each radionuclide was converted into pseudo-partition coefficients for use in PORFLOW. The conventional

application of partitioning in PORFLOW involves the transfer of contaminant from solid to liquid phase via a linear and completely reversible reaction. This reaction is represented in the form of a distribution coefficient (K_d) which is used in the calculation of the retardation factor (Equation 1, R_f). K_d is defined as the concentration of contaminant in the solid phase relative to the concentration of contaminant in solution with typical units of ml/g (Freeze and Cherry, 1979). For the air pathway analysis, the partitioning of contaminants is from the liquid to the gas phase rather than from the solid to the liquid phase. Therefore, it was necessary to develop a relationship between the apparent Henry's Law constants and the K_d concept used in PORFLOW. The development of this relationship is presented in Appendix A and the resulting partition coefficients used in the PORFLOW air pathway analysis are given in Table 5.

To correctly implement the partition coefficients in PORFLOW, it was necessary to redefine the material properties for the waste layer. The typical simulation in PORFLOW involves a solid, liquid, and a gas, with partitioning of contaminants between the solid and liquid phase (via K_d) and advective and diffusive transport occurring through the liquid phase. Inputs include the bulk density of the solid phase and the porosity of the gas-liquid phase. For gaseous diffusion problems, the particle density is that of the solid material, the porosity is the void space occupied by the gas (air-filled porosity), and the fluid density is the density of air. If the gaseous contaminants are assumed to be totally in the gas phase and the waste is assumed to be dry, then the air filled porosity equals the total porosity and there is no partitioning. For this analysis, the waste was assumed to be 50 percent saturated with the radionuclides of interest partitioned between the gas and liquid phase. In order to implement the K_d approach to partitioning, the liquid takes on the role usually played by the solid in a typical groundwater transport problem. Likewise, the gas takes on the role usually played by the liquid. The solid phase can be thought of as having the role typically played by gas where it is not involved in the transport process. In this implementation, the total porosity is the content of the solid and gas phases. The air-filled porosity, which is the porosity used in the transport analysis, is determined by multiplying the total porosity by the gas saturation.

Air is the fluid through which the radioactive gasses diffuse to the ground surface. As such, the fluid density input to PORFLOW was the density of air. For each simulation, a 1 Ci inventory of each radionuclide was placed in the waste layer and partitioned between the liquid and gas phases according to the partition coefficients presented in Table 5. Once in the gas phase, the radionuclides diffused to the land surface based on the diffusion coefficients presented in Table 6 and the transport equation provided by equation 1.

3.2.3 Effective Air Diffusion Coefficients

The effective air diffusion coefficient of each radionuclide or compound within each material zone was determined. Nielson et al. (1984) established a relationship between moisture saturation and the radon effective air-diffusion coefficient for various pore sizes of earthen materials. Using this method, a radon effective air-diffusion coefficient was determined for each material type based upon the average moisture saturation for the material. Subsequently, using Graham's Law, the effective air-diffusion coefficient of each

radionuclide or compound evaluated was determined for each material type based on the radon effective air-diffusion coefficient using the following relationship:

$$D = D' \sqrt{\frac{MWT'}{MWT}} \tag{2}$$

Where:

D = the effective diffusion coefficient of the radionuclide of interest (m^2/yr) within the material zone of interest

D' = the effective diffusion coefficient of Rn-222 (m^2/yr) within the material zone of interest

MWT' = the molecular weight of the reference radionuclide (Rn-222)

MWT = the molecular weight of the element or compound of interest

A summary of the radon effective air-diffusion coefficients and the calculated effective air-diffusion coefficients for each radionuclide/compound by material zone are presented in Table 6.

3.2.4 Air Pathway Model Results

3.2.4.1 Air Pathway Flux to Ground Surface

Model simulations were conducted to evaluate the peak flux of each radionuclide emanating from the top of the model domain. A unit inventory of 1 Ci was assigned to the HTF Type I and Type II waste tank waste zones for each radionuclide considered in the analysis. The results are presented for each radionuclide and tank in Figure 6 and Figure 7. The peak fluxes emanating at the land surface are presented for each time period for the HTF Type I tank in Table 7. The peak fluxes emanating at the land surface are presented for each time period for the HTF Type II tank in Table 8.

3.2.5 Air Pathway Dose Calculations

An evaluation was conducted to assess the potential dose to a maximally exposed individual (MEI) located at the SRS boundary, several seepline locations (Fourmile Branch, Crouch Branch, McQueen Branch, and Upper Three Runs), and at the 100 m location (Farfan, 2010). During the 100 year institutional control period, the SRS boundary is the compliance point for the dose calculations. Therefore, the peak flux during this time period was used to assess the dose to the MEI. For the remainder of the time period, the 100 m boundary is the compliance point. Thus, the peak flux between 100 and 10,100 years was used for these calculations. In addition, dose calculations were performed for the seepline locations using the peak flux between 100 and 10,100 years. Dose-release factors (DRF) were calculated for each radionuclide potentially released from the HTF using CAP88, the EPA model for National Emissions Standards for Hazardous Air Pollutants (NESHAP). DRFs represent the dose to the receptor exposed to 1 Ci of the specified radionuclide potentially released to the

atmosphere. For the receptor located at the SRS boundary and at the seepline locations, the distance from the HTF is sufficient for an assumption of a point source. However, the DRFs for the 100 m receptor requires evaluation of an area source because of the close proximity of the HTF to the 100 m receptor. For radionuclides not contained within the CAP88 library (Se-79, Cl-36) atmospheric transport was estimated by assigning surrogates with similar radiological properties (Farfan, 2010). Doses for these radionuclides were estimated by applying their dosimetric properties to the surrogate's relative air concentrations estimated by the model. See Farfan (2010) for details on the estimation of all DRFs.

The dose to the MEI due to waste remaining in the Type I tank was calculated at various distances from the HTF including the SRS boundary and the 100-m compliance point. The results are presented in Table 9 through Table 16. The dose to the MEI due to waste remaining in the Type II tank was also calculated at various distances from the HTF including the SRS boundary and the 100-m compliance point. The results are presented in Table 17 through Table 24.

3.3 HTF RADON ANALYSIS (TYPE I AND TYPE II TANKS)

This section describes the investigation conducted to evaluate the potential magnitude of radon release from the HTF during the 10,100-year simulation period. This investigation addresses only Rn-222. It is assumed that the short half-life of Rn-220 (55.6 seconds) renders it unable to escape the HTF waste tanks and migrate to the land surface via air-diffusion before it is transformed by radioactive decay.

The permissible radon flux for USDOE facilities is addressed in DOE M 435.1-1. Section IV.P.(1).(c) states the radon flux limitations associated with the development of a disposal facility and maintenance of a performance assessment and the closure of the disposal facility. This requirement is that the release of radon shall be less than an average yearly flux of 20 $pCi/m^2/sec$ at the surface of the disposal facility. The requirements state that this standard was adopted from the uranium mill tailings requirements in 40 CFR Part 192 and 10 CFR Part 40. 10 CFR Part 40 discusses both Rn-222 from uranium and Rn-220 from thorium, therefore the performance objective refers only to radon, and the correct species must be analyzed depending on the characteristics of the waste stream. The instantaneous Rn-222 flux at the land surface was evaluated for the simulation period and the maximum flux was then compared to the USDOE performance objective.

The potential parent radionuclides that can contribute to the creation of Rn-222 are illustrated in Figure 8. The diagram indicates the specific decay chains that lead to the formation of Rn-222, as well as the half-lives for each radionuclide. The extremely long half-life of U-238 (4.468E+9 years) cause the other radionuclides higher up on the chain of parents to be of little concern with regard to their potential to contribute significantly to the Rn-222 flux at the land surface over the period of interest. In Figure 8, the parent radionuclides that were individually evaluated are indicated with the gray shaded area (i.e., beginning with Pu-238 and U-238). Rn-222 generated within the waste zone is in the gaseous phase and diffuses outward from this zone into the air-filled soil pores surrounding the HTF, eventually resulting in some of the radon emanating at the land surface. As such, air is the fluid through which Rn-222 diffuses, although some Rn-222 may dissolve in residual pore water.

The parent radionuclides are assumed to exist in the solid phase and therefore do not migrate upward through the air-filled pore space, although they could be leached and transported downward from the waste zone by pore water movement. This potential downward migration of the parent radionuclides was not considered in the radon analysis.

Decay chains evaluated were U-238→Th-234→Pa-234m→U-234→Th-230→ Ra-226→Rn-222 and Pu-238 →U-234→Th-230→Ra-226→Rn-222. Each parent in these chains, except Th-234 and Pa-234m, were simulated separately as the starting point of the decay chain. Th-234 and Pa-234m have extremely short half-lives compared to the other parent radionuclides in these chains. Only a fraction of the Rn-222 generated by the decay of each parent is available for migration away from its source and into open pore space. Since the Rn-222 parent radionuclides exist as oxides or in other crystalline forms, only a fraction of Rn-222 generated by decay of Ra-226 has sufficient energy to migrate away from its original location into adjacent pore space before further decay occurs (3.82 day half-life for Rn-222).

The emanation coefficient is generally defined as the fraction of the total amount of Rn-222 produced by radium decay that escapes from soil particles and enters the pore space of the medium. This is the fraction of the Rn-222 that is available for transport. In the case of the HTF, the parent radionuclides are not embedded in soil but are contained within waste entombed in concrete/grout. Literature values for the Rn-222 emanation factor for these conditions are not available. Studies have shown the emanation factor to vary between 0.02 and 0.7 for various soil types depending primarily on moisture content. Generally, higher emanation factors are associated with higher moisture contents.

The RESidual RADioactivity Computer Software (RESRAD) is a model used to estimate radiation dose and risk from residual radioactive materials. This USDOE and Nuclear Regulatory Commission (NRC) approved code, assumes an emanation factor of 0.25 for Rn-222 which is representative of a silty loam soil with a low moisture content. For the HTF radon pathway analysis, the RESRAD default emanation factor of 0.25 was chosen recognizing that literature values for wastes similar to the HTF are not available. The use of 0.25 should be conservative since the waste is assumed to be partially saturated and emanation factors reported in the literature for drier soils are much lower (Yu, et al. 2001). To account for the emanation factor in the model, an effective source term of 0.25 Ci of parent radionuclide was utilized for each Ci disposed within the facility.

Some radon dissolves in pore water but since diffusion proceeds more slowly in that fluid, air diffusion was the only transport process by which Rn-222 was allowed to reach the land surface of the HTF. This assertion is substantiated in Yu, et al. 2001. In that report the effective diffusion coefficient for soil is reported to range from the radon open air diffusion coefficient of 1.0E-05 m^2/sec to that of fully saturated soil, 1.0E-10 m^2/sec. This 5-order of magnitude difference is consistent with the comparison of water diffusion coefficients to air diffusion coefficients of other common molecular compounds and reported in many references. Thus, the larger volume of water-filled pore space compared to air-filled pore

space (maximum of 1 order of magnitude difference) is inconsequential, in terms of the ability of water-dissolved radon to diffuse through water-filled pores as compared to the ability of the same compounds to diffuse as gas in the vapor-filled pore spaces.

The molecular diffusion coefficient of Rn-222 in open air is 347 m^2/yr (Nielson et al., 1984). Nielson et al. (1984) established a relationship between moisture saturation and the radon effective air-diffusion coefficient for various pore sizes of earthen materials. This method was used to calculate a radon effective air-diffusion coefficient for each material type based upon the average moisture saturation for the material. Tortuosity was assigned a unit value for each material type. A summary of the radon air-diffusion coefficients by material type are presented in Table 6.

3.3.1 Radon Pathway Model Results

Model simulations were conducted to evaluate the peak instantaneous Rn-222 flux at the land surface for the simulation period of 10,100 years for Type I and Type II tanks. The simulation was divided into two time periods: 1) 100 year institutional control period and 2) 10,000 year post-closure compliance period. Model results were output in Ci/m^2/yr per Ci of inventory, consistent with the set of units employed in the model. The results for the Type I and Type II tanks are presented in Figure 9 and Figure 10. The units are converted to pCi/m^2/sec per Ci/m^2, which are the units used to define the regulatory flux limit in DOE M 435.1-1. The peak fluxes represent the peak Rn-222 flux per square meter at the land surface for the two time periods and are given in Table 25 for Type I tanks and in Table 26 for Type II tanks.

4.0 SUMMARY

An analysis was conducted to evaluate the potential magnitude of gaseous release of radionuclides from the HTF over the 100-year institutional control period and 10,000-year post-closure compliance period. Specifically, an air and radon pathways analysis has been conducted to estimate the flux of volatile radionuclides and radon at the ground surface due to waste stored in Type I and Type II tanks. This analysis was used as the basis to estimate the dose to the maximally exposed individual (MEI) for the air pathway per Curie (Ci) of each radionuclide remaining in HTF.

For the air pathway analysis, several gaseous radionuclides were considered. These included carbon-14 (C-14), chlorine-36 (Cl-36), iodine-129 (I-129), selenium-79 (Se-79), antimony-125 (Sb-125), tin-126 (Sn-126), tritium (H-3), and technetium-99 (Tc-99). For Type I and Type II tanks, the dose to the MEI was estimated at the SRS Boundary during the 100 year institutional control period. For the 10,000 year post closure compliance period, the dose to the MEI was estimated at the 100 m compliance point. Dose to the MEI was also calculated at several seepage outcrop locations at various distances from the facility.

For the radon pathway analysis, five parent radionuclides and their progeny were analyzed. These parent radionuclides included uranium-238 (U-238), plutonium-238 (Pu-238), uranium-234 (U-234), thorium-230 (Th-230), and radium-226 (Ra-226). The peak flux of radon-222 due to each parent radionuclide was estimated for the simulation period of 10,100 years for both Type I and Type II tanks.

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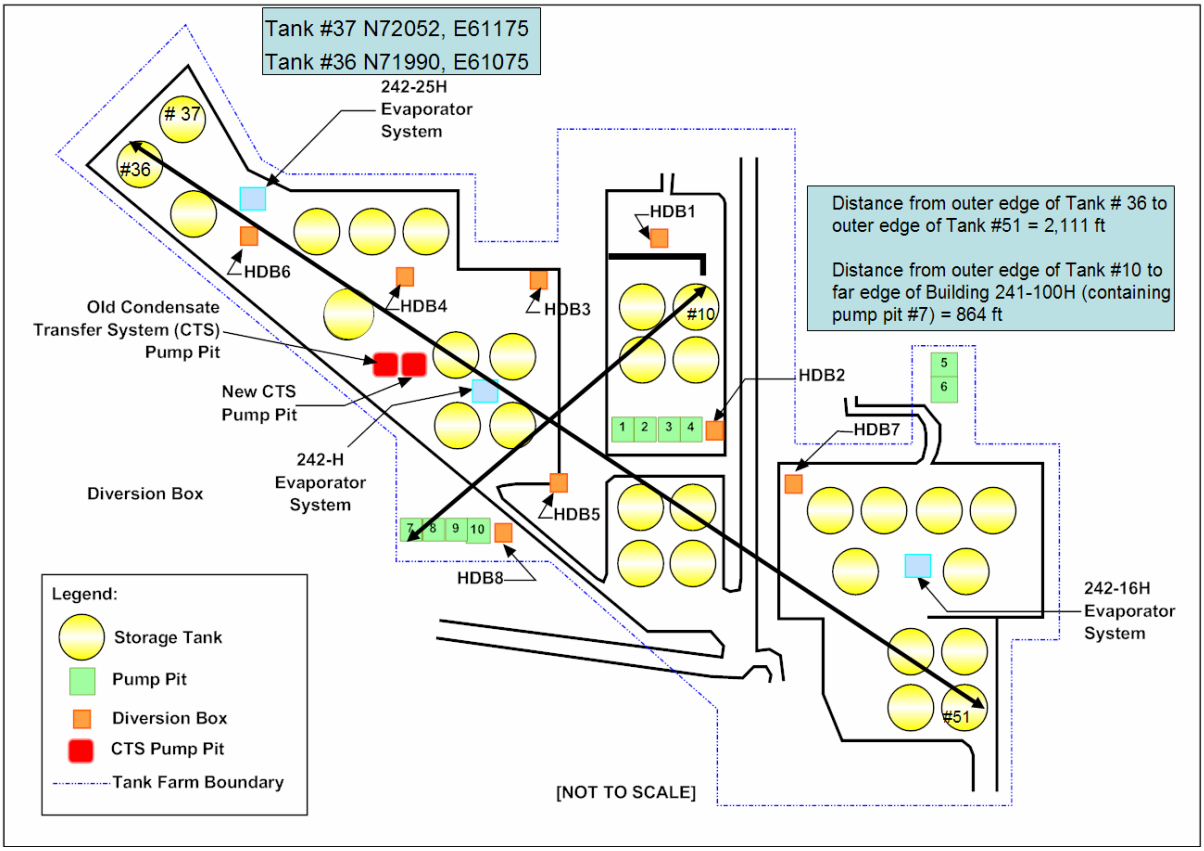
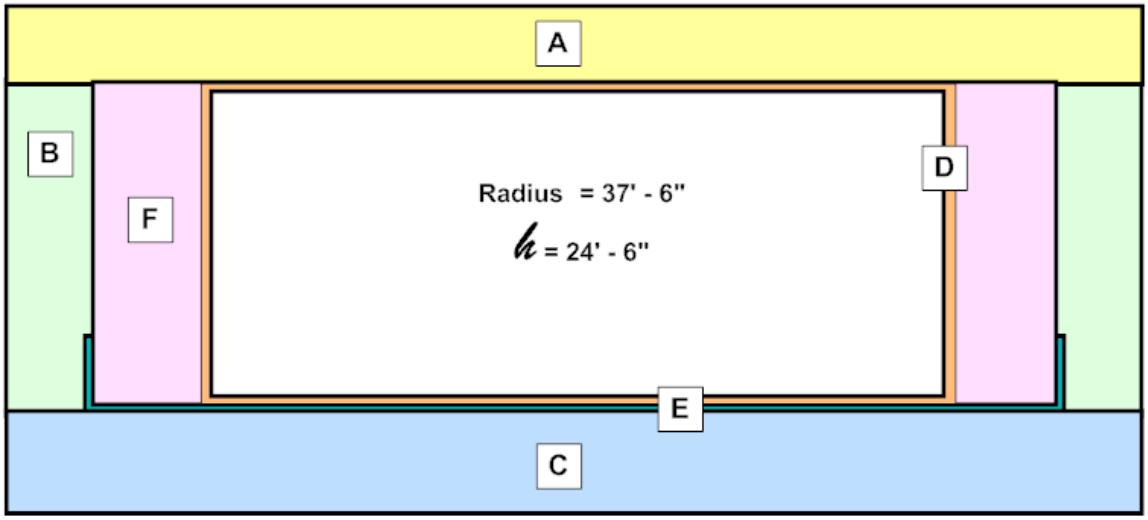


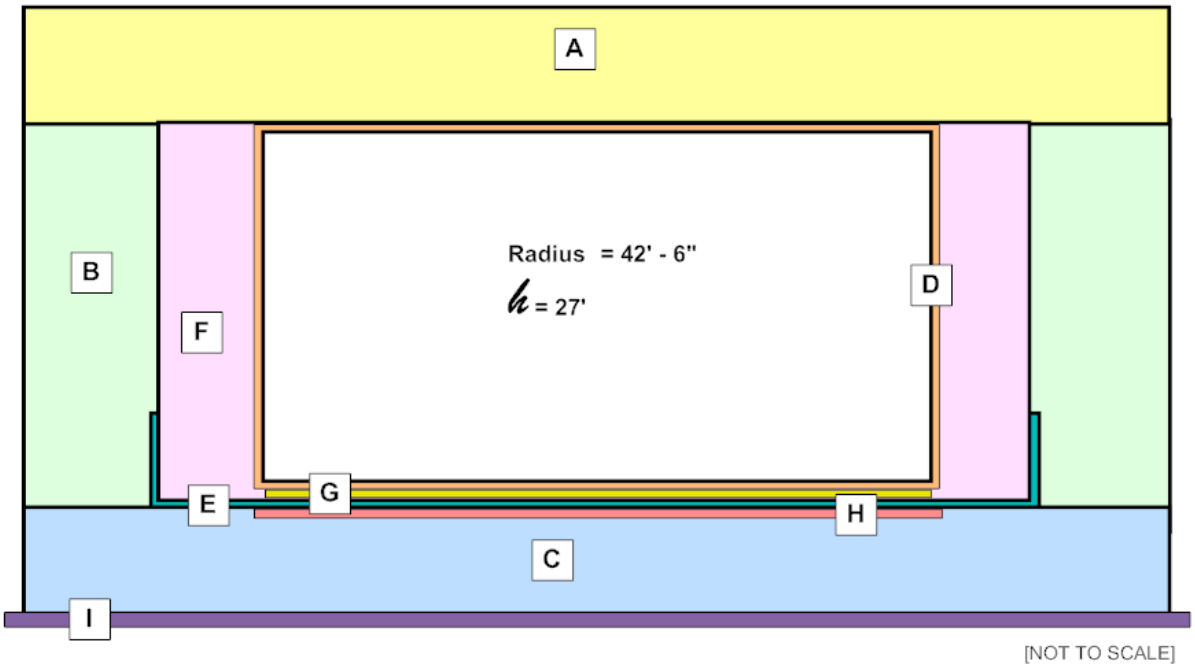
Figure 1. H-Area Tank Farm Conceptual Layout



[NOT TO SCALE]

LABEL	THICKNESS	MATERIAL
A Concrete Roof	22"	Concrete
B Concrete Wall	22"	Concrete
C Concrete Basemat	30"	Concrete
D Primary Liner	0.5"	Carbon Steel
E Secondary Liner	5' high and 0.5" thick	Carbon Steel
F Grouted Annulus	30"	Tank Fill Grout

Figure 2. Type I Waste Tank Modeling Dimensions (SRR, 2010a).



LABEL	THICKNESS	MATERIAL
A Concrete Roof	45"	Concrete
B Concrete Wall	33"	Concrete
C Concrete Basemat	42"	Concrete
D Primary Liner	0.5"	Carbon Steel
E Secondary Liner	5' high and 0.5" thick	Carbon Steel
F Grouted Annulus	30.625"	Tank Fill Grout
G Primary Liner Sand Bed	1"	Sand
H Secondary Liner Sand Bed	1"	Sand
I Concrete Working Slab	6"	Concrete

Figure 3. Type II Waste Tank Modeling Dimensions (SRR, 2010b)

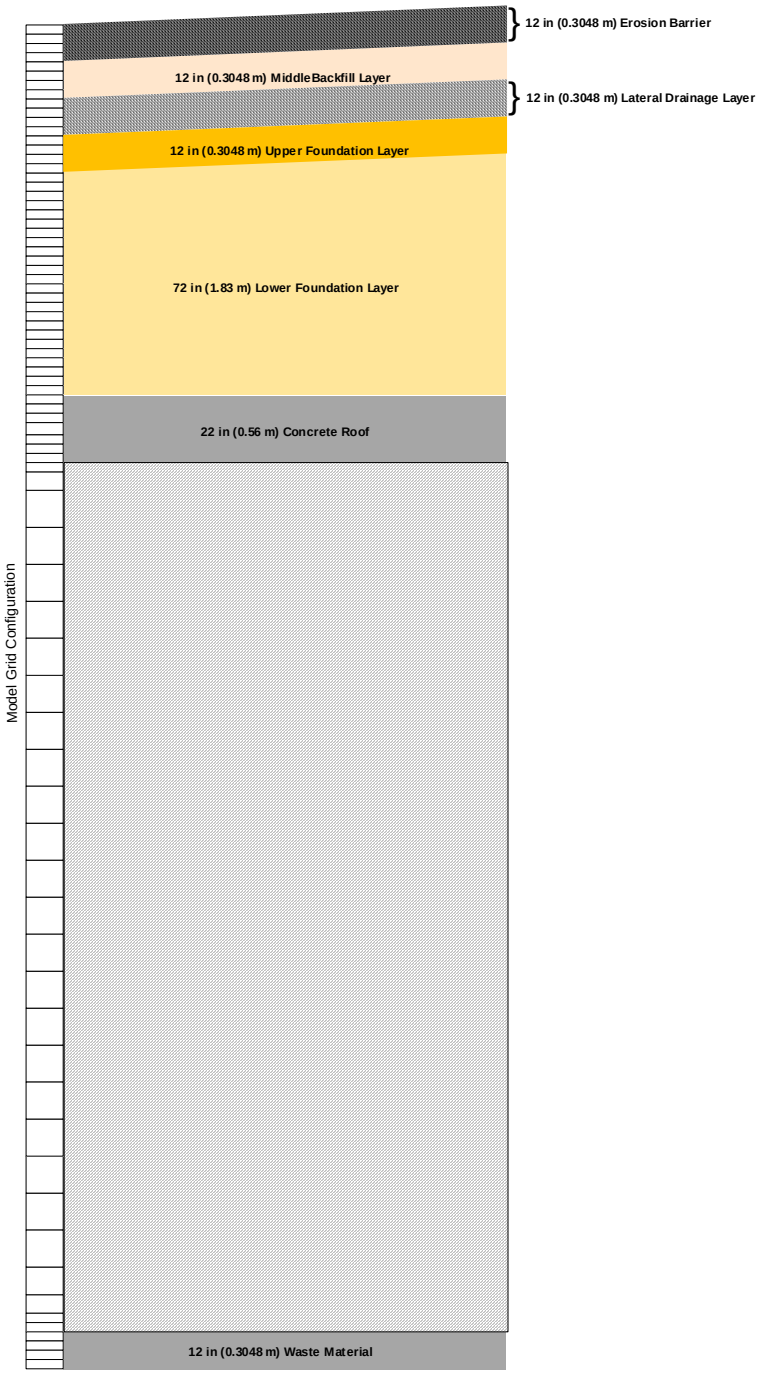


Figure 4. Schematic of PORFLOW Model Grid for the Type I Tank Air and Radon Pathway Analysis

Note: For conservatism the model grid does not include the following layers: topsoil, upper backfill, HPDE geomembrane, and GCL.

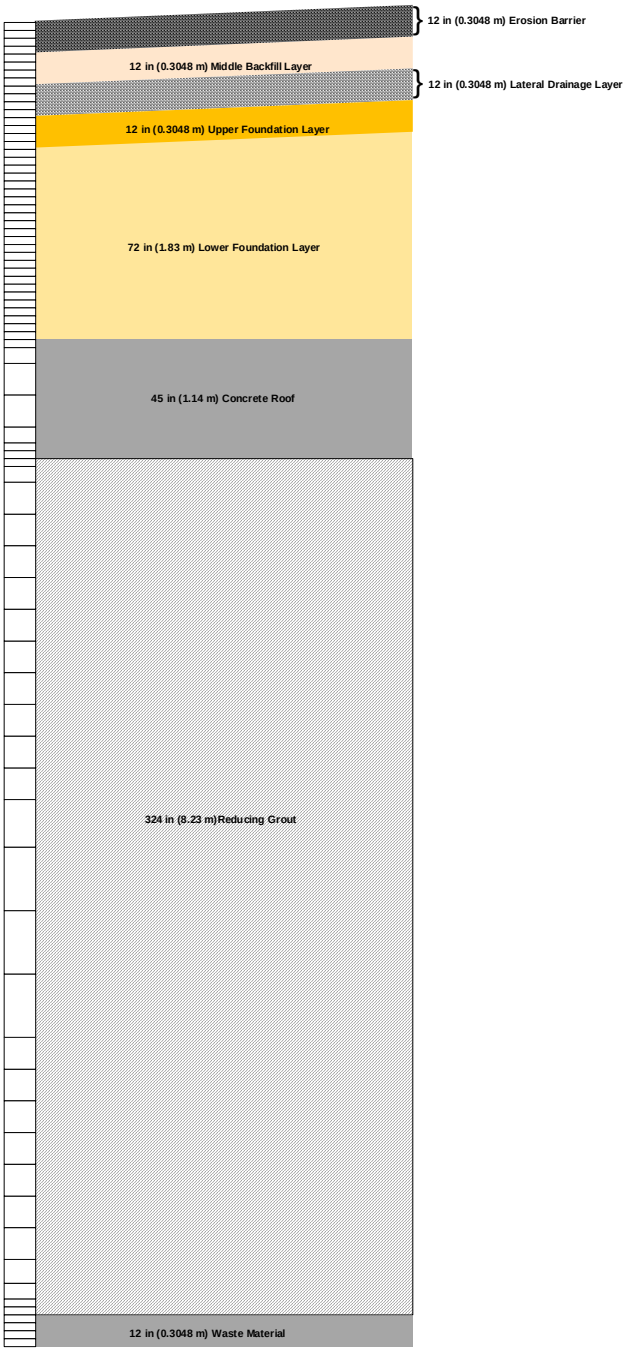


Figure 5. Schematic of PORFLOW Model Grid for the Type II Tank Air and Radon Pathway Analysis

Note: For conservatism the model grid does not include the following layers: topsoil, upper backfill, HPDE geomembrane, and GCL.

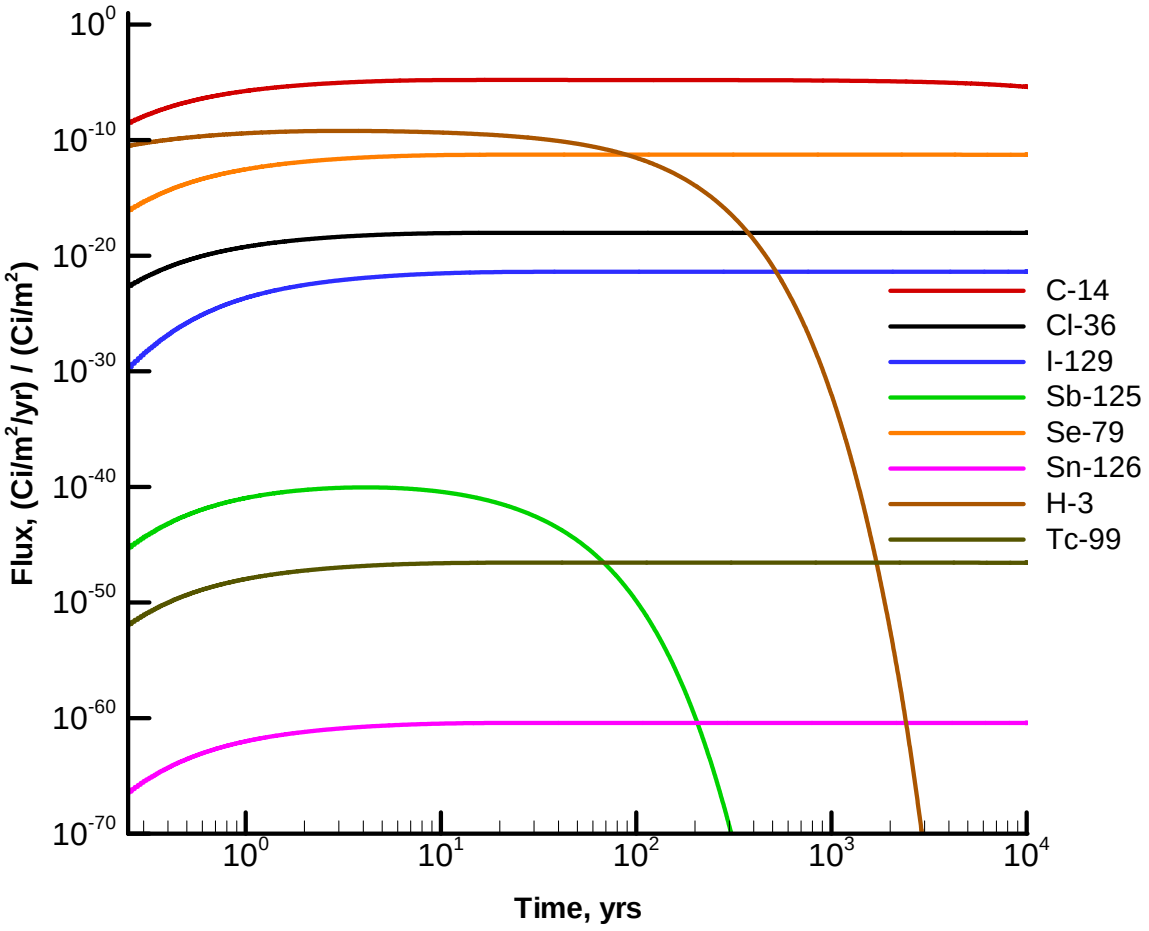


Figure 6. Flux at Land Surface for C-14, Cl-36, I-129, Sb-125, Se-79, Sn-126, H-3, and Tc-99 per Ci of Radionuclide Remaining in the HTF Type I Waste Tank.

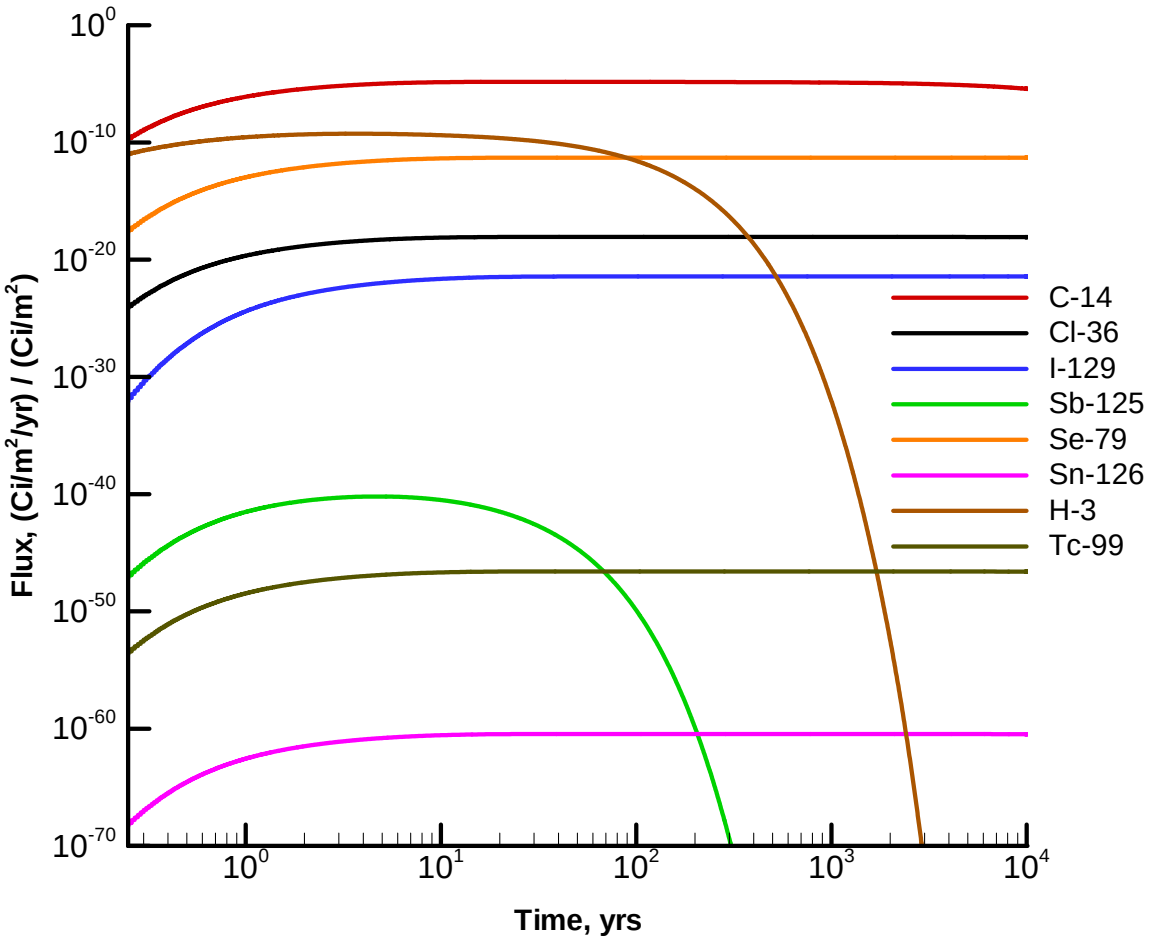


Figure 7. Flux at Land Surface for C-14, Cl-36, I-129, Sb-125, Se-79, Sn-126, H-3, and Tc-99 per Ci of Radionuclide Remaining in the HTF Type II Waste Tank.

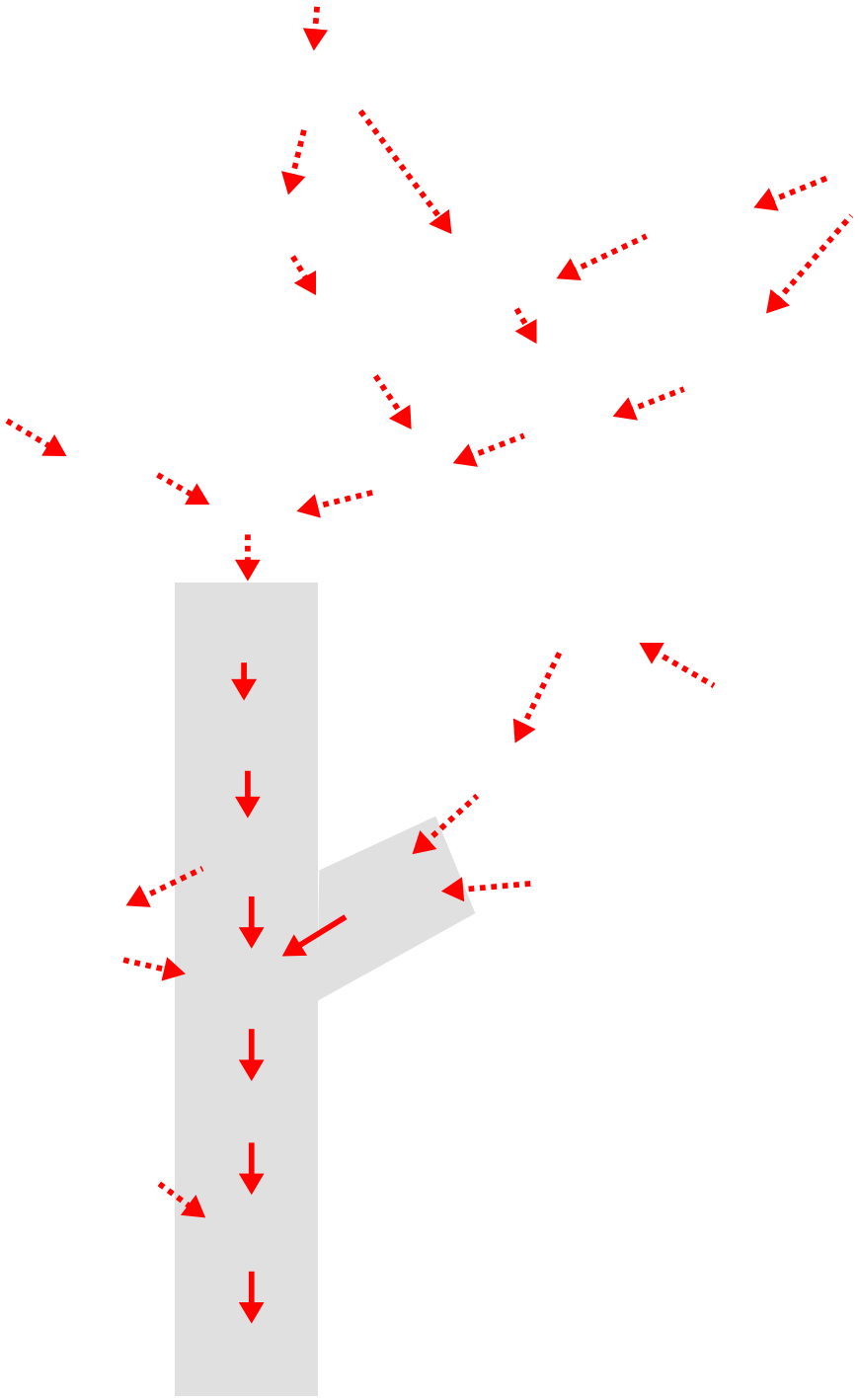


Figure 8. Radioactive Decay Chains Leading to Rn-222

242m

24 **Am**

141 yrs 242

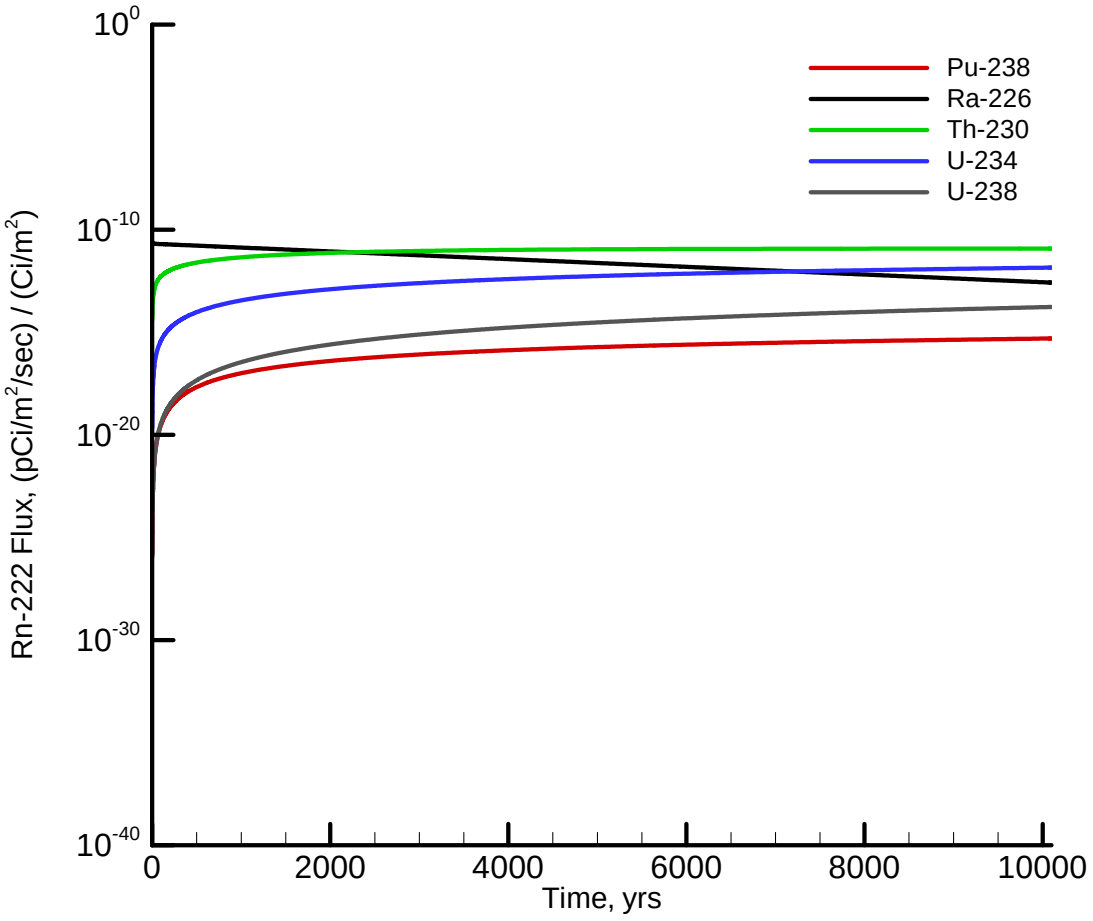


Figure 9. Rn-222 Flux at Land Surface Resulting from Unit Source Term for Type I Tank.

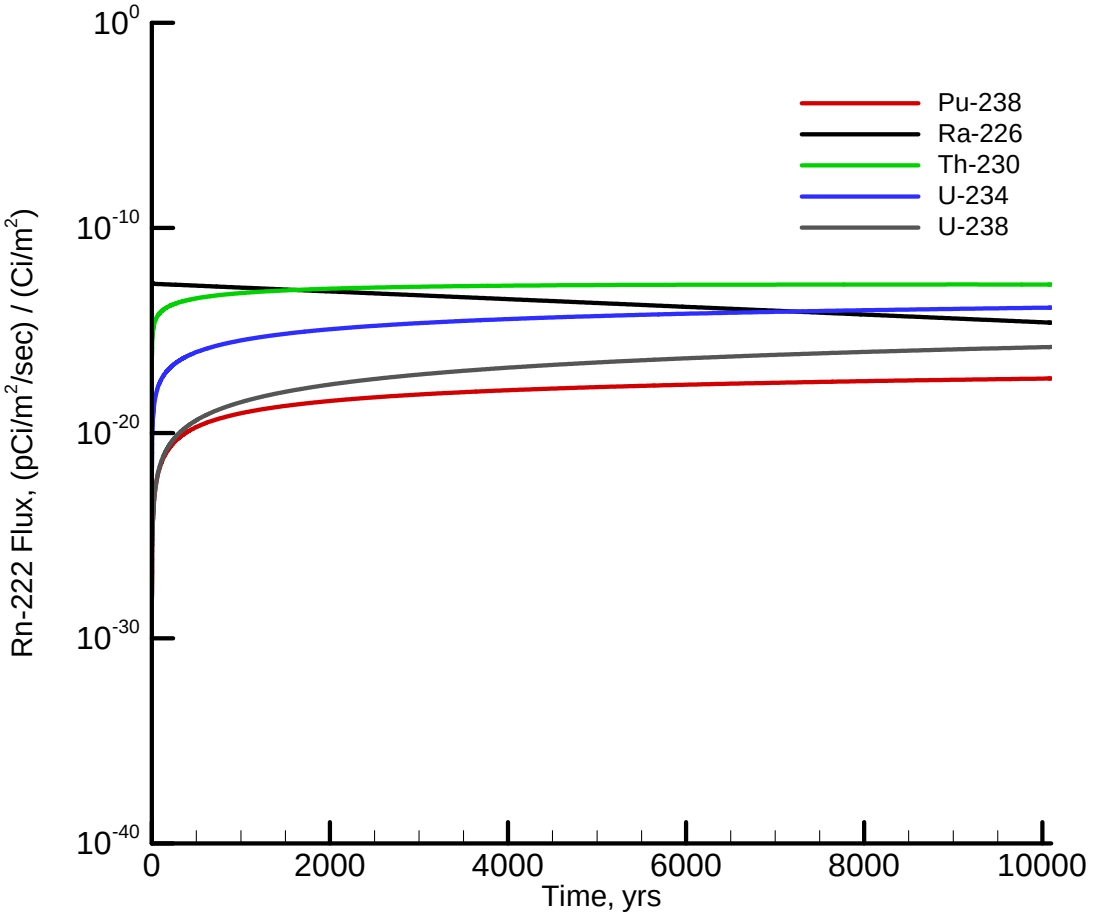


Figure 10. Rn-222 Flux at Land Surface Resulting from Unit Source Term for Type II Tank.

Table 1. Vertical Layer Sequence and Associated Thickness for HTF Type I and Type II Waste Tanks and Cover Material

Layer	Thickness (inches)	Thickness (ft)	Thickness (m)
Erosion barrier	12	1.00	0.30
Middle backfill layer	12	1.00	0.30
Lateral drainage layer	12	1.00	0.30
Upper Foundation layer	12	1.00	0.30
Lower Foundation layer	72 (minimum)	6.00	1.83
Type I Tank Concrete Roof	22	1.83	0.56
Type I Tank Reducing Grout	282	23.5	7.16
Type I Tank Waste Layer	12	1.00	0.30
Type II Tank Concrete Roof	45	3.75	1.14
Type II Tank Reducing Grout	324	27.00	8.23
Type II Tank Waste Layer	12	1.00	0.30

SOURCE: Adapted from SRR 2010a and b.

Table 2. Particle Density, Total Porosity, Average Saturation, and Air-Filled Porosity by Layer for the HTF Type I and Type II Tanks.

Layer	Particle Density (g/cm^3)	Total Porosity (fraction)	Average Saturation (fraction)	Air-filled Porosity (fraction)
Erosion barrier layer [1, 3]	2.65	0.150	0.84	0.024
Middle backfill layer [2, 3]	2.63	0.371	0.82	0.067
Lateral drainage layer [1, 3]	2.65	0.417	0.61	0.162
Upper Foundation layer [2, 3]	2.63	0.35	0.72	0.098
Foundation Layer [2, 3]	2.63	0.457	0.28	0.328
Concrete Roof [4, 7]	2.51	0.168	0.50	0.084
Reducing Grout [5, 7]	2.51	0.266	0.50	0.133
Waste Layer [6, 7]	2.51	0.266	0.50	0.133

1 Particle density assumed to be that typical of quartz (Hillel 1982)
2 Values for particle density taken as that of control compacted backfill from Phifer et al., 2006.
3 Total porosity, average saturation, and air-filled porosity values derived from Phifer et al. (2007).
4 The concrete roof is assumed to be similar to the base mat surrogate as given by Dixon and Phifer, 2007. Particle density and porosity taken from Dixon and Phifer, 2007.
5 Particle density and porosity of reducing grout taken from Dixon and Phifer, 2007.
6 The waste is assumed to have the properties of reducing grout.
7 The concrete roof, reducing grout, and waste layer are conservatively assumed to be at 50 percent saturation.

Table 3. Radionuclides and Compounds of Interest for air and radon pathway analysis.

Radionuclide	Half-life[1] (yrs)	Approximate Atomic Wt.[2]	Molecular form in gaseous state	Molecular Wt.[2]
$^{14}CO_2$	5.700E+03	14	CO_2	45.99
2(^{36}Cl)	3.010E+05	36	Cl_2	72
2(^{129}I)	1.570E+07	129	I_2	258
^{125}Sb	2.759E+00	125	Sb	125
^{79}Se	2.950E+05	79	Se	79
^{126}Sn	2.300E+05	126	Sn	126
$^{3}H_2$	12.32E+00	3	H_2	6
^{99}Tc	2.111E+05	99	Tc	99
^{222}Rn	1.047E-02	222	Rn	222

[1]2005 Nuclear Wallet Cards (Tuli, 2005)
[2]Pocket Ref (Glover, 2000)

Table 4. Apparent Henry's Law coefficients for various pore solutions for submerged and non-submerged tanks (from Denham, 2010)

	Non-Submerged Tank			**Submerged Tank**				
	Reducing Region II	**Oxidizing Region II**	**Oxidizing Region III**	**Condition A[1]**	**Condition B[2]**	**Condition C[3]**	**Condition D[4]**	**Minimum[5]**
Isotope	**H**	**H**	**H**	**H**	**H**	**H**	**H**	**H**
C-14	7.966E+04	8.138E+04	2.807E+00	3.790E-02	3.586E+01	1.569E+02	1.617E+02	3.790E-02
Cl-36	2.961E+17	3.211E+17	3.580E+14	5.160E+11	4.147E+15	1.406E+16	1.439E+16	5.160E+11
I-129	3.632E+20	1.068E+33	1.346E+29	6.329E+14	5.089E+18	1.725E+19	6.959E+29	6.329E+14
Sb-125	1.785E+35	8.726E+70	4.883E+38	6.868E+32	4.294E+44	3.509E+34	9.862E+44	6.868E+32
Se-79	1.789E+06	2.505E+101	3.798E+87	2.822E+25	2.356E+44	8.525E+04	1.594E+96	8.525E+04
Sn-126	1.262E+61	1.806E+71	6.086E+61	9.597E+53	5.115E+69	4.728E+60	4.787E+98	9.597E+53
H-3	2.139E+03	2.139E+03	2.138E+03	2.138E+03	2.138E+03	2.138E+03	2.138E+03	2.138E+03
Tc-99	4.831E+67	5.741E+51	7.168E+45	1.490E+40	9.625E+47	2.108E+68	1.159E+49	1.490E+40

[1]Condition A = groundwater
[2]Condition B = groundwater equilibrated with calcite
[3]Condition C = mixture 0.9 groundwater + 0.1 Reduced Region II
[4]Condition D = mixture 0.9 groundwater + 0.1 Oxidized Region II
[5]The minimum apparent Henry's law coefficient is for all pore solutions (submerged and non-submerged)

Table 5. Apparent Henry's Law Constant and Partition Coefficient (K_d) for Each Radionuclide (Tank I and II).

Radionuclide	H[1] (mole/atm-kg)	K_d (ml/g)
Tritium	2.138E+03	5.141E+04
C-14	3.790E-02	9.111E-01
Cl-36	5.160E+11	1.241E+13
I-129	6.329E+14	1.522E+16
Tc-99	1.490E+40	3.582E+41
Sn-121m, 126	9.597E+53	2.307E+55
Sb-125, 126	6.868E+32	1.651E+34
Se-79	8.525E+04	2.050E+06

[1]Used the minimum apparent Henry's Law coefficient for all conditions to calculate K_d.

Table 6. Effective Air-Diffusion Coefficients for Each Radionuclide/Compound, by Material for HTF Type I and Type II Tanks and Closure Cap.

Radionuclide	Tank Waste, Reducing Grout, and Concrete Roof Layer (m^2/yr)	Lower Foundation Layer (m^2/yr)	Upper Foundation Layer (m^2/yr)	Lateral Drainage Layer (m^2/yr)	Middle Backfill Layer (m^2/yr)	Erosion Barrier Layer (m^2/yr)
^{222}Rn[1]	6.181E+00	1.210E+01	2.618E+00	4.194E+00	1.455E+00	1.301E+00
^{14}C	1.358E+01	2.658E+01	5.752E+00	9.213E+00	3.196E+00	2.858E+00
^{36}Cl	1.085E+01	2.124E+01	4.597E+00	7.364E+00	2.555E+00	2.284E+00
^{129}I	5.734E+00	1.122E+01	2.429E+00	3.890E+00	1.350E+00	1.207E+00
^{125}Sb	8.237E+00	1.612E+01	3.489E+00	5.589E+00	1.939E+00	1.734E+00
^{79}Se	1.036E+01	2.028E+01	4.389E+00	7.030E+00	2.439E+00	2.181E+00
^{126}Sn	8.205E+00	1.606E+01	3.475E+00	5.567E+00	1.931E+00	1.727E+00
$^{3}H_2$	3.760E+01	7.359E+01	1.593E+01	2.551E+01	8.850E+00	7.912E+00
^{99}Tc	9.256E+00	1.812E+01	3.921E+00	6.280E+00	2.179E+00	1.948E+00

[1]The effective diffusion coefficient for ^{222}Rn was used to determine the effective air diffusion coefficient of each radionuclide/compound based on Graham's law.

Table 7. Summary of the Peak Fluxes for Each Radionuclide for HTF Type I Tank

		Peak Flux (Ci/yr/Ci)	
Radionuclide	**Activity in Waste (Ci)**	**0 - 100 Yrs**	**100 – 10,100 Yrs**
^{14}C	1.0	1.62E-05	1.60E-05
^{36}Cl	1.0	9.53E-19	9.53E-19
^{129}I	1.0	4.11E-22	4.11E-22
^{125}Sb	1.0	9.10E-41	1.31E-50
^{79}Se	1.0	5.51E-12	5.51E-12
^{126}Sn	1.0	3.88E-61	3.88E-61
$^{3}H_2$	1.0	6.33E-10	2.93E-12
^{99}Tc	1.0	2.82E-47	2.82E-47

Table 8. Summary of the Peak Fluxes for Each Radionuclide for HTF Type II Tank

		Peak Flux (Ci/yr/Ci)	
Radionuclide	**Activity in Waste (Ci)**	**0 - 100 Yrs**	**100 – 10,100 Yrs**
^{14}C	1.0	1.47E-05	1.45E-05
^{36}Cl	1.0	8.65E-19	8.64E-19
^{129}I	1.0	3.73E-22	3.73E-22
^{125}Sb	1.0	6.35E-41	1.19E-50
^{79}Se	1.0	5.00E-12	5.00E-12
^{126}Sn	1.0	3.52E-61	3.52E-61
$^{3}H_2$	1.0	5.53E-10	2.66E-12
^{99}Tc	1.0	2.56E-47	2.55E-47

Table 9. SRS Boundary Dose Release Factors Dose to the MEI for the 0-100 Year Time Period per Ci of Radionuclide Remaining in HTF Type I Waste Tanks

Radionuclide	Peak Flux (Ci/yr/Ci)[1]	SRS Boundary Dose Release Factor (mrem/Ci)[2]	Dose to MEI at SRS Boundary (mrem/yr/Ci)[3]
^{14}C	1.62E-05	1.0E-04	1.6E-09
^{36}Cl	9.53E-19	3.4E-04	3.2E-22
^{129}I	4.11E-22	2.1E-06	8.6E-28
^{125}Sb	9.10E-41	4.4E-02	4.0E-42
^{79}Se	5.51E-12	6.3E-03	3.5E-14
^{126}Sn	3.88E-61	5.7E-04	2.2E-64
$^{3}H_2$	6.33E-10	2.1E-06	1.3E-15
^{99}Tc	2.82E-47	1.7E-03	4.8E-50

[1]Peak flux from 0 to 100 yrs.
[2]From (Farfan, 2010).
[3]Dose to MEI at SRS Boundary = Peak Flux × Dose Release Factor.

Table 10. 100-meter Dose Release Factors and Dose to the MEI for the 100 – 10,100 Year Time Period per Ci of Radionuclide Remaining in HTF Type I Waste Tanks

Radionuclide	Peak Flux (Ci/yr/Ci)[1]	SRS 100 m Dose Release Factor (mrem/Ci)[2]	Dose to MEI at 100 m Boundary (mrem/yr/Ci)[3]
^{14}C	1.60E-05	8.1E-03	1.3E-07
^{36}Cl	9.53E-19	1.7E-02	1.6E-20
^{129}I	4.11E-22	1.2E+01	4.9E-21
^{125}Sb	1.31E-50	2.3E-01	3.0E-51
^{79}Se	5.51E-12	2.3E-02	1.3E-13
^{126}Sn	3.88E-61	1.1E+01	4.3E-60
$^{3}H_2$	2.93E-12	1.7E-04	5.0E-16
^{99}Tc	2.82E-47	6.4E-02	1.8E-48

[1]Peak flux from 100 to 10,100 yrs.
[2]From (Farfan, 2010).
[3] Dose to MEI at SRS Boundary = Peak Flux × Dose Release Factor.

Table 11. Fourmile Branch Seepline (1170-meter) Dose Release Factors and Dose to the MEI for the 100 – 10,100 Year Time Period per Ci of Radionuclide Remaining in HTF Type I Waste Tanks

Radionuclide	Peak Flux (Ci/yr/Ci)[1]	FMB 1170 m Dose Release Factor (mrem/Ci)[2]	Dose to MEI at 1170 m (mrem/yr/Ci)[3]
^{14}C	1.60E-05	3.9E-03	6.2E-08
^{36}Cl	9.53E-19	9.5E-03	9.1E-21
^{129}I	4.11E-22	3.6E+00	1.5E-21
^{125}Sb	1.31E-50	1.5E-01	2.0E-51
^{79}Se	5.51E-12	1.4E-02	7.7E-14
^{126}Sn	3.88E-61	6.6E+00	2.6E-60
$^{3}H_2$	2.93E-12	8.0E-05	2.3E-16
^{99}Tc	2.82E-47	4.0E-02	1.1E-48

[1]Peak flux from 100 to 10,100 yrs.
[2]From (Farfan, 2010).
[3]Dose to MEI at SRS Boundary = Peak Flux × Dose Release Factor.

Table 12. Fourmile Branch Seepline (1230-meter) Dose Release Factors and Dose to the MEI for the 100 – 10,100 Year Time Period per Ci of Radionuclide Remaining in HTF Type I Waste Tanks

Radionuclide	Peak Flux (Ci/yr/Ci)[1]	FMB 1230 m Dose Release Factor (mrem/Ci)[2]	Dose to MEI at 1230 m (mrem/yr/Ci)[3]
^{14}C	1.60E-05	3.6E-03	5.8E-08
^{36}Cl	9.53E-19	8.8E-03	8.4E-21
^{129}I	4.11E-22	3.3E+00	1.4E-21
^{125}Sb	1.31E-50	1.4E-01	1.8E-51
^{79}Se	5.51E-12	1.3E-02	7.2E-14
^{126}Sn	3.88E-61	6.1E+00	2.4E-60
$^{3}H_2$	2.93E-12	7.4E-05	2.2E-16
^{99}Tc	2.82E-47	3.7E-02	1.0E-48

[1]Peak flux from 100 to 10,100 yrs.
[2]From (Farfan, 2010).
[3]Dose to MEI at SRS Boundary = Peak Flux × Dose Release Factor.

Table 13. Fourmile Branch Seepline (1700-meter) Dose Release Factors and Dose to the MEI for the 100 – 10,100 Year Time Period per Ci of Radionuclide Remaining in HTF Type I Waste Tanks

Radionuclide	Peak Flux (Ci/yr/Ci)[1]	FMB 1700 m Dose Release Factor (mrem/Ci)[2]	Dose to MEI at 1700 m (mrem/yr/Ci)[3]
^{14}C	1.60E-05	2.1E-03	3.4E-08
^{36}Cl	9.53E-19	5.3E-03	5.0E-21
^{129}I	4.11E-22	1.8E+00	7.4E-22
^{125}Sb	1.31E-50	8.3E-02	1.1E-51
^{79}Se	5.51E-12	7.8E-03	4.3E-14
^{126}Sn	3.88E-61	3.8E+00	1.5E-60
$^{3}H_2$	2.93E-12	4.3E-05	1.3E-16
^{99}Tc	2.82E-47	2.3E-02	6.5E-49

[1]Peak flux from 100 to 10,100 yrs.
[2]From (Farfan, 2010).
[3]Dose to MEI at SRS Boundary = Peak Flux × Dose Release Factor.

Table 14. McQueen Branch Seepline (1010-meter) Dose Release Factors and Dose to the MEI for the 100 – 10,100 Year Time Period per Ci of Radionuclide Remaining in HTF Type I Waste Tanks

Radionuclide	Peak Flux[1] (Ci/yr/Ci)	McQueen Branch 1010 m Dose Release Factor[2] (mrem/Ci)	Dose to MEI at 1010 m[3] (mrem/yr/Ci)
^{14}C	1.60E-05	5.0E-03	8.0E-08
^{36}Cl	9.53E-19	1.2E-02	1.1E-20
^{129}I	4.11E-22	4.8E+00	2.0E-21
^{125}Sb	1.31E-50	1.8E-01	2.4E-51
^{79}Se	5.51E-12	1.7E-02	9.4E-14
^{126}Sn	3.88E-61	8.3E+00	3.2E-60
$^{3}H_2$	2.93E-12	1.0E-04	2.9E-16
^{99}Tc	2.82E-47	5.0E-02	1.4E-48

[1]Peak flux from 100 to 10,100 yrs.
[2]From (Farfan, 2010).
[3]Dose to MEI at SRS Boundary = Peak Flux × Dose Release Factor.

Table 15. Crouch Branch Seepline (1480-meter) Dose Release Factors and Dose to the MEI for the 100 – 10,100 Year Time Period per Ci of Radionuclide Remaining in HTF Type I Waste Tanks

Radionuclide	Peak Flux (Ci/yr/Ci)[1]	Crouch Branch 1480 m Dose Release Factor (mrem/Ci)[2]	Dose to MEI at 1480 m (mrem/yr/Ci)[3]
^{14}C	1.60E-05	2.6E-03	4.2E-08
^{36}Cl	9.53E-19	6.6E-03	6.3E-21
^{129}I	4.11E-22	2.3E+00	9.4E-22
^{125}Sb	1.31E-50	1.0E-01	1.3E-51
^{79}Se	5.51E-12	9.7E-03	5.3E-14
^{126}Sn	3.88E-61	4.7E+00	1.8E-60
$^{3}H_2$	2.93E-12	5.4E-05	1.6E-16
^{99}Tc	2.82E-47	2.8E-02	7.9E-49

[1]Peak flux from 100 to 10,100 yrs.
[2]From (Farfan, 2010).
[3]Dose to MEI at SRS Boundary = Peak Flux × Dose Release Factor.

Table 16. Upper Three Runs (2360-meter) Dose Release Factors and Dose to the MEI for the 100 – 10,100 Year Time Period per Ci of Radionuclide Remaining in HTF Type I Waste Tanks

Radionuclide	Peak Flux (Ci/yr/Ci)[1]	UTR 2360 m Dose Release Factor (mrem/Ci)[2]	Dose to MEI at 2360 m (mrem/yr/Ci)[3]
^{14}C	1.60E-05	1.2E-03	1.9E-08
^{36}Cl	9.53E-19	3.2E-03	3.0E-21
^{129}I	4.11E-22	9.3E-01	3.8E-22
^{125}Sb	1.31E-50	5.2E-02	6.8E-52
^{79}Se	5.51E-12	4.8E-03	2.6E-14
^{126}Sn	3.88E-61	2.4E+00	9.3E-61
$^{3}H_2$	2.93E-12	2.5E-05	7.3E-17
^{99}Tc	2.82E-47	1.4E-02	3.9E-49

[1]Peak flux from 100 to 10,100 yrs.
[2]From (Farfan, 2010).
[3]Dose to MEI at SRS Boundary = Peak Flux × Dose Release Factor.

Table 17. SRS Boundary Dose Release Factors Dose to the MEI for the 0-100 Year Time Period per Ci of Radionuclide Remaining in HTF Type II Waste Tanks

Radionuclide	Peak Flux (Ci/yr/Ci)[1]	SRS Boundary Dose Release Factor (mrem/Ci)[2]	Dose to MEI at SRS Boundary (mrem/yr/Ci)[3]
^{14}C	1.47E-05	1.0E-04	1.5E-09
^{36}Cl	8.65E-19	3.4E-04	2.9E-22
^{129}I	3.73E-22	4.4E-02	1.6E-23
^{125}Sb	6.35E-41	6.3E-03	4.0E-43
^{79}Se	5.00E-12	5.7E-04	2.8E-15
^{126}Sn	3.52E-61	2.9E-01	1.0E-61
$^{3}H_2$	5.53E-10	2.1E-06	1.2E-15
^{99}Tc	2.56E-47	1.7E-03	4.3E-50

[1]Peak flux from 0 to 100 yrs.
[2]From (Farfan, 2010).
[3]Dose to MEI at SRS Boundary = Peak Flux × Dose Release Factor.

Table 18. 100-meter Dose Release Factors and Dose to the MEI for the 100 – 10,100 Year Time Period per Ci of Radionuclide Remaining in HTF Type II Waste Tanks

Radionuclide	Peak Flux (Ci/yr/Ci)[1]	SRS 100 m Dose Release Factor (mrem/Ci)[2]	Dose to MEI at 100 m Boundary (mrem/yr/Ci)[3]
^{14}C	1.45E-05	8.1E-03	1.2E-07
^{36}Cl	8.64E-19	1.7E-02	1.5E-20
^{129}I	3.73E-22	1.2E+01	4.5E-21
^{125}Sb	1.19E-50	2.3E-01	2.7E-51
^{79}Se	5.00E-12	2.3E-02	1.1E-13
^{126}Sn	3.52E-61	1.1E+01	3.9E-60
$^{3}H_2$	2.66E-12	1.7E-04	4.5E-16
^{99}Tc	2.55E-47	6.4E-02	1.6E-48

[1]Peak flux from 100 to 10,100 yrs.
[2]From (Farfan, 2010).
[3] Dose to MEI at SRS Boundary = Peak Flux × Dose Release Factor.

Table 19. Fourmile Branch Seepline (1170-meter) Dose Release Factors and Dose to the MEI for the 100 – 10,100 Year Time Period per Ci of Radionuclide Remaining in HTF Type II Waste Tanks

Radionuclide	Peak Flux (Ci/yr/Ci)[1]	FMB 1170 m Dose Release Factor (mrem/Ci)[2]	Dose to MEI at 1170 m (mrem/yr/Ci)[3]
^{14}C	1.45E-05	3.9E-03	5.7E-08
^{36}Cl	8.64E-19	9.5E-03	8.2E-21
^{129}I	3.73E-22	3.6E+00	1.3E-21
^{125}Sb	1.19E-50	1.5E-01	1.8E-51
^{79}Se	5.00E-12	1.4E-02	7.0E-14
^{126}Sn	3.52E-61	6.6E+00	2.3E-60
$^{3}H_2$	2.66E-12	8.0E-05	2.1E-16
^{99}Tc	2.55E-47	4.0E-02	1.0E-48

[1]Peak flux from 100 to 10,100 yrs.
[2]From (Farfan, 2010).
[3]Dose to MEI at SRS Boundary = Peak Flux × Dose Release Factor.

Table 20. Fourmile Branch Seepline (1230-meter) Dose Release Factors and Dose to the MEI for the 100 – 10,100 Year Time Period per Ci of Radionuclide Remaining in HTF Type II Waste Tanks

Radionuclide	Peak Flux (Ci/yr/Ci)[1]	FMB 1230 m Dose Release Factor (mrem/Ci)[2]	Dose to MEI at 1230 m (mrem/yr/Ci)[3]
^{14}C	1.45E-05	3.6E-03	5.2E-08
^{36}Cl	8.64E-19	8.8E-03	7.6E-21
^{129}I	3.73E-22	3.3E+00	1.2E-21
^{125}Sb	1.19E-50	1.4E-01	1.7E-51
^{79}Se	5.00E-12	1.3E-02	6.5E-14
^{126}Sn	3.52E-61	6.1E+00	2.1E-60
$^{3}H_2$	2.66E-12	7.4E-05	2.0E-16
^{99}Tc	2.55E-47	3.7E-02	9.4E-49

[1]Peak flux from 100 to 10,100 yrs.
[2]From (Farfan, 2010).
[3]Dose to MEI at SRS Boundary = Peak Flux × Dose Release Factor.

Table 21. Fourmile Branch Seepline (1700-meter) Dose Release Factors and Dose to the MEI for the 100 – 10,100 Year Time Period per Ci of Radionuclide Remaining in HTF Type II Waste Tanks

Radionuclide	Peak Flux (Ci/yr/Ci)[1]	SRS 1700 m Dose Release Factor (mrem/Ci)[2]	Dose to MEI at 1700 m Boundary (mrem/yr/Ci)[3]
^{14}C	1.45E-05	2.1E-03	3.0E-08
^{36}Cl	8.64E-19	5.3E-03	4.6E-21
^{129}I	3.73E-22	1.8E+00	6.7E-22
^{125}Sb	1.19E-50	8.3E-02	9.8E-52
^{79}Se	5.00E-12	7.8E-03	3.9E-14
^{126}Sn	3.52E-61	3.8E+00	1.3E-60
$^{3}H_2$	2.66E-12	4.3E-05	1.1E-16
^{99}Tc	2.55E-47	2.3E-02	5.9E-49

[1]Peak flux from 100 to 10,100 yrs.
[2]From (Farfan, 2010).
[3]Dose to MEI at SRS Boundary = Peak Flux × Dose Release Factor.

Table 22. McQueen Branch Seepline (1010-meter) Dose Release Factors and Dose to the MEI for the 100 – 10,100 Year Time Period per Ci of Radionuclide Remaining in HTF Type II Waste Tanks

Radionuclide	Peak Flux (Ci/yr/Ci)[1]	McQueen Branch 1010 m Dose Release Factor (mrem/Ci)[2]	Dose to MEI at 1010 m (mrem/yr/Ci)[3]
^{14}C	1.45E-05	5.0E-03	7.3E-08
^{36}Cl	8.64E-19	1.2E-02	1.0E-20
^{129}I	3.73E-22	4.8E+00	1.8E-21
^{125}Sb	1.19E-50	1.8E-01	2.1E-51
^{79}Se	5.00E-12	1.7E-02	8.5E-14
^{126}Sn	3.52E-61	8.3E+00	2.9E-60
$^{3}H_2$	2.66E-12	1.0E-04	2.7E-16
^{99}Tc	2.55E-47	5.0E-02	1.3E-48

[1]Peak flux from 100 to 10,100 yrs.
[2]From (Farfan, 2010).
[3]Dose to MEI at SRS Boundary = Peak Flux × Dose Release Factor.

Table 23. Crouch Branch Seepline (1480-meter) Dose Release Factors and Dose to the MEI for the 100 – 10,100 Year Time Period per Ci of Radionuclide Remaining in HTF Type II Waste Tanks

Radionuclide	Peak Flux (Ci/yr/Ci)[1]	Crouch Branch 1480 m Dose Release Factor (mrem/Ci)[2]	Dose to MEI at 1480 m (mrem/yr/Ci)[3]
^{14}C	1.45E-05	2.6E-03	3.8E-08
^{36}Cl	8.64E-19	6.6E-03	5.7E-21
^{129}I	3.73E-22	2.3E+00	8.6E-22
^{125}Sb	1.19E-50	1.0E-01	1.2E-51
^{79}Se	5.00E-12	9.7E-03	4.8E-14
^{126}Sn	3.52E-61	4.7E+00	1.7E-60
$^{3}H_2$	2.66E-12	5.4E-05	1.4E-16
^{99}Tc	2.55E-47	2.8E-02	7.2E-49

[1]Peak flux from 100 to 10,100 yrs.
[2]From (Farfan, 2010).
[3]Dose to MEI at SRS Boundary = Peak Flux × Dose Release Factor.

Table 24. Upper Three Runs (2360-meter) Dose Release Factors and Dose to the MEI for the 100 – 10,100 Year Time Period per Ci of Radionuclide Remaining in HTF Type II Waste Tanks

Radionuclide	Peak Flux (Ci/yr/Ci)[1]	UTR 2360 m Dose Release Factor (mrem/Ci)[2]	Dose to MEI at 2360 m (mrem/yr/Ci)[3]
^{14}C	1.45E-05	1.2E-03	1.7E-08
^{36}Cl	8.64E-19	3.2E-03	2.8E-21
^{129}I	3.73E-22	9.3E-01	3.5E-22
^{125}Sb	1.19E-50	5.2E-02	6.2E-52
^{79}Se	5.00E-12	4.8E-03	2.4E-14
^{126}Sn	3.52E-61	2.4E+00	8.4E-61
$^{3}H_2$	2.66E-12	2.5E-05	6.7E-17
^{99}Tc	2.55E-47	1.4E-02	3.6E-49

[1]Peak flux from 100 to 10,100 yrs.
[2]From (Farfan, 2010).
[3]Dose to MEI at SRS Boundary = Peak Flux × Dose Release Factor.

Table 25. Simulated Peak Instantaneous Rn-222 Flux over 10,100-Years at the Land Surface from HTF Type I Tanks

	Peak Instantaneous Rn-222 flux at Land Surface ($pCi/m^2/sec$) / (Ci/m^2)	
Parent Source ($1\ Ci/m^2$)	0-100 years	100-10,100 years
Pu-238	3.23E-20	5.01E-16
U-238	3.89E-20	1.72E-14
U-234	4.10E-16	1.42E-12
Th-230	5.49E-13	1.19E-11
Ra-226	2.08E-11	2.08E-11

Table 26. Simulated Peak Instantaneous Rn-222 Flux over 10,100-Years at the Land Surface from HTF Type II Tanks

	Peak Instantaneous Rn-222 flux at Land Surface ($pCi/m^2/sec$) / (Ci/m^2)	
Parent Source ($1\ Ci/m^2$)	**0-100 years**	**100-10,100 years**
Pu-238	2.95E-22	4.59E-18
U-238	3.56E-22	1.58E-16
U-234	3.76E-18	1.30E-14
Th-230	8.09E-15	1.75E-13
Ra-226	1.91E-13	1.91E-13

Distribution

J. J. Mayer, 773-42A
H. H. Burns, 773-41A
M. A. Phifer, 773-42A
K. H. Rosenberger, 705-1C
T. C. Robinson, 705-1C
E&CPT Files 773-43A, Rm. 213

APPENDIX A. DEVELOPMENT OF LIQUID TO GAS PARTITION COEFFICIENTS FOR THE AIR PATHWAY ANALYSIS

The ideal gas law is used to develop a relationship between partial pressure and the concentration of contaminant in the gas phase.

$$PV = nRT \tag{1}$$

where:
P = pressure, atm
V = volume, m^3
n = number moles
R = Universal Gas Constant, 8.3143 J/mol-K
T = temperature, K

Rearranging equation 1 yields the volumetric concentration of contaminant in the gas phase.

$$\frac{n}{V} = \frac{P}{RT} \tag{2}$$

$$c_g^v = \frac{n}{V} \tag{3}$$

where:
c_g^v = volumetric concentration of contaminant in the gas phase, mol/ml .

Making the assumption of a single ideal gas occupying the representative volume, the pressure term, P, can be thought of as the partial pressure

$$c_g^v = \frac{X_p}{RT} \tag{4}$$

where:
X_p = partial pressure of the gas, atm

Rearranging and solving for the partial pressure yields:

$$X_p = c_g^v RT \tag{5}$$

Henry's law may be written as:

$$[X_a] = H\ X_p \tag{6}$$

where:

X_a = aqueous concentration of contaminant on a mass basis, mol/g
X_p = partial pressure of the gas, atm
H = Henry's law constant, mol/atm-g

The partition coefficient, K_d, may be defined as:

$$K_d = \frac{c_f^m}{c_g^v} \tag{7}$$

where
c_f^m = aqueous concentration of contaminant on a mass basis, mol/g

By analogy,

$$c_f^m = X_a \tag{8}$$

Substituting equation 8 into equation 6 yields:

$$c_f^m = H\ X_p \tag{9}$$

Substituting equation 5 into equation 9 yields:

$$c_f^m = H\ c_g^v RT \tag{10}$$

Rearranging and grouping terms in equation 10 yields:

$$c_f^m = (H\ RT) c_g^v \tag{11}$$

By analogy with equation 7,

$$K_d = (H\ RT) \tag{12}$$

Example Calculation:

For C-14, from Table 5, H = 2.138 x 10^3 mol/atm-kg

$$K_d = (H\ RT)$$

$$K_d \frac{ml}{g} = \left(2.138\,x10^3 \frac{mol}{atm-kg}\right)\left(8.3143 \frac{J}{mol-K}\right)(293\,K)\left(\frac{atm-m^2}{101325\,N}\right)\left(\frac{N-m}{J}\right)\left(10^6 \frac{ml}{m^3}\right)\left(\frac{kg}{1000\,g}\right)$$

$$K_d = 2.138\,x10^3 \frac{(8.3143)(293)(10^6)}{(101325)(10^3)} \frac{ml}{g}$$

$$K_d = 5.141\,x10^4 \frac{ml}{g}$$

APPENDIX B. DESIGN CHECK

Re: HTF Air and Radon Pathway Design Check
Tad Whiteside to: Kenneth Dixon 04/06/2010 08:29 AM

Ken,

The report looks good.

All issues have been adequately addressed.

Tad

Tad Whiteside, PhD
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803-725-8267
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Kenneth Dixon Tad, Thanks. I have made the corrections. I pla... 04/05/2010 04:41:27 PM

From: Kenneth Dixon/SRNL/Srs
To: Tad Whiteside/SRNL/Srs@Srs
Date: 04/05/2010 04:41 PM
Subject: Re: HTF Air and Radon Pathway Design Check

Tad,

Thanks. I have made the corrections. I placed a revised version of the report back in the folder titled "SRNL-STI-2010-00135_DRAFT_D.doc. I also revised the spreadsheet as noted. Please confirm that I made the appropriate corrections. If so, please confirm by e-mail that the issues have been adequately addressed.

Thanks,
Ken

Tad Whiteside Design Check: There were only a three items: 04/05/2010 01:26:27 PM

From: Tad Whiteside/SRNL/Srs
To: Kenneth Dixon/SRNL/Srs@srs
Date: 04/05/2010 01:26 PM
Subject: Re: HTF Air and Radon Pathway Design Check

Design Check:

There were only a three items:

1) Figure 2 has multiple white arrows on it and don't seem to point to anything. They are hard to see and might have been left over from a previous image on that page.

2) Table 20 is for the 1230m distance but two of the columns are labeled 1700m (the values are ok).

3) Table 22 the DRF for Tc-99 is listed as 4.8e+00, however it should be 5.0e-02 - the error is in the Tank2_LimitsCalc.xls and carried over into the draft document. The Dose to MEI is 1.2e-46, it should be

1.3e-48.

Other than those it looks good.

Tad

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803-725-8267
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Kenneth Dixon Please perform a design check of the document... 03/31/2010 03:29:17 PM

From: Kenneth Dixon/SRNL/Srs
To: Tad Whiteside/SRNL/Srs@Srs
Date: 03/31/2010 03:29 PM
Subject: HTF Air and Radon Pathway Design Check

Kenneth Dixon/SRNL/Srs

Please perform a design check of the document SRNL-STI-2010-00135_DRAFT_C.doc and associated files. This report covers the air and radon pathway analysis conducted for the H-Area Tank Farm. The files to be checked may be located at the following path:

\\wg02\KLD\HTank_Design_Check

This analysis included 2 cases which are:

1)Tank 1
2)Tank 2

The file structure implemented is consistent with this nomenclature. We can meet to discuss the general concepts and file layout so that you can get up to speed quicker if you would like to do so. The cost code for your time is LWHTFAIRR.

Thanks,
Ken
5-5205

Design checking should include, but is not limited to, the following elements:

- Check the PORFLOW input, output, and associated graphics files to ensure that the conceptual approach has been correctly implemented as outlined in SRNL-STI-2010-00135_DRAFT_C.doc.

- Verify that the approach used to implement liquid-gas partitioning for the air pathway analysis is sound. This is discussed in Section 3.2 and Appendix B.

- Check the worksheets within Htank_model_setup_R1.xls for accuracy. Values may be spot checked.

- Check the worksheets within Htank_DiffusionCoefficients.xls for accuracy. Values may be spot

checked.

- Check that the grid dimensions used in the PORFLOW models adequately represent the dimensions of Tank 1, Tank 2, and cover material. Check that the grid density is adequate to compute diffusive flux of radon at the land surface.

- Verify that the results of the PORFLOW simulation given in \<Tank[]>\<parent>\flux.out are reasonable and that these results have been accurately transferred to file \<Tank[]>\flux_rn.xls for each parent radionuclide and Tank.

- Check that the flux summaries given in file \<Tank[]>\flux_rn.xls, worksheet "Summary" are accurate and that these data have been accurately presented in SRNL-STI-2010-00135_DRAFT_C.doc.

- Check that the flux curves (radon and air pathway) presented in SRNL-STI-2010-00135_DRAFT_C.doc are reasonable.

- Confirm that the correct diffusion coefficients are used for each radionuclide in the PORFLOW input file \air_kd\run.dat. These values may be spot checked.

- Verify that the results of the PORFLOW simulation given in \<Tank[]>\air_kd\flux.out are reasonable and that these results have been accurately transferred to file \<Tank[]>\air_kd\Tank[]_LimitsCalc.xls, worksheet "Porflow_Flux".

- Verify that the dose calculations are accurate in \<Tank[]>\air_kd\Tank[]_LimitsCalc.xls, worksheet "<Tank[]_Dose>" and verify that these data have been accurately presented in SRNL-STI-2010-00135_DRAFT_C.doc.

- Check that the DRFs from SRNL-STI-2010-00018.doc have been accurately transferred to \<Tank[]>\air_kd\Tank[]_LimitsCalc.xls and SRNL-STI-2010-00135_DRAFT_C.doc.

- Verify that the appropriate dose release factors are used in the disposal limit calculations presented in \<Tank[]>\air_kd\Tank[]_LimitsCalc.xls, worksheet "<Tank[]_Dose>".

- Check that the flux summary data from file \<Tank[]>\air_kd\Tank[]_LimitsCalc.xls, worksheet "Porflow_Flux" have been accurately presented in SRNL-STI-2010-00135_DRAFT_C.doc. These values may be spot checked.