SUBSECTION 2.4.13: ACCIDENTAL RELEASES OF RADIOACTIVE LIQUID EFFLUENTS IN GROUND AND SURFACE WATERS

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2.4.13 ACCIDENTAL RELEASES OF RADIOACTIVE LIQUID EFFLUENTS IN GROUND AND SURFACE WATERS

The information presented in this subsection describes the ability of groundwater and surface water systems to delay, disperse, dilute, or concentrate radioactive liquid effluents released from Units 6 & 7. The source of the liquid effluent would be a postulated tank rupture in the liquid waste management system. The likelihood of an environmental release of liquid waste is remote due to multiple levels of protection in the liquid waste management system.

2.4.13.1 Groundwater

This subsection provides an analysis of a postulated accidental release of radioactive liquid effluent to the groundwater at Units 6 & 7. The accident scenario is described in this subsection along with the conceptual model used to evaluate radionuclide transport to potential receptors.

The analysis, as outlined in NUREG-0800, Section 2.4.13 and NUREG-0800, BTP 11-6 (Reference 201) considers the impact of the release on the nearest potable water supply and the use of water for direct human consumption or indirectly through animals (livestock watering), crops (agricultural irrigation), and food processing (water as an ingredient). For direct consumption, results are considered acceptable if an accidental release will not result in radionuclide concentrations in excess of the effluent concentration limits (ECLs) included in 10 CFR Part 20, Appendix B, Table 2 at the nearest source of potable water located in an unrestricted area. For indirect consumption, bioaccumulation of radionuclides in the consumed animal or plant organisms is the pathway for exposure. For indirect consumption, results are considered acceptable if the dose associated with an accidental release does not exceed the annual dose limit given in 10 CFR 20.1301 of 100 mrem/yr.

The groundwater in the vicinity of Turkey Point property is classified as G-III (non-potable water use); the salinity of Biscayne Bay also precludes its use as a potable water supply. Therefore, direct consumption of water impacted from an accidental release of radioactive effluent is not a plausible receptor scenario. An indirect consumption pathway, through the consumption of seafood (fish and crustaceans/mollusks) from an area of Biscayne Bay that could be impacted from a release of radioactive liquid effluent, is a plausible receptor scenario. Therefore, this indirect consumption-of-seafood pathway is used to determine compliance for

Units 6 & 7. Although not used for final compliance determination, the ECLs are used as part of the screening analysis described in Subsections 2.4.13.1.5.1, 2.4.13.1.5.2 and 2.4.13.1.5.3.

2.4.13.1.1 Source Term

The source term has been selected based on information provided by Westinghouse and guidance provided in NUREG-0800, BTP 11-6 (Reference 201). Based on the expected types of liquid waste streams processed by the liquid waste management systems, the effluent holdup tanks have the highest potential radioactive inventory based on radionuclide concentrations and volume. The effluent holdup tanks also have the highest potential exposure consequences to users of water resources as their inventory includes long-lived fission and activation products and environmentally mobile radionuclides. Therefore, they have been selected by Westinghouse as the limiting tanks for evaluating an accidental release of radioactive liquid effluents that could lead to the most adverse contamination of groundwater or surface water via the groundwater pathway.

There are two effluent holdup tanks for each unit, each tank has a capacity of 28,000 gallons. These tanks are located in the lowest level of the auxiliary building. The accidental release evaluation postulates a release from a single effluent holdup tank, based on guidance provided in NUREG-0800, Section 2.4.13, and assumes that the radionuclide inventory for the tank is based on 80 percent of the tank capacity, using guidance provided in NUREG-0800, BTP 11-6 (Reference 201).

Westinghouse indicates the radioactive contents of the effluent holdup tanks should be assumed to be 101 percent of the reactor coolant. The radionuclide concentrations in reactor coolant itself are as follows:

- For tritium (H-3), a coolant concentration of 1.0 µCi/g is used. This was taken directly from the DCD, Table 11.1-8.

- Corrosion product (Cr-51, Mn-54, Mn-56, Fe-55, Fe-59, Co-58, and Co-60) concentrations are taken directly from the DCD, Table 11.1-2, *Design Basis Reactor Coolant Activity*.

- Other radionuclide concentrations are based on the DCD, Table 11.1-2, multiplied by 0.12/0.25 to adjust the failed fuel rate from the design basis to a conservatively bounding value for this analysis.

The expected radionuclide concentrations in the effluent holdup tanks have been calculated, and the results are summarized in Table 2.4.13-201.

2.4.13.1.2 Conceptual Models

The objective of developing a conceptual model is to evaluate the potential pathways that an accidental release of radioactive liquid effluent could travel to groundwater or to surface water via the groundwater pathway. The key elements and assumptions embodied in the conceptual model development are described and discussed below.

2.4.13.1.2.1 Evaluation of Exposure Pathways

As indicated in Subsection 2.4.13.1.1, the effluent holdup tanks are assumed to be the source of the release, with each tank having a capacity of 28,000 gallons and radionuclide concentrations as summarized in Table 2.4.13-201. These tanks are located at the lowest level of the auxiliary building, which has a floor elevation (El.) of approximately -7.5 feet NAVD 88 or approximately 10 feet below the predicted post-construction water table elevation within the subsurface cut-off wall, based on the groundwater contour plot presented on Figure 2CC-262.

One of these tanks is postulated to rupture, and 80 percent of the liquid volume is assumed to be released (i.e., 22,400 gallons) in accordance with NUREG-0800, BTP 11-6 (Reference 201). Liquid from a tank rupture would initially flood the tank room and begin to flow to the auxiliary building's radiologically-controlled area sump via floor drains as described in Subsection 3.4.1.2.2.2 of the DCD. According to the DCD, this would result in the 22,400-gallon release flooding the balance of level 1 of the auxiliary building via the interconnecting floor drains. Once level 1 is flooded, it is conservatively assumed that a pathway is created that would allow the entire 22,400 gallons to instantly enter the saturated structural fill adjacent the building. This pathway would require the following conservative assumptions be made:

1. Failure of the floor drain collection system

2. Instantaneous penetration of the 3-foot-thick exterior concrete walls

3. Outward flow of liquid effluent in the direction of increasing potential (i.e., tank is below the water table).

One area of review discussed in NUREG-0800, Section 2.4.13 is alternate conceptual models of the site hydrology. To address this area of review, two basic

conceptual models, referred to in this analysis as the “primary” and “alternate” models, were evaluated. The primary conceptual model assumes the industrial wastewater facility (IWF) surrounding Turkey Point Units 6 & 7 (Figure 2.4.12-210) is operational (i.e., the circulating water pumps for the existing units are operating) at the time of, and subsequent to, the postulated release. The alternate conceptual model assumes the industrial wastewater facility is not operational at the time of, or subsequent to, the postulated release.

The industrial wastewater facility is a 5900-acre closed-cycle system used for cooling for the existing Turkey Point Units 1 through 4. The canal system also accepts cooling tower blowdown and recycled wastewater discharge from Turkey Point Unit 5. The canal system has a total circulating water flow of approximately 4000 cfs. The water contained in the canals is classified as hypersaline, indicating that it is more saline than seawater.

The primary and alternate conceptual models were also evaluated for cases assuming the radial collector wells were operational on a steady-state basis. Radial collector wells (RCWs) will be installed on Turkey Point peninsula as shown in Figures 2.4.12-218 and 2CC-242 to provide backup cooling tower makeup water for the proposed units when the primary supply of makeup water is not available. The total system pumping rate is approximately 87,000 gpm. The RCWs are only expected to be operated on a basis equivalent to 90 days per year at the maximum pumping rate.

The Phase II post-construction groundwater flow model developed for the site was used to evaluate potential pathways and groundwater travel times for a postulated accidental release of radioactive liquid effluent as described in Subsection 2.4.13.1.3. The Phase II post-construction model is described in Appendix 2CC, Subsection 6.0.

2.4.13.1.3 Pathway Analysis

Particle tracking simulations using MODPATH and the Phase II post-construction groundwater flow model developed for the site, as described in Appendix 2CC, Subsection 6.0, were used to evaluate potential pathways and groundwater travel times for a postulated accidental release of radioactive liquid effluent for several cases.

In these simulations, particles were released into the structural fill around the Units 6 & 7 nuclear islands in model layer 3 as shown in Figure 2.4.13-201. A cross section of the model (without particles) is presented in Figure 2CC-255.

Figure 2CC-262 presents the simulated groundwater contours for model layer 1. In the nuclear island areas, model layer 3 (from El. -5 to -14 feet NAVD 88) represents the approximate elevation of the effluent holdup tanks. The particles were modeled as being released at the mid-point of the cell elevation (i.e., approximately El. -9 feet NAVD 88). Particles were placed inside the cut-off wall around the entire perimeter of the nuclear island, rather than just at the location of the effluent holdup tanks, to determine the fastest groundwater pathway. A total of 264 particles were modeled as being released.

Four particle tracking cases were run:

- IWF-operational, RCW-off (Case 1)
- IWF-operational, RCW-on (Case 2)
- IWF-non-operational, RCW-off (Case 3)
- IWF-non-operational, RCW-on (Case 4)

Table 2.4.13-202 presents the minimum groundwater travel time to the terminal point for each case. In particle tracking analyses, particles move through the modeled groundwater system until they reach a boundary where flow is out of the system, or until they enter a cell containing an internal sink (flow out of system), this boundary or sink is referred to as the terminal point in this analysis (Reference 229).

For the primary conceptual model (IWF-operational), the particles with the shortest groundwater travel times from both Case 1 (IWF-operational, RCW-off) and Case 2 (IWF-operational, RCW-on) terminate in the IWF. Given that the Case 1 travel time is faster than that of Case 2, Case 1 is limiting because it allows for less radioactive decay of a postulated accidental release of radioactive liquid effluent. Therefore, Case 2 (IWF-operational, RCW-on) will not be further addressed in this analysis. Figure 2.4.13-202 presents the steady-state particle tracking results for Case 1 and shows that the particles terminate in the IWF. Case 1 plots representing model layer versus time and distance versus time for the particle with the shortest travel time are presented as Figures 2.4.13-203 and 2.4.13-204, respectively. The particle with the shortest travel time (particle #123) originates from Unit 7.

Although the IWF is within the restricted area for Units 6 & 7 and cannot be accessed by the public, it serves as the terminal point for the primary conceptual

model particle tracking analyses, making it a logical point to evaluate radionuclide concentrations from a postulated accidental release.

With respect to the alternate conceptual model, Figure 2.4.13-205 presents the particle tracking results for Case 3. Case 3 (IWF-non-operational, RCW-off) results indicate the particle with the shortest travel time originates from Unit 6 and terminates offsite in Biscayne Bay with a travel time of 3759 days. Case 3 plots representing model layer versus time and distance versus time for the particle with the shortest travel time (particle #36) are presented as Figures 2.4.13-206 and 2.4.13-207, respectively. Case 4 (IWF-non-operational, RCW-on) results indicate that the particle with the shortest travel time terminates at the RCWs with a travel time of 4079 days (Table 2.4.13-202).

Particle tracking results indicate that the Case 4 particles are still within the plant area at a time of 3759 days (the shortest travel time for Case 3). Because the Case 3 fastest particle has reached Biscayne Bay at a time of 3759 days whereas Case 4 particles have not, Case 3 is the limiting case, for the IWF-non-operational cases, with respect to potential impact to Biscayne Bay. Therefore, Case 4 (IWF-non-operational, RCW-on) will not be addressed further in this analysis.

Because the RCWs are only expected to be operated on a basis equivalent to 90 days per year at the maximum pumping rate, the particle tracking simulations that assume steady-state RCWs operation overestimate their impact on the groundwater system and are therefore conservative.

2.4.13.1.4 Radionuclide Transport Analysis

A radionuclide transport analysis has been conducted to estimate the radionuclide concentrations assuming an instantaneous release of the radioactive liquid in an AP1000 effluent holdup tank. The results of this analysis are used to determine compliance with 10 CFR Part 20.

The analysis commenced with the simplest of models, using demonstratively conservative assumptions and coefficients. For screening purposes, radionuclide concentrations resulting from the preliminary analysis were then compared against the ECLs identified in 10 CFR Part 20, Appendix B, Table 2. Further analysis, using progressively more realistic and less conservative assumptions and modeling techniques, was conducted when the preliminary results exceeded the ECLs.

Radionuclide transport along a groundwater flow path is governed by the advection-dispersion-reaction equation (Reference 203), which, after conservatively neglecting hydrodynamic dispersion and integrating, is given as:

$$C = C_0 \exp(-\lambda t)$$ Equation 2.4.13-1

Where,

C = radionuclide activity concentration
C_0 = initial radionuclide activity concentration
λ = radioactive decay constant
t = radionuclide travel time, defined as:

$$t = LR/v$$ Equation 2.4.13-2

Where,

L = groundwater flow path length
R = retardation factor
v = average linear velocity

The retardation factor is defined from the relationship:

$$R = 1 + \frac{\rho_b K_d}{n_e}$$ Equation 2.4.13-3

Where,

ρ_b = bulk density
K_d = distribution coefficient
n_e = effective porosity

The average linear velocity is determined using Darcy's law, which is:

$$v = -\frac{K}{n_e}\frac{dh}{dx}$$ Equation 2.4.13-4

Where,

K = hydraulic conductivity
dh/dx = hydraulic gradient

The radioactive decay constant can be written as:

$$\lambda = \frac{\ln 2}{t_{1/2}}$$ Equation 2.4.13-5

Where,

$t_{1/2}$ = radionuclide half-life.

Similar relationships exist for progeny radionuclides. For the first progeny in the decay chain, the advection-dispersion-reaction equation, g39

again conservatively neglecting hydrodynamic dispersion, is:

$$C_2 = K_1 \exp(-\lambda_1 t) + K_2 \exp(-\lambda_2 t)$$ Equation 2.4.13-6

$$t = R_2 L / v$$ Equation 2.4.13-7

Where,

$$K_1 = \frac{d_{12}\lambda_2 C_{10}}{\lambda_2 - \lambda_1}$$

$$K_2 = C_{20} - \frac{d_{12}\lambda_2 C_{10}}{\lambda_2 - \lambda_1}$$

Where subscript 2 denotes the properties/concentration of the first progeny radionuclide, and:

- d_{12} = the fraction of parent radionuclide transitions that result in production of progeny radionuclide
- C_{10} = initial activity concentration of the parent radionuclide
- C_{20} = initial radionuclide activity concentration of the first progeny

The advection-dispersion-reaction equation for the second progeny in the decay chain is:

$$C_3 = K_1 \exp(-\lambda_1 t) + K_2 \exp(-\lambda_2 t) + K_3 \exp(-\lambda_3 t)$$ Equation 2.4.13-8

$$t = R_3 L / v$$ Equation 2.4.13-9

Where,

$$K_1 = \frac{d_{13}\lambda_3 C_{10}}{\lambda_3 - \lambda_1} + \frac{d_{23}\lambda_2 d_{12}\lambda_3 C_{10}}{(\lambda_3 - \lambda_1)(\lambda_2 - \lambda_1)}$$

$$K_2 = \frac{d_{23}\lambda_3 C_{20}}{\lambda_3 - \lambda_2} - \frac{d_{23}\lambda_2 d_{12}\lambda_3 C_{10}}{(\lambda_3 - \lambda_2)(\lambda_2 - \lambda_1)}$$

$$K_3 = C_{30} - \frac{d_{13}\lambda_3 C_{10}}{\lambda_3 - \lambda_1} - \frac{d_{23}\lambda_3 C_{20}}{\lambda_3 - \lambda_2} + \frac{d_{23}\lambda_2 d_{12}\lambda_3 C_{10}}{(\lambda_3 - \lambda_1)(\lambda_3 - \lambda_2)}$$

Where subscript 3 denotes the properties/concentration of the second progeny radionuclide, and:

d_{13} = the fraction of parent radionuclide transitions that result in production of second progeny radionuclide
d_{23} = the fraction of first progeny radionuclide transitions that result in production of second progeny radionuclide
C_{30} = initial radionuclide activity concentration of the second progeny

2.4.13.1.5 Primary Conceptual Model — IWF-Operational (Case 1)

2.4.13.1.5.1 Transport Considering Radioactive Decay Only

An initial screening analysis was performed considering radioactive decay only. This analysis assumed that all radionuclides migrate at the same rate as groundwater and considered no adsorption and retardation, which would otherwise result in a longer travel time and more radioactive decay. The radionuclide source term concentrations presented in Table 2.4.13-201 were decayed for 4300 days, a period approximately equal to the Case 1 minimum groundwater travel time (Table 2.4.13-202), neglecting the travel time in the Upper Higher Flow Zone (UHFZ), from the point of release to the IWF, using Equations 2.4.13-1, 2.4.13-6 and 2.4.13-8.

Table 2.4.13-203 summarizes the results. Only radionuclides with a groundwater concentration (C) to ECL ratio (C/ECL) greater than 1.0E-06 were considered significant contributors to exposure and were carried forward for additional analysis. Note that in calculating this ratio, values less than 1.0E-06 were considered to be negligible. The radionuclides exceeding this criterion are Cs-137, Cs-134, H-3, Sr-90, Y-90, Co-60, Fe-55, I-129, Mn-54, Ce-144, Pr-144 and Ag-110m.

2.4.13.1.5.2 Transport Considering Radioactive Decay and Adsorption

An initial evaluation of radionuclides likely to be important in demonstrating 10 CFR Part 20 compliance was performed prior to conducting the Turkey Point Units 6 & 7 field investigation. This evaluation concluded that isotopes of Mn, Fe, Co, Sr, Ag, Te, Ce, and Cs were of interest. Site-specific rock samples were then collected during the field investigation to enable distribution coefficient (K_d) analysis for the elements of interest.

Eight samples of the Miami Limestone were obtained from within the Units 6 & 7 plant area (Reference 205). The samples were submitted to Argonne National

Laboratory for preparation and analysis. The samples were prepared by crushing into different size fractions and each size fraction was used for the analysis. Representative samples of site groundwater were provided to the laboratory for use as the contact liquid. The laboratory testing yielded distribution coefficients as shown on Table 2.4.13-204. A plot of the measured K_d values for Cs, the element yielding the highest C/ECL ratios from Subsection 2.4.13.1.5.1, is presented as Figure 2.4.13-208. A histogram of the Cs K_d values is presented as Figure 2.4.13-209.

Review of the K_d data for the other elements of interest indicates the data ranges from being fairly uniform to positively skewed. The geometric mean is commonly used as the representative value for positively skewed data sets (Reference 213). Additionally, Reference 206 presents the geometric mean K_d value for various elements and soil types, indicating the geometric mean is the representative value. For fairly uniform values the mean and geometric mean are very similar, with the geometric mean being slightly lower. Therefore, the geometric mean of the site-specific K_d values for all elements, with the exception of Fe-55, is selected as the representative K_d value for this analysis. The K_d value of Fe-55 is conservatively assumed to be zero for all analyses presented here due its low reported K_d values and the prevalence of “less than” values presented in Table 2.4.13-204.

In the case of Y-90, the K_d value was assumed to be the same as that used for Sr-90, serving as the parent radionuclide. Pr-144m and Pr-144 are also assumed to have the same K_d value as their parent radionuclide, Ce-144. These assumptions are of little consequence to the results of this analysis given the short half-lives (i.e., less than 3 days) of these daughter products.

The radionuclides of interest from Subsection 2.4.13.1.5.1 also include I-129 and H-3. These radionuclides are assumed to have a K_d of zero because they do not adsorb.

Retardation factors (R) for the radionuclides of interest were calculated using Equation 2.4.13-3, the geometric mean of the K_d values from Table 2.4.13-204, an effective porosity of 0.15 and a bulk density of 1.59 g/cm^3. Calculated retardation factors are presented in Table 2.4.13-205. The development of the effective porosity and bulk density values is presented below.

The bulk density of the Miami Limestone is selected to compute the retardation factor. The particle tracking simulation indicates the particle with the shortest travel time originates from Unit 7, travels in the fill materials, the Miami Limestone

and the UHFZ prior to terminating in the IWF (Figure 2.4.13-203). The majority of the travel time is within the Miami Limestone, with less than 30 days of travel time in the UHFZ. The travel time selected for this analysis neglects the travel time within the UHFZ. Moreover, the bulk density of the Miami Limestone is lower than that of the structural or non-structural fills, resulting in a lower and more conservative calculated retardation value.

With a measured or assumed grain density value and total porosity, the dry bulk density of the Miami Limestone can be calculated from the following relationships. Density and total porosity are related by the following equations (Reference 212):

$$n = (\rho_g - \gamma_{sat}) / (\rho_g - \rho_w) \qquad \text{Equation 2.4.13-10}$$

$$n = 1 - \gamma_{dry} / \rho_g \qquad \text{Equation 2.4.13-11}$$

where

n = total porosity
γ_{dry} = dry density (dry unit weight)
γ_{sat} = saturated density (saturated unit weight)
ρ_g = grain density (solids density)
ρ_w = water density

A saturated density (saturated unit weight) of 2.0 g/cm^3 for Miami Limestone was selected from Table 2.5.4-209.

A grain density of 2.7 g/cm^3 is assumed, the average value from Table 2.4.12-207.

From Equation 2.4.13-10 and the saturated density and grain density values, a total porosity of 0.41 can be calculated. Equation 2.4.13-11 can then be used to calculate a bulk dry density for the Miami Limestone of 1.59 g/cm^3.

The effective porosity of the fill materials (non-structural and structural) and the Miami Limestone is assumed to be 0.15. This value is significantly less than the total porosities (0.26-0.41) for these materials as presented in Table 2.4.13-206. The value of 0.15 is also less than the value of 0.20 that was used to represent the Biscayne Aquifer in References 209 and 210. A lower effective porosity results in conservative (i.e., higher) radionuclide concentrations.

The concentration of each radionuclide of interest was then calculated accounting for retardation. Table 2.4.13-205 presents the results of this analysis. The sum of fractions for this analysis after accounting for advection, decay and adsorption is

approximately 1.1E+05. As before, the C/ECL values less than 1.0E-06 were considered to be negligible. Radionuclides with C/ECL ratios exceeding 1.0E-06 include Cs-137, H-3, Sr-90, Y-90, Cs-134, Fe-55 and I-129. These radionuclides require further evaluation.

2.4.13.1.5.3 Transport Considering Radioactive Decay, Adsorption, and Dilution

The particle tracking simulation results indicate a postulated release would flow into the IWF (Figure 2.4.13-202), where it would be diluted. A dilution factor of 5.6E-06 was applied to the results presented in Subsection 2.4.13.1.5.2 based on diluting the volume of the release (22,400 gallons) with the volume of water in the canal system (4,000,000,000 gallons) (Reference 202). Table 2.4.13-207 presents the results of this analysis.

An average background tritium concentration of 5250 pCi/L or 5.25E-06 µCi/cm^3 is present in the IWF. This concentration is accounted for in the H-3 concentration presented in Table 2.4.13-207, as follows. The total background Curies of tritium in the IWF are calculated (i.e., H-3 concentration x IWF volume). The added tritium Curies to the IWF from a postulated release is calculated (i.e., H-3 concentration from Table 2.4.13-205 x release volume). The background and added tritium Curies are summed and divided by the IWF water volume.

This analysis assumes the release is completely mixed within the volume of water present in the IWF. Given that the IWF is a closed loop system coupled with its large circulating flow rate of approximately 4000 cfs, the completely-mixed assumption is reasonable.

The results presented in Table 2.4.13-207 show that, after dilution within the IWF, the sum of fractions for this release scenario is approximately 0.6, and therefore, meets the 10 CFR Part 20 drinking water limits of 1.0. However, considering that the water in the IWF is hypersaline and non-potable, and that the IWF is within the restricted area for Units 6 & 7 and cannot be accessed by the public, direct consumption of water from the IWF is not plausible. To address the potential transport of radionuclides from the IWF to a publicly accessible location, further analysis is conducted as discussed in Subsection 2.4.13.1.5.4.

2.4.13.1.5.4 Biological Uptake and Potential Consumption of Fish, Crustaceans, and Mollusks

Because radionuclides postulated to be present in the IWF could potentially migrate to an area accessible by the public, additional analyses were conducted to evaluate 10 CFR Part 20 compliance at potential receptor locations.

The groundwater in the vicinity of Turkey Point property is classified as G-III (non-potable water use); the salinity of Biscayne Bay also precludes its use as a potable water supply. Therefore, the only plausible exposure pathway is through the consumption of seafood (fish and crustaceans/mollusks) from an area of Biscayne Bay that could be impacted from a release of radioactive liquid effluent.

The analysis conservatively assumes that the radionuclide concentrations calculated for a postulated release that is fully mixed in the IWF are present in Biscayne Bay without further dilution. Using the radionuclide concentrations calculated in Subsection 2.4.13.1.5.3 (Table 2.4.13-207) and the fish-water and mollusk/crustacean-water uptake ratios (bioaccumulation factors) for saltwater given in Table A-1 of Regulatory Guide 1.109 (Reference 211), the biological uptake is calculated. Given Biscayne Bay's median salinity of 34.3 practical salinity units from Appendix 2AA, the use of the saltwater bioaccumulation factors is appropriate. The biological uptake of I-129 is not calculated given its low C/ECL ratio as presented in Table 2.4.13-207.

From Table D.2 of Reference 206, it is assumed that 5.4 kg of fish and 0.9 kg of crustaceans/ mollusks are consumed annually. Of this seafood consumed, it is assumed that 50 percent (Reference 206) are exposed (i.e., contaminated) to the radionuclide concentrations presented in Table 2.4.13-207. It is therefore assumed that 2.7 kg of contaminated fish and 0.45 kg of contaminated crustaceans/mollusks are consumed annually.

The assumption of 2.7 kg of contaminated fish annually is a reasonable assumption given that this value is approximately equal to the EPA Exposure Factors Handbook recommended mean annual uptake of fish (2.6 kg/yr) by recreational marine anglers in a Gulf location (Reference 220, Table 10-83). Harvest and consumption of seafood from Biscayne Bay by a recreational angler is a plausible exposure scenario.

The dose to humans via each consumption pathway (fish and mollusks/ crustaceans) was determined using the dose conversion factors from the “effective” column from Table 2.2 of Reference 221. These dose conversion factors are considered acceptable to the NRC staff (Reference 222).

The resultant dose for each radionuclide of interest by each intake exposure pathway was summed, and a total dose was determined. These results are presented in Table 2.4.13-208 and indicate a resultant dose of approximately 4 mrem/yr, which is below the 10 CFR Part 20.1301 limit of 100 mrem/yr.

The assumptions concerning the fraction of fish and mollusks/crustaceans contaminated were evaluated in a sensitivity analysis. Assuming all of the fish and mollusks/crustaceans consumed are contaminated, which is twice the previous assumption of 50 percent, the resultant dose increases by a factor of two to approximately 8 mrem/yr, which is still below the 10 CFR Part 20.1301 limit of 100 mrem/yr.

2.4.13.1.6 Alternate Conceptual Model - IWF-Non-operational (Case 3)

The alternate conceptual model assumes the IWF is non-operational. Operation of the IWF is not required for Turkey Point Units 6 & 7. To represent this case, the river boundary condition cells representing the IWF in the post-construction groundwater model were removed and the cell properties were revised to represent a high hydraulic conductivity (K =100 cm/s) material. The high hydraulic conductivity is intended to simulate open water, ensuring that the cells, which were previously river cells, do not impede the flow of water within the model.

Using this revised model, particle tracking simulations were conducted as described in Subsection 2.4.13.1.3. Results from this analysis indicate the particle with the shortest travel time originates from Unit 6 and travels in the fill materials, Miami Limestone, the UHFZ and offshore sediments prior to terminating in Biscayne Bay as shown in Figure 2.4.13-206. The majority of the travel time is within the Miami Limestone, with approximately 60 days of travel time in the UHFZ. The travel time from the point of release to Biscayne Bay assumed for this analysis is 3600 days, which is the approximate time the fastest particle enters the UHFZ. Given that the fastest particle is predicted to reach Biscayne Bay in approximately 3800 days, the use of 3600 days in this screening analysis is conservative.

In the screening analysis performed for the primary conceptual model, an assumed travel time from the point of release to the IWF of 4300 days was used, a period approximately equal to the Case 1 minimum groundwater travel time (Table 2.4.13-202). Despite incorporating advection, radioactive decay, and adsorption, several radionuclides have C/ECL ratios exceeding 1.0E-06 (Table 2.4.13-206).

Because the travel time for the Case 3 alternate conceptual model (i.e., 3600 days) is approximately equal to that of the primary conceptual model, the radionuclides of interest for the alternate conceptual model are the same as those identified for the primary conceptual model. These radionuclides include: Cs-137, H-3, Cs-134, Sr-90, Y-90, Fe-55 and I-129. These radionuclides, with the

exception of I-129, are further analyzed to demonstrate compliance with 10 CFR 20 limits for the alternate conceptual model. Due to its low C/ECL ratio (Table 2.4.13-205) and low potential for bioaccumulation, I-129 is not analyzed further.

2.4.13.1.6.1 Transport Considering Radioactive Decay, Adsorption and Dispersion

To further analyze the radionuclides of interest presented in Subsection 2.4.13.1.6, groundwater transport modeling simulations were conducted using the MT3DMS program. The MT3DMS simulations include the effects of advection, adsorption, dispersion, and radioactive decay for each radionuclide during transport. Y-90 is not modeled using MT3DMS.

Y-90 is a short-lived daughter product of Sr-90. Y-90 is assumed to be in secular equilibrium with Sr-90, and therefore, its concentration is assumed equal to the MT3DMS-predicted Sr-90 concentration.

2.4.13.1.6.1.1 Source Term

Particle tracking simulations indicate that, for the IWF-non-operational case, the shortest travel time to Biscayne Bay is for a release from Unit 6. Therefore, the transport modeling simulations assume a release from Unit 6. The radionuclide release is represented in the model as an initial condition by specifying the dissolved radionuclide concentration for model layer 3 cells along a portion of the southern end of the Unit 6 auxiliary building (Figure 2.4.13-210). The southern end of the Unit 6 auxiliary building is a likely area of release given its proximity to an effluent holdup tank.

The radionuclide release is represented in the model assuming that no dilution occurs in the instantaneous transfer of the release from the building to the adjacent fill material (i.e., the initial concentrations in the fill material are assumed to equal the expected effluent holdup tank concentrations). This assumption is made to provide conservatism in the transport analyses. Without revising the numerical grid for the groundwater flow model, it is not possible to simulate an accidental release that matches both the solute concentration and total activity released. In these simulations, the total activity released is overrepresented by 3 to 18 percent, depending on the isotope distribution coefficient. Since MT3DMS instantaneously creates an adsorbed component for a given initial solute concentration, the spatial extent of release within the model is different for radionuclides with different distribution coefficients to approximate the total activity

released. Table 2.4.13-209 provides a comparison of total activity for each radionuclide in the postulated release and the MT3DMS simulated release.

The representation of the source term in these simulations is conservative for a number of reasons:

- The effluent holdup tanks are located within the auxiliary building, below the post-construction water level. A simultaneous failure of the auxiliary building exterior walls and an effluent holdup tank would result in groundwater entering the building, initially precluding the release of liquid effluents. Additionally, the influx of groundwater into the building would dilute the radionuclide concentrations released from the failed tank.

- The sorption of radionuclides on the fill material should decrease the dissolved concentration of the released radionuclides.

- A postulated release would occur over time, rather than instantaneously.

2.4.13.1.6.1.2 Bulk Density and Porosity Values

Effective porosity, total porosity, and bulk density values for each material as implemented in the groundwater transport model are presented in Table 2.4.13-206 and described below. Note that the dry bulk density is only used in the transport model to calculate a retardation factor.

All materials were assigned an effective porosity of 0.15, except as described below. The effective porosity of 0.15 for most materials in the model is significantly less than their total porosity values. The value of 0.15 is also less than the value of 0.20 that was used to represent the Biscayne Aquifer in References 209 and 210. The value of 0.15 is assumed to provide conservatism for the transport analyses.

In order to determine total porosity and bulk density values, a grain density of 2.7 g/cm^3 is assumed for all materials, the average value from Table 2.4.12-207.

Using the total unit weights (saturated density) in Table 2.5.4-209, total porosity can be calculated using Equation 2.4.13-10. Total porosity is then used with Equation 2.4.13-11 to calculate bulk density. Total unit weights are provided for muck, Miami Limestone, Key Largo, Fort Thompson, and Tamiami Formations. Freshwater Limestone is assumed to be similar to the Fort Thompson Formation. The dry bulk density of the offshore sediment is assumed to be the same as muck.

The UHFZ and Lower Higher Flow Zone (LHFZ) were assigned an effective porosity of 0.40 based on the results of a tracer test conducted in the karst limestone of the Biscayne Aquifer in northern Miami-Dade County (Reference 218 and Reference 219). This tracer test was conducted to develop a hydrogeologic conceptual model of groundwater flow and chemical transport in the Biscayne Aquifer (Reference 218).

A total porosity of 0.50 was assigned to be higher than effective porosity. This value is consistent with the maximum total porosity reported in literature of 0.49 for Miami Limestone and 0.50 for the Fort Thompson Formation (Table 2.4.12-207). Using total porosity and Equation 2.4.13-11, bulk density can be calculated.

For concrete (mudmat and fill), total porosity was assigned a value of 0.07, as reported in the literature for concrete (Reference 227). The effective porosity for concrete, 0.05, is assumed to be slightly lower than the total porosity. Using total porosity and Equation 2.4.13-11, bulk density is calculated.

Structural and non-structural backfills are assigned bulk density values for crushed limerock at 95 percent and 92 percent maximum dry density (Reference 228), respectively. These bulk density values can be used with Equation 2.4.13-11 to calculate total porosity.

The grouted strata at the base of the excavation consist of Key Largo, Freshwater Limestone, and Upper Fort Thompson. The total porosity of the ungrouted strata ranges from 0.28 to 0.31. After grouting, the total porosity of these strata is assumed to be reduced to 0.25. This total porosity is then used with Equation 2.4.13-11 to determine bulk density.

Given that the IWF is non-operational, a total porosity of 0.30 for all cells simulating open water of the IWF is assumed. In this case, high hydraulic conductivity cells replaced cells representing a river boundary to simulate open water. Realistically, the porosity of open water would be 1. Using the assumed porosity, as opposed to a value of 1, yields a more conservative (i.e., higher) seepage velocity. Total porosity is used to calculate bulk density using Equation 2.4.13-11.

2.4.13.1.6.1.3 Dispersivity Values

The value for longitudinal dispersivity (α_L) used in the MT3DMS analysis is based on a tracer test conducted in the Biscayne aquifer (References 218 and 219). In Reference 218 a longitudinal dispersivity of 2 meters for a travel distance of 100 meters is calculated. For application to this analysis, the 2 meters longitudinal

dispersivity value from Reference 218 is upscaled using Equation 19 (Reference 214) for a transport distance of 1305 feet (398 meters), the distance between the release location at Unit 6 and the receptor location (simulated concentration observation well) as follows:

$$\alpha_L = c\,(\log_{10} L)^{2.414} \qquad \text{Equation 2.4.13-12}$$

where

α_L = longitudinal dispersivity in meters
c = scaling coefficient
L = travel distance in meters.

From the Reference 218 tracer test, α_L = 2 meters and L = 100 meters, therefore c = 0.38. Using this formation-specific equation and the analysis-specific distance of 1305 feet (398 meters), the analysis-specific longitudinal dispersivity is 12 feet (3.77 meters).

Transverse dispersivities typically are one to two orders of magnitude smaller than longitudinal values (for flow through a “spatially random permeability field” [Reference 223]). For this analysis, the horizontal transverse dispersivity (α_T) is assumed to be 10 percent of longitudinal dispersivity, and the vertical dispersivity is assumed to be 1 percent of the longitudinal dispersivity. These ratios are within the ranges described in the literature:

- α_T/α_L = 0.01 to 0.2 (Reference 224)
- α_T/α_L = 0.05 to 0.17 (Reference 225)
- α_T/α_L = 0.1 to 0.3 (Reference 226)
- α_T/α_L = 0.1 (Reference 209)
- α_V/α_T = 0.1 (Reference 231)

2.4.13.1.6.1.4 Molecular Diffusion Coefficient

A molecular diffusion coefficient of zero is assumed for all isotopes. As noted in the MT3DMS manual, “molecular diffusion is generally secondary and negligible compared to the effects of mechanical dispersion, and only becomes important when groundwater velocity is very low” (Reference 215).

2.4.13.1.6.1.5 MT3DMS Porosity Options

MT3DMS has the option to run the simulation using the total or effective porosity. The effective porosity option was selected for all simulations. A sensitivity analysis indicates the effective porosity produces higher peak concentrations and is, therefore, conservative. Additionally, the Visual MODFLOW manual (Reference 216) recommends the effective porosity option for advection-dominated transport.

2.4.13.1.6.1.6 Distribution Coefficient

A distribution coefficient of zero is applied to the UHFZ and LHFZ, which correspond to model layers 5 and 11, respectively. This assumption is made to provide conservatism for transport in the higher permeability layers.

For all materials in the model (e.g., fill, native formations, concrete) other than the HFZs, the geometric mean of the distribution coefficient from laboratory testing, as presented in Table 2.4.13-204, is assumed to be representative of subsurface conditions. Since site-specific values have been determined by testing, additional conservatism (e.g., applying the minimum distribution coefficient from laboratory tests) is deemed unnecessary (see Subsection 2.4.13.1.5.2), particularly considering the other conservative assumptions already included in the release scenario and other parameter values.

The literature K_d values for concrete (Reference 217), with the exception of that for Cs isotopes, generally exceed those assumed in this analysis (Table 2.4.13-204). Given the low hydraulic conductivity of concrete relative to the fill and native aquifer materials, the predicted peak concentrations at the simulated observation well (i.e., postulated receptor) are expected to be relatively insensitive to the K_d of concrete.

2.4.13.1.6.1.7 Solution Method

The MT3DMS solutions presented in this analysis, with the exception of sensitivity analyses, were generated using the advective transport total-variation-diminishing (TVD) solution method within MT3DMS. The TVD and method of characteristics (MOC) methods are recommended for advection-dominated problems (Reference 215). Test runs with the MOC method produced results that had larger mass balance errors and more oscillation as compared to the TVD method. The TVD method was therefore selected for all the simulations used to demonstrate compliance with 10 CFR Part 20.

2.4.13.1.6.1.8 Predicted Radionuclide Concentrations

A simulated concentration observation well, CW-2s, was placed in the model to record the maximum offshore predicted radionuclide concentrations in model layer 1 (Figure 2.4.13-211). Model layer 1 is selected because it is assumed that the predicted concentrations in this layer are representative of the radionuclide concentrations that would be discharged into Biscayne Bay (the receptor location). The observation well was located at the offshore peak of the plume centerline and was used to record predicted radionuclide concentrations with time.

The predicted concentration time series for model layer 1 at CW-2s for the radionuclides of interest (Cs-137, Cs-134, H-3, Sr-90, and Fe-55) are presented in Figure 2.4.13-212. The peak radionuclide concentrations in model layer 1 at CW-2s are presented in Table 2.4.13-210. The Cs-137 plume contour map for model layer 1 (top layer) for time = 10 years is shown in Figure 2.4.13-213 in which the Cs-137 ECL of 1.0E-06 µCi/cm^3 is shown as a dark red contour line.

Note that the cut-off wall around the nuclear island is implicitly represented in the groundwater flow model using a horizontal flow boundary. The implicit representation of a horizontal flow barrier, such as a concrete cut-off wall, has been shown to yield premature breakthrough and solute flux rates through the barrier that are erroneously high (References 230 and 232). Solute fluxes are overestimated in this case because (1) the barrier width is assumed to be infinitesimally small such that solute storage and transport time in the barrier is not simulated, and (2) the finite difference representation of the dispersive fluxes associated with the cross-product terms of the dispersion tensor causes the solute flux to be overestimated across the horizontal flow barrier. As a consequence of representing the cut-off wall implicitly using a horizontal flow barrier, the predicted radionuclide flux through the cut-off wall has therefore been overestimated. This overestimation of radionuclide flux results in higher predicted radionuclide concentrations at the potential receptor location (i.e., CW-2s) and is therefore conservative with respect to demonstrating compliance with 10 CFR Part 20.

2.4.13.1.6.1.9 Sensitivity Analyses

Several sensitivity analyses were conducted for the Cs-137 simulations (the radionuclide producing the highest dose from Subsection 2.4.13.1.5.4). Note that these sensitivity analyses were performed with the advective transport

upstream finite difference (UFD) solution method within MT3DMS due to its faster simulation times; the results of these sensitivity analyses are therefore relative. The peak Cs-137 concentration predicted with the UFD method is approximately 24 percent lower than that using the TVD method. Given the similarity of the UFD method results to those from the TVD method, the results of the sensitivity analyses are expected to be similar to those that would be found using the TVD method.

Percent changes, as compared to the base case using the UFD method, are presented. Increasing the longitudinal dispersivity to 27 feet (from 12 feet in the base case), based on a travel distance of 1305 feet and Equation 14b from Reference 214, results in the peak concentration increasing by approximately 46 percent. Decreasing the longitudinal dispersivity to 6.6 feet (the value presented in Reference 218) results in the peak concentration decreasing by approximately 27 percent.

Decreasing the assumed Cs-137 K_d value from the geometric mean (0.17 cm^3/g) to 0.04 cm^3/g, the minimum measured, results in the peak concentration increasing by approximately 124 percent. Increasing the K_d value would decrease the peak concentration; a simulation with increased K_d was not performed.

Simulating a Cs-137 release on the southwestern edge of the auxiliary building, as opposed to the southeastern edge as shown in Figure 2.4.13-210, results in the peak concentration decreasing by approximately 8 percent.

2.4.13.1.6.1.10 Biological Uptake and Potential Consumption of Fish, Crustaceans, and Mollusks after Accounting for Radioactive Decay, Adsorption and Dispersion

Using the predicted radionuclide concentrations from Subsection 2.4.13.1.6.1.8 (model layer 1 [offshore sediment]) as presented in Table 2.4.13-210 and the methodology for calculating human dose presented in Subsection 2.4.13.1.5.4, the radiological dose for the alternate conceptual model when accounting for radioactive decay, adsorption and dispersion is calculated. These results are presented in Table 2.4.13-211. These results indicate the summed dose is approximately 32 mrem/yr, which is below the 10 CFR Part 20.1301 limit of 100 mrem/yr.

The results presented in Table 2.4.13-211 are based on superposition of radionuclide peak concentrations. If the dose were calculated based on the

simulated concentration histories (Figure 2.4.13-214), a lower peak dose of approximately 28 mrem/yr is calculated.

The assumptions concerning the fraction of fish and mollusks/crustaceans contaminated were evaluated in a sensitivity analysis. The sensitivity analysis assumes all the fish and mollusks/crustaceans consumed are exposed to the offshore sediment radionuclide concentrations presented in Table 2.4.13-210. The results of this analysis indicate that increasing the percentage of fish and crustaceans/mollusks contaminated by a factor of two causes the resultant dose to increase by a factor of 2 to approximately 64 mrem/yr, which is below the 10 CFR Part 20.1301 limit of 100 mrem/yr.

2.4.13.2 Surface Water

Outdoor tanks do not contain radioactive material in the Westinghouse AP1000 design. In particular, the AP1000 design does not require boron changes for load following and does not recycle boric acid or reactor coolant water, so the boric acid tank is not radioactive. An accident scenario resulting in the release of radioactive liquid effluent directly to surface water is a non-plausible pathway because the AP1000 outdoor tanks do not contain radioactive material.

2.4.13.3 Conclusions

An analysis of a postulated accidental release of radioactive liquid effluents in ground and surface waters at the FPL Turkey Point site for two conceptual models (IWF-operational and IWF-non-operational) has been performed for Units 6 & 7. The conclusions resulting from this analysis are as follows:

- An accidental release of liquid from an AP1000 effluent holdup tank to groundwater would not affect any potable water supplies. If an accidental release is postulated, there is a potential for radionuclide accumulation in mollusks, crustaceans, and fish in Biscayne Bay, which could be subsequently harvested and consumed by humans. The dose to humans from this exposure pathway was evaluated, and the potential dose is below regulatory limits for both conceptual models. Sensitivity analyses performed to determine the effects of using a larger fraction of aquatic food that is contaminated resulted in a potential dose that is still below regulatory limits.

- An accidental release of radioactive liquid effluent directly to surface water is a non-plausible pathway because the AP1000 outdoor tanks do not contain radioactive material.

The exposure parameters assumed for these analyses are conservative. For example, it is assumed that 2.7 kg of contaminated fish and 0.45 kg of contaminated crustaceans/mollusks are harvested and ingested by an individual member of the public annually. Due to the highly localized area of potential impact on Biscayne Bay, the likely amount of contaminated seafood consumed would be much lower, resulting in a much lower overall exposure.

Additionally, these analyses do not take credit for dilution of a release within Biscayne Bay. Accounting for dilution of a postulated release in Biscayne Bay would further reduce the predicted radionuclide concentrations.

2.4.13.4 References

201. U.S. Nuclear Regulatory Commission, Branch Technical Position 11-6, *Postulated Radioactive Releases Due to Liquid-Containing Tank Failures*, NUREG-0800, March 2007.

202. Florida Power & Light, *Turkey Point Uprate Project Site Certification Application*, January 2008. Available at http://publicfiles.dep.state.fl.us/Siting/Outgoing/FPL_Turkey_Point/Units_6_7/Application/, accessed October 17, 2011.

203. Javandel, I., C. Doughty, and C-F Tsang, *Groundwater Transport: Handbook of Mathematical Models, Water Resources Monograph 10*, American Geophysical Union, 1984.

204. Kennedy, W. and D. Strenge, *Residual Radioactive Contamination From Decommissioning*, NUREG/CR-5512, Vol. 1, Pacific Northwest Laboratory, October 1992.

205. MACTEC Engineering and Consulting, Inc., *Final Data Report—Geotechnical Exploration and Testing: Turkey Point COL Project Florida City, Florida, Rev. 2*, included in COL Application Part 11, October 6, 2008.

206. Yu, C. et al., Users Manual for RESRAD Version 6, Argonne National Laboratory, ANL/EAD-4, July 2001.

207. U.S. Department of Health, Education, and Welfare, *Radiological Health Handbook,* January 1970.

208. International Commission on Radiation Protection, *Radionuclide Transformations — Energy and Intensity of Emissions*, ICRP Publication 38, Volumes 11–13, Pergamon Press, New York, 1983.

209. Hughes, J., C. Langevin, and L. Brakefield-Goswami, *Effect of Hypersaline Cooling Canals on Aquifer Salinization*, Hydrogeology Journal, Vol. 18, pp. 25–38, 2010.

210. Merritt, M., *Simulation of the Water-Table Altitude in the Biscayne Aquifer, Southern Dade County, Florida, Water Years 1945–89*, U.S. Geological Survey, Water Supply Paper 2458, 1996.

211. U.S. Nuclear Regulatory Commission, Regulatory Guide 1.109, *Calculation of Annual Doses to Man from Routine Releases of Reactor Effluents for the Purpose of Evaluating Compliance with 10 CFR Part 50, Appendix I*, Office of Standards Development, Revision 1, October 1977.

212. Terzaghi, K. and R. Peck, *Soil Mechanics in Engineering Practice*, 2d ed., John Wiley & Sons, New York, 1967.

213. Helsel, D. and R. Peck, Statistical Methods in Water Resources, Elsevier Science, Amsterdam, The Netherlands, 1995.

214. Xu, M. and Y. Eckstein, *Use of Weighted Least-Squares Method in Evaluation of the Relationship Between Dispersivity and Field Scale*, Ground Water, Vol. 33, No. 6, pp. 905–908, 1995.

215. Zheng, C. and P. Wang, *MT3DMS Documentation and Users Guide*, November 1999.

216. Schlumberger Water Services, *Visual MODFLOW Professional Ver.4.3, User's Manual*, 2008.

217. Savannah River Remediation, *Closure & Waste Disposal Authority, Performance Assessment for the Saltstone Disposal Facility at the Savannah River Site*, SRR-CWDA-2009-00017, Rev. 0, October 2009.

218. Renken, R. et al., *Pathogen and Chemical Transport in the Karst Limestone of the Biscayne Aquifer: 1. Revised Conceptualization of Groundwater Flow,* Water Resources Research, Vol. 44, 2008.

219. Shapiro, A. et al., *Pathogen and Chemical Transport in the Karst Limestone of the Biscayne Aquifer: 2. Chemical Retention from Diffusion and Slow Advection*, Water Resources Research, Vol. 44, 2008.

220. U.S. Environmental Protection Agency, *Exposure Factors Handbook*, August 1997.

221. U.S. Environmental Protection Agency, *Limiting Values of Radionuclide Intake and Air Concentration and Dose Conversion Factors for Inhalation, Submersion, and Ingestion*, Federal Guidance Report No. 11, EPA-520/1-88-020, September 1988.

222. U.S. Nuclear Regulatory Commission, Regulatory Guide 1.183, *Alternative Radiological Source Terms for Evaluating Design Basis Accidents at Nuclear Power Reactors*, Office of Nuclear Regulatory Research, July 2000.

223. Phillips, O., *Geological Fluid Dynamics*, Cambridge University Press, Cambridge, United Kingdom, 2009.

224. de Marsily, G., *Quantitative Hydrogeology – Groundwater Hydrology for Engineers*, Academic Press, Inc., San Diego, California, 1986.

225. Fetter, C., *Contaminant Hydrogeology,* Macmillan Publishing Company, New York, 1993.

226. Bedient, P., H. Rifai, and C. Newell, *Ground Water Contamination – Transport and Remediation,* PTR Prentice Hall, Englewood Cliffs, New Jersey, 1994.

227. Hearn, N., R. Hooton, and R. Mills, *Pore Structure and Permeability,* P. Klieger and J. Lamond, (eds.), Significance of Tests and Properties of Concrete and Concrete-Making Materials, ASTM STP 169C, 1994.

228. Florida Department of Transportation, *Evaluating Thick Lift Limerock Base Course*, SR-826 Miami Florida, Draft Final Report, April 2005.

229. Pollock, D., *User's Guide for MODPATH/MODPATH-PLOT, Ver. 3: A Particle Tracking Post-Processing Package for MODFLOW, the U. S. Geological Survey Finite-Difference Ground-Water Flow Model*, U. S. Geological Survey, Open-File Report 94-464, 1994.

230. Hornberger, G., L. Konikow, and P. Harte, *Simulating Solute Transport Across Horizontal-Flow Barriers Using the MODFLOW Ground-Water Transport Process*, U. S. Geological Survey, Open-File Report 02-52, 2002.

231. Gelhar, L., C. Welty, and K. Rehfeldt, *A Critical Review of Data on Field-Scale Dispersion in Aquifers*, Water Resources Research, Vol. 28, No. 7, pp. 1955–1974, 1992.

232. Neville, C., M. Riley, and C. Zheng, *Implicit Modeling of Low Permeability Features: An Appraisal for Solute Transport*, E. Poeter, C. Zheng, and M. Hill (eds.), MODFLOW 98 Proceedings: Colorado School of Mines, Golden, Colorado, Vol. 1, pp. 353–362, 1998.

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Table 2.4.13-201 (Sheet 1 of 2)
Radionuclide Concentrations in the AP1000 Effluent Holdup Tanks

Radionuclide	Design Basis Reactor Coolant Activity[a] (µCi/g)	Reactor Coolant Concentration[b] (µCi/cm^3)	Effluent Holdup Tank Concentration[c] (µCi/cm^3)
H-3	1.00E+00	1.00E+00	1.01E+00
Cr-51	1.30E-03	1.30E-03	1.31E-03
Mn-54	6.70E-04	6.70E-04	6.77E-04
Mn-56	1.70E-01	1.70E-01	1.72E-01
Fe-55	5.00E-04	5.00E-04	5.05E-04
Fe-59	1.30E-04	1.30E-04	1.31E-04
Co-58	1.90E-03	1.90E-03	1.92E-03
Co-60	2.20E-04	2.20E-04	2.22E-04
Br-83	3.20E-02	1.54E-02	1.55E-02
Br-84	1.70E-02	8.16E-03	8.24E-03
Kr-88	1.50E+00	7.20E-01	7.27E-01
Rb-88	1.50E+00	7.20E-01	7.27E-01
Rb-89	6.90E-02	3.31E-02	3.35E-02
Sr-89	1.10E-03	5.28E-04	5.33E-04
Sr-90	4.90E-05	2.35E-05	2.38E-05
Sr-91	1.70E-03	8.16E-04	8.24E-04
Sr-92	4.10E-04	1.97E-04	1.99E-04
Y-90	1.30E-05	6.24E-06	6.30E-06
Y-91m	9.20E-04	4.42E-04	4.46E-04
Y-91	1.40E-04	6.72E-05	6.79E-05
Y-92	3.40E-04	1.63E-04	1.65E-04
Y-93	1.10E-04	5.28E-05	5.33E-05
Nb-95	1.60E-04	7.68E-05	7.76E-05
Zr-95	1.60E-04	7.68E-05	7.76E-05
Mo-99	2.10E-01	1.01E-01	1.02E-01
Tc-99m	2.00E-01	9.60E-02	9.70E-02
Ru-103	1.40E-04	6.72E-05	6.79E-05
Rh-103m	1.40E-04	6.72E-05	6.79E-05
Ag-110m	4.00E-04	1.92E-04	1.94E-04
Te-127m	7.60E-04	3.65E-04	3.68E-04
Te-129m	2.60E-03	1.25E-03	1.26E-03
Te-129	3.80E-03	1.82E-03	1.84E-03
Te-131m	6.70E-03	3.22E-03	3.25E-03
Te-131	4.30E-03	2.06E-03	2.08E-03
Te-132	7.90E-02	3.79E-02	3.83E-02
Te-134	1.10E-02	5.28E-03	5.33E-03
I-129	1.50E-08	7.20E-09	7.27E-09
I-130	1.10E-02	5.28E-03	5.33E-03
I-131	7.10E-01	3.41E-01	3.44E-01
I-132	9.40E-01	4.51E-01	4.56E-01
I-133	1.30E+00	6.24E-01	6.30E-01
I-134	2.20E-01	1.06E-01	1.07E-01

PTN COL 2.4-5

Table 2.4.13-201 (Sheet 2 of 2)
Radionuclide Concentrations in the AP1000 Effluent Holdup Tanks

Radionuclide	Design Basis Reactor Coolant Activity[a] (µCi/g)	Reactor Coolant Concentration[b] (µCi/cm^3)	Effluent Holdup Tank Concentration[c] (µCi/cm^3)
I-135	7.80E-01	3.74E-01	3.78E-01
Cs-134	6.90E-01	3.31E-01	3.35E-01
Cs-136	1.00E+00	4.80E-01	4.85E-01
Cs-137	5.00E-01	2.40E-01	2.42E-01
Cs-138	3.70E-01	1.78E-01	1.79E-01
Xe-138	2.50E-01	1.20E-01	1.21E-01
Ba-140	1.00E-03	4.80E-04	4.85E-04
La-140	3.10E-04	1.49E-04	1.50E-04
Ce-141	1.60E-04	7.68E-05	7.76E-05
Ce-143	1.40E-04	6.72E-05	6.79E-05
Pr-143	1.50E-04	7.20E-05	7.27E-05
Ce-144	1.20E-04	5.76E-05	5.82E-05
Pr-144	1.20E-04	5.76E-05	5.82E-05

Notes:

(a) Values from AP1000 DCD, Table 11.1-2.

(b) For tritium (H-3), a coolant concentration of 1.0 µCi/g is used (DCD Table 11.1-8); corrosion products (Cr-51, Mn-54, Mn-56, Fe-55, Fe-59, Co-58 and Co-60) are taken directly from the AP1000 DCD, Table 11.1-2, and other radionuclides are based on the AP1000 DCD, Table 11.1-2 multiplied by 0.12/0.25. The density of all liquids is assumed to be 1 g/cm^3.

(c) Values are 101 percent of the reactor coolant concentrations.

The following radionuclides are not included in the source term as they do not have an ECL and are not parent radionuclides to dosimetrically significant radionuclides: Kr-83m, Kr-85m, Kr-85, Kr-87, Kr-89, Br-85, Rh-106, Xe-131m, Xe-133, Xe-133m, Xe-135, Xe-135m, Xe-137, Ba-137m.

PTN COL 2.4-5

Table 2.4.13-202
Particle Tracking Results

Case	IWF Status	RCW Status	Minimum Travel Time (days)	Terminal Point
1	Operational	Off	4352	IWF
2	Operational	On	4511	IWF
3	Non-operational	Off	3759	Biscayne Bay
4	Non-operational	On	4079	RCW

PTN COL 2.4-5

Table 2.4.13-203 (Sheet 1 of 2)
Groundwater Concentrations for Primary Conceptual Model Considering Advection and Decay Only

Principal Radionuclide	Decay Chain Progeny	Half-life[a] (days)	d_{12}[b]	d_{13}[b]	d_{23}[b]	Decay Constant ($days^{-1}$)[c]	Effluent Holdup Tank Concentration ($\mu Ci/cm^3$)[d]	K_1[e]	K_2[f]	K_3[g]	Travel Time (days)[h]	Groundwater Concentration (C) ($\mu Ci/cm^3$)[i]	ECL ($\mu Ci/cm^3$)[j]	C/ECL Ratio[k]
Cs-137		1.10E+04	--	--	--	6.30E-05	2.42E-01	--	--	--	4.30E+03	1.85E-01	1.00E-06	1.85E+05
Cs-134		7.53E+02	--	--	--	9.21E-04	3.35E-01	--	--	--	4.30E+03	6.40E-03	9.00E-07	7.11E+03
H-3		4.51E+03	--	--	--	1.54E-04	1.01E+00	--	--	--	4.30E+03	5.22E-01	1.00E-03	5.22E+02
Sr-90		1.06E+04	--	--	--	6.54E-05	2.38E-05	--	--	--	4.30E+03	1.80E-05	5.00E-07	3.59E+01
	Y-90	2.67E+00	1	--	--	2.60E-01	6.30E-06	2.38E-05	-1.75E-05	--	4.30E+03	1.80E-05	7.00E-06	2.57E+00
Co-60		1.93E+03	--	--	--	3.59E-04	2.22E-04	--	--	--	4.30E+03	4.74E-05	3.00E-06	1.58E+01
Fe-55		9.86E+02	--	--	--	7.03E-04	5.05E-04	--	--	--	4.30E+03	2.46E-05	1.00E-04	2.46E-01
I-129		5.73E+09	--	--	--	1.21E-10	7.27E-09	--	--	--	4.30E+03	7.27E-09	2.00E-07	3.63E-02
Mn-54		3.13E+02	--	--	--	2.21E-03	6.77E-04	--	--	--	4.30E+03	4.95E-08	3.00E-05	1.65E-03
Ce-144		2.84E+02	--	--	--	2.44E-03	5.82E-05	--	--	--	4.30E+03	1.61E-09	3.00E-06	5.37E-04
	Pr-144m	5.00E-03	0.0178	--	--	1.39E+02	0.00E+00	1.04E-06	-1.04E-06	--	4.30E+03	2.87E-11	NA	NA
	Pr-144	1.20E-02	--	0.9822	0.999	5.78E+01	5.82E-05	5.82E-05	7.39E-07	-7.41E-07	4.30E+03	1.61E-09	6.00E-04	2.68E-06
Ag-110m		2.50E+02	--	--	--	2.77E-03	1.94E-04	--	--	--	4.30E+03	1.29E-09	6.00E-06	2.15E-04
Cr-51		2.77E+01	--	--	--	2.50E-02	1.31E-03	--	--	--	4.30E+03	2.44E-50	5.00E-04	0.00E+00
Mn-56		1.07E-01	--	--	--	6.48E+00	1.72E-01	--	--	--	4.30E+03	0.00E+00	7.00E-05	0.00E+00
Fe-59		4.45E+01	--	--	--	1.56E-02	1.31E-04	--	--	--	4.30E+03	1.07E-33	1.00E-05	0.00E+00
Co-58		7.08E+01	--	--	--	9.79E-03	1.92E-03	--	--	--	4.30E+03	1.00E-21	2.00E-05	0.00E+00
Br-83		9.96E-02	--	--	--	6.96E+00	1.55E-02	--	--	--	4.30E+03	0.00E+00	9.00E-04	0.00E+00
Br-84		2.21E-02	--	--	--	3.14E+01	8.24E-03	--	--	--	4.30E+03	0.00E+00	4.00E-04	0.00E+00
Kr-88		1.18E-01	--	--	--	5.86E+00	7.27E-01	--	--	--	4.30E+03	0.00E+00	NA	NA
	Rb-88	1.24E-02	1	--	--	5.59E+01	7.27E-01	8.12E-01	-8.51E-02	--	4.30E+03	0.00E+00	4.00E-04	0.00E+00
Rb-89		1.06E-02	--	--	--	6.54E+01	3.35E-02	--	--	--	4.30E+03	0.00E+00	9.00E-04	0.00E+00
	Sr-89	5.05E+01	1	--	--	1.37E-02	5.33E-04	-7.03E-06	5.40E-04	--	4.30E+03	1.26E-29	8.00E-06	0.00E+00
Sr-91		3.96E-01	--	--	--	1.75E+00	8.24E-04	--	--	--	4.30E+03	0.00E+00	2.00E-05	0.00E+00
	Y-91m	3.45E-02	0.578	--	--	2.01E+01	4.46E-04	5.22E-04	-7.57E-05	--	4.30E+03	0.00E+00	2.00E-03	0.00E+00
	Y-91	5.85E+01	--	0.422	1	1.18E-02	6.79E-05	-5.93E-06	4.47E-08	7.38E-05	4.30E+03	5.51E-27	8.00E-06	0.00E+00
Sr-92		1.13E-01	--	--	--	6.13E+00	1.99E-04	--	--	--	4.30E+03	0.00E+00	4.00E-05	0.00E+00
	Y-92	1.48E-01	1	--	--	4.68E+00	1.65E-04	-6.42E-04	8.07E-04	--	4.30E+03	0.00E+00	4.00E-05	0.00E+00
Y-93		4.21E-01	--	--	--	1.65E+00	5.33E-05	--	--	--	4.30E+03	0.00E+00	2.00E-05	0.00E+00
Zr-95		6.40E+01	--	--	--	1.08E-02	7.76E-05	--	--	--	4.30E+03	4.62E-25	2.00E-05	0.00E+00
	Nb-95m	3.61E+00	0.007	--	--	1.92E-01	0.00E+00	5.76E-07	-5.76E-07	--	4.30E+03	3.43E-27	3.00E-05	0.00E+00
	Nb-95	3.52E+01	--	0.993	1	1.97E-02	7.76E-05	1.73E-04	6.58E-08	-9.50E-05	4.30E+03	1.03E-24	3.00E-05	0.00E+00
Mo-99		2.75E+00	--	--	--	2.52E-01	1.02E-01	--	--	--	4.30E+03	0.00E+00	2.00E-05	0.00E+00
	Tc-99m	2.51E-01	0.876	--	--	2.76E+00	9.70E-02	9.83E-02	-1.33E-03	--	4.30E+03	0.00E+00	1.00E-03	0.00E+00
Ru-103		3.93E+01	--	--	--	1.76E-02	6.79E-05	--	--	--	4.30E+03	7.85E-38	3.00E-05	0.00E+00
	Rh-103m	3.90E-02	0.997	--	--	1.78E+01	6.79E-05	6.78E-05	1.36E-07	--	4.30E+03	7.83E-38	6.00E-03	0.00E+00
Te-127m		1.09E+02	--	--	--	6.36E-03	3.68E-04	--	--	--	4.30E+03	4.90E-16	9.00E-06	0.00E+00
	Te-127	3.90E-01	0.976	--	--	1.78E+00	0.00E+00	3.60E-04	-3.60E-04	--	4.30E+03	4.80E-16	1.00E-04	0.00E+00
Te-129m		3.36E+01	--	--	--	2.06E-02	1.26E-03	--	--	--	4.30E+03	3.76E-42	7.00E-06	0.00E+00
	Te-129	4.83E-02	0.65	--	--	1.44E+01	1.84E-03	8.20E-04	1.02E-03	--	4.30E+03	2.45E-42	4.00E-04	0.00E+00
I-130		5.15E-01	--	--	--	1.35E+00	5.33E-03	--	--	--	4.30E+03	0.00E+00	2.00E-05	0.00E+00
Te-131m		1.25E+00	--	--	--	5.55E-01	3.25E-03	--	--	--	4.30E+03	0.00E+00	8.00E-06	0.00E+00
	Te-131	1.74E-02	0.222	--	--	3.98E+01	2.08E-03	7.32E-04	1.35E-03	--	4.30E+03	0.00E+00	8.00E-05	0.00E+00
	I-131	8.04E+00	--	0.778	1	8.62E-02	3.44E-01	-6.00E-04	-2.92E-06	3.45E-01	4.30E+03	3.46E-162	1.00E-06	0.00E+00
Te-132		3.26E+00	--	--	--	2.13E-01	3.83E-02	--	--	--	4.30E+03	0.00E+00	9.00E-06	0.00E+00
	I-132	9.58E-02	1	--	--	7.24E+00	4.56E-01	3.95E-02	4.17E-01	--	4.30E+03	0.00E+00	1.00E-04	0.00E+00
Te-134		2.90E-02	--	--	--	2.39E+01	5.33E-03	--	--	--	4.30E+03	0.00E+00	3.00E-04	0.00E+00

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Table 2.4.13-203 (Sheet 2 of 2)
Groundwater Concentrations for Primary Conceptual Model Considering Advection and Decay Only

Principal Radionuclide	Decay Chain Progeny	Half-life[a] (days)	d_{12}[b]	d_{13}[b]	d_{23}[b]	Decay Constant ($days^{-1}$)[c]	Effluent Holdup Tank Concentration ($\mu Ci/cm^3$)[d]	K_1[e]	K_2[f]	K_3[g]	Travel Time (days)[h]	Groundwater Concentration (C) ($\mu Ci/cm^3$)[i]	ECL ($\mu Ci/cm^3$)[j]	C/ECL Ratio[k]
	I-134	3.65E-02	1	--	--	1.90E+01	1.07E-01	-2.06E-02	1.28E-01	--	4.30E+03	0.00E+00	4.00E-04	0.00E+00
I-133		8.67E-01	--	--	--	7.99E-01	6.30E-01	--	--	--	4.30E+03	0.00E+00	7.00E-06	0.00E+00
I-135		2.75E-01	--	--	--	2.52E+00	3.78E-01	--	--	--	4.30E+03	0.00E+00	3.00E-05	0.00E+00
Cs-136		1.31E+01	--	--	--	5.29E-02	4.85E-01	--	--	--	4.30E+03	7.49E-100	6.00E-06	0.00E+00
Xe-138		9.84E-03	--	--	--	7.04E+01	1.21E-01	--	--	--	4.30E+03	0.00E+00	NA	NA
	Cs-138	2.24E-02	1	--	--	3.09E+01	1.79E-01	-9.48E-02	2.74E-01	--	4.30E+03	0.00E+00	4.00E-04	0.00E+00
Ba-140		1.27E+01	--	--	--	5.46E-02	4.85E-04	--	--	--	4.30E+03	5.78E-106	8.00E-06	0.00E+00
	La-140	1.68E+00	1	--	--	4.13E-01	1.50E-04	5.59E-04	-4.09E-04	--	4.30E+03	6.67E-106	9.00E-06	0.00E+00
Ce-141		3.25E+01	--	--	--	2.13E-02	7.76E-05	--	--	--	4.30E+03	1.15E-44	3.00E-05	0.00E+00
Ce-143		1.38E+00	--	--	--	5.02E-01	6.79E-05	--	--	--	4.30E+03	0.00E+00	2.00E-05	0.00E+00
	Pr-143	1.36E+01	1	--	--	5.10E-02	7.27E-05	-7.67E-06	8.04E-05	--	4.30E+03	5.33E-100	2.00E-05	0.00E+00
													Sum	**1.92E+05**

(a) Values from Table E-1 (Reference 204). Reference 207 for Sr-92, and Reference 208 for Pr-144, Pr-144m, Kh-88, Xe-138.
(b) Reference 208.
(c) Equation 2.4.13-5.
(d) Table 2.4.13-201.
(e) Equation 2.4.13-6 and Equation 2.4.13-8.
(f) Equation 2.4.13-6 and Equation 2.4.13-8.
(g) Equation 2.4.13-8.
(h) Subsection 2.4.13.1.5.1.
(i) Calculated using Equation 2.4.13-1, Equation 2.4.13-6, or Equation 2.4.13-8 depending on position in decay chain.
(j) Values from 10 CFR Part 20, Appendix B, Table 2, Column 2.
(k) Values less than 1.0E-06 are reported as zero.
N/A = Not Applicable

PTN COL 2.4-5

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Table 2.4.13-204
Results of K_d Analysis

Sample Location And Size	Element Distribution Coefficient							
	Mn	Fe	Co	Sr	Ag	Te	Cs	Ce
606-2 (1 mm)	15.3	1	2.1	1	1.5	21.8	0.22	580
606-2 (1mm) duplicate	18.4	0.06	1.9	1	1.3	56.6	0.13	531
606-2 (1 mm) triplicate	17.9	1	1.7	1	1.3	93.6	0.17	523
606-2 (1 cm)	7.9	1	1.5	0.03	1.6	30.6	0.1	505
621-9 (1mm)	24.7	0.46	4.1	0.27	7.2	421	0.15	443
621-9 (1 cm)	29.4	16.4**	1.6	0.33	2.9	32.5	0.09	427
706-1 (1 mm)	26.1	0.25	1.4	0.09	0.89	73.2	0.16	654
706-1 (1 cm)	15.8	0.44	0.85	0.15	1	7.7	0.09	620
721-8 (1 mm)	28	0.86	2.1	0.1	1.4	73.6	0.28	561
721-8 (1 cm)	17.8	0.58	1.5	0.08	0.32	12.1	0.21	580
735-9 (1 mm)	26.1	1	0.6	0.23	6.1	169	0.68	623
735-9 (1 cm)	18.6	1	1.9	0.24	7.5	99.1	0.42	670
735-9 (1 cm) duplicate	17.3	1	2	0.18	6.2	107	0.29	512
802-8 (1 cm)	18.3	1	1.4	0.28	2.4	36.4	0.13	608
805 (1 mm)	27.4	1	3	0.56	3.3	816	0.17	439
805 (1 cm)	6.3	1.3	2.1	0.75	1.9	23.6	0.2	324
809-1 (1 mm)	26.5	1	3.1	0.27	3.1	124	0.17	659
809-1 (1 mm) duplicate	26.4	1	2.8	0.1	2.6	221	0.04	686
809-1 (1 cm)	18	0.1	1.6	0.3	0.6	27.4	0.2	680
Minimum	6.3	0.06	0.6	0.03	0.32	7.7	0.04	324
Maximum	29.4	16.4	4.1	0.75	7.5	816	0.68	686
Average	20.3	1.2	2.0	0.2	2.8	128.7	0.2	559
Geometric Mean	19	0.20*	1.8	0.14	2.0	64	0.17	550

Notes: All results in cubic centimeter per gram
(1 mm) -- sample crushed to 1 millimeter passing
(1 cm) -- sample crushed to 1 centimeter passing
Yellow shaded area indicates the value was reported as a less than value; for calculation of the average and geometric mean, the minimum reported value is assumed for the less than (yellow) values.
Blue shaded area indicates value was reported as greater than value included in this table; greater than sign was ignored for calculation purposes
*The K_d for Fe is assumed to equal zero for all analyses in this calculation (Subsection 2.4.13.1.5.2)
** Possible outlier

PTN COL 2.4-5

Table 2.4.13-205
Groundwater Concentrations for Primary Conceptual Model Considering Advection, Decay, and Retardation

Principal Radionuclide	Decay Chain Progeny	Half-life[a] (days)	d_{12}[b]	d_{13}[b]	d_{23}[b]	Decay Constant ($days^{-1}$)[c]	Effluent Holdup Tank Concentration ($\mu Ci/cm^3$)[d]	K_1[e]	K_2[f]	K_3[g]	K_d[h] (cm^3/g)	R[i]	Travel Time[j] (days)	Groundwater Concentration (C) ($\mu Ci/cm^3$)[k]	ECL ($\mu Ci/cm^3$)[l]	C/ECL Ratio[m]
Cs-137		1.10E+04	--	--	--	6.30E-05	2.42E-01	--	--	--	1.70E-01	2.80E+00	1.20E+04	1.13E-01	1.00E-06	1.13E+05
H-3		4.51E+03	--	--	--	1.54E-04	1.01E+00	--	--	--	0.00E+00	1.00E+00	4.30E+03	5.22E-01	1.00E-03	5.22E+02
Sr-90		1.06E+04	--	--	--	6.54E-05	2.38E-05	--	--	--	1.40E-01	2.48E+00	1.07E+04	1.18E-05	5.00E-07	2.37E+01
	Y-90	2.67E+00	1	--	--	2.60E-01	6.30E-06	2.38E-05	-1.75E-05	--	1.40E-01	2.48E+00	1.07E+04	1.18E-05	7.00E-06	1.69E+00
Cs-134		7.53E+02	--	--	--	9.21E-04	3.35E-01	--	--	--	1.70E-01	2.80E+00	1.20E+04	5.11E-06	9.00E-07	5.68E+00
Fe-55		9.86E+02	--	--	--	7.03E-04	5.05E-04	--	--	--	0.00E+00	1.00E+00	4.30E+03	2.46E-05	1.00E-04	2.46E-01
I-129		5.73E+09	--	--	--	1.21E-10	7.27E-09	--	--	--	0.00E+00	1.00E+00	4.30E+03	7.27E-09	2.00E-07	3.63E-02
Co-60		1.93E+03	--	--	--	3.59E-04	2.22E-04	--	--	--	1.80E+00	2.01E+01	8.63E+04	7.57E-18	3.00E-06	0.00E+00
Mn-54		3.13E+02	--	--	--	2.21E-03	6.77E-04	--	--	--	1.90E+01	2.02E+02	8.70E+05	0.00E+00	3.00E-05	0.00E+00
Ce-144		2.84E+02	--	--	--	2.44E-03	5.82E-05	--	--	--	5.50E+02	5.83E+03	2.51E+07	0.00E+00	3.00E-06	0.00E+00
	Pr-144m	5.00E-03	0.0178	--	--	1.39E+02	0.00E+00	1.04E-06	-1.04E-06	--	5.50E+02	5.83E+03	2.51E+07	0.00E+00	NA	NA
	Pr-144	1.20E-02	--	0.9822	0.999	5.78E+01	5.82E-05	5.82E-05	7.39E-07	-7.41E-07	5.50E+02	5.83E+03	2.51E+07	0.00E+00	6.00E-04	0.00E+00
Ag-110m		2.50E+02	--	--	--	2.77E-03	1.94E-04	--	--	--	2.00E+00	2.22E+01	9.55E+04	2.20E-119	6.00E-06	0.00E+00
															Sum	**1.14E+05**

(a) Values from Table E.1 (Reference 204), Reference 208 for Pr-144 and Pr-144m
(b) Reference 208
(c) Equation 2.4.13-5.
(d) Table 2.4.13-201.
(e) Equation 2.4.13-6 and Equation 2.4.13-8.
(f) Equation 2.4.13-6 and Equation 2.4.13-8.
(g) Equation 2.4.13-8.
(h) Table 2.4.13-204 as applicable
(i) Equation 2.4.13-3
(j) Equation 2.4.13-2
(k) Calculated using Equation 2.4.13-1, Equation 2.4.13-6, or Equation 2.4.13-8 depending on position in decay chain
(l) Values from 10 CFR Part 20, Appendix B, Table 2, Column 2.
(m) Values less than 1.0E-06 are reported as zero

NA = Not Applicable

PTN COL 2.4-5

Table 2.4.13-206
Transport Model - Hydrogeologic Parameters

Material	Model Layer(s)	Effective Porosity, n_e	Total Porosity, n	Bulk Density, ρ_b (g/cm^3)
In Situ Materials				
Muck	1-2	0.15	0.83	0.45
Offshore Sediment	1-2	0.15	0.83	0.45
Miami Limestone	1-4	0.15	0.41	1.59
Upper Higher Flow Zone	5	0.40	0.50	1.35
Key Largo SW	6-8	0.15	0.31	1.87
Key Largo NE	6-8	0.15	0.31	1.87
Freshwater Limestone	8	0.15	0.28	1.95
Lower Higher Flow Zone	11	0.40	0.50	1.35
Fort Thompson	9-10 & 12-14	0.15	0.28	1.95
Tamiami	15	0.15	0.46	1.47
Concrete				
Concrete Mud Mat	4	0.05	0.07	2.51
Concrete Fill	5-6	0.05	0.07	2.51
Other Materials				
Backfill – Non-Structural	1-2	0.15	0.28	1.93
Backfill - Structural	1-4	0.15	0.26	1.99
Grouted *In Situ* Materials	7-9	0.15	0.25	2.03
Canal (water)*	1-6	0.15	0.30	1.89

* Note that the Canal properties are only applicable to the IWF-non-operational cases

PTN COL 2.4-5

Table 2.4.13-207
Surface Water Concentrations for Primary Conceptual Model Considering Advection, Decay, Retardation and Dilution

Radionuclide	ECL ($\mu Ci/cm^3$)	Groundwater Concentration[(a)] ($\mu Ci/cm^3$)	Surface Water Concentration (C)[(b)] ($\mu Ci/cm^3$)	C/ECL Ratio[(c)]
Cs-137	1.0E-06	1.13E-01	6.34E-07	6.34E-01
H-3	1.0E-03	5.22E-01	8.17E-06[(d)]	8.17E-03
Sr-90	5.0E-07	1.18E-05	6.63E-11	1.33E-04
Cs-134	9.0E-07	5.11E-06	2.86E-11	3.18E-05
Y-90	7.0E-06	1.18E-05	6.63E-11	9.47E-06
Fe-55	1.0E-04	2.46E-05	1.38E-10	1.38E-06
I-129	2.0E-07	7.27E-09	4.07E-14	0.00E+00
			Sum	**6.43E-01**

(a) From Table 2.4.13-206.
(b) Equals groundwater concentration with a dilution factor of 5.6E-06 applied
(c) Values less than 1.0E-06 reported as zero
(d) H-3 concentration includes background H-3

PTN COL 2.4-5

Table 2.4.13-208
Primary Conceptual Model Dose Results

Radionuclide	Water Concentration[a] (μCi/cm³)	Water Concentration (pCi/L)	Fish-Water Concentration Ratio[b] (FWR) (L/Kg)	Crustacean Mollusk-Water Concentration Ratio[b] (CMWR) (L/Kg)	Fraction of Aquatic Food (Crustacean/ Mollusk) that is Contaminated[c] (FR) (unitless)	Fraction of Aquatic Food (Fish) that is Contaminated[c] (FR) (unitless)	Dietary Factor for Annual Consumption of Fish[d] (DFf) (kg/year)	Dietary Factor for Annual Consumption of Crustaceans and Mollusks[d] (DFcm) (kg/year)	Intake from Fish Ingestion[e] (pCi/year)	Intake from Crustacean/ Mollusk Ingestion[f] (pCi/year)	Dose Conversion Factor[g] (DCF) (mrem/pCi)	Dose from Fish Ingestion[h] (mrem/year)	Dose from Crustacean/ Mollusk Ingestion[i] (mrem/year)	Total Dose -- Aquatic Ingestion[j] (mrem/year)
Cs-137	6.34E-07	6.34E+02	4.00E+01	2.50E+01	0.5	0.5	5.4	0.9	6.85E+04	7.14E+03	5.00E-05	3.42E+00	3.56E-01	3.78E+00
H-3	8.17E-06	8.17E+03	9.00E-01	9.30E-01	0.5	0.5	5.4	0.9	1.99E+04	3.42E+03	6.40E-08	1.27E-03	2.19E-04	1.49E-03
Fe-55	1.38E-10	1.38E-01	3.00E+03	2.00E+04	0.5	0.5	5.4	0.9	1.11E+03	1.24E+03	6.07E-07	6.76E-04	7.52E-04	1.43E-03
Y-90	6.63E-11	6.63E-02	2.50E+01	1.00E+03	0.5	0.5	5.4	0.9	4.48E+00	2.98E+01	1.08E-05	4.82E-05	3.21E-04	3.69E-04
Cs-134	2.86E-11	2.86E-02	4.00E+01	2.50E+01	0.5	0.5	5.4	0.9	3.09E+00	3.22E-01	7.33E-05	2.26E-04	2.36E-05	2.50E-04
Sr-90	6.63E-11	6.63E-02	2.00E+00	2.00E+01	0.5	0.5	5.4	0.9	3.58E-01	5.97E-01	1.42E-04	5.10E-05	8.50E-05	1.36E-04
											TOTALS	3.42E+00	3.58E-01	3.78E+00

Notes:

(a) Concentrations from Table 2.4.13-207. No dilution in the bay is assumed.

(b) Table A-1 (saltwater) from Reference 211.

(c) Section D.2.2 in Appendix D of Reference 206

(d) Table D.2 in Reference 206.

(e) Calculated as: [Water conc (pCi/L)] * FWR * DFf *FR

(f) Calculated as: [Water conc (pCi/L)] * CMMR * DFcm *FR

(g) "Effective" column of Table 2.2, Reference 221.

(h) Calculated as: Intake from Fish Ingestion (pCi/year) * DCF (mrem/pCi)

(i) Calculated as: Intake from Crustacean/Mollusk Ingestion (pCi/year) * DCF (mrem/pCi)

(j) Calculated as: Dose from Fish Ingestion (mrem/year) + Dose from Crustacean/Mollusk Ingestion (mrem/year)

PTN COL 2.4-5

Table 2.4.13-209
Transport Model - Total Activity

Radionuclide	Effluent Holdup Tank Release (Ci)	Simulated Release in Model (Ci)	Over-Estimate (%)
H-3	85.6	88.6	3
Fe-55	0.0428	0.0443	3
Sr-90	0.00202	0.00239	18
Cs-134	28.4	31.9	12
Cs-137	20.5	23.1	12

Note: Total activity in simulated release includes instantaneously absorbed component.

PTN COL 2.4-5

Table 2.4.13-210
MT3DMS Output - Model Layer 1 Maximum Concentration at CW-2s

Radionuclide	Offshore Sediment (Layer 1) Maximum Concentration (uCi/cm^3)
H-3	5.1E-05
Cs-137	4.1E-06
Cs-134	8.7E-07
Fe-55	1.5E-08
Sr-90	4.9E-10

PTN COL 2.4-5

Table 2.4.13-211
Alternate Conceptual Model Dose Results Considering Advection, Decay, Retardation and Dispersion

Radionuclide	Water Concentration[a] ($\mu Ci/cm^3$)	Water Concentration (pCi/L)	Fish-Water Concentration Ratio[b] (FWR) (L/Kg)	Crustacean Mollusk-Water Concentration Ratio[b] (CMWR) (L/Kg)	Fraction of Aquatic Food (Crustacean/ Mollusk) that is Contaminated[c] (FR) (unitless)	Fraction of Aquatic Food (Fish) that is Contaminated[c] (FR) (unitless)	Dietary Factor for Annual Consumption of Fish[d] (DFf) (kg/year)	Dietary Factor for Annual Consumption of Crustaceans and Mollusks[d] (DFcm) (kg/year)	Intake from Fish Ingestion[e] (pCi/year)	Intake from Crustacean/ Mollusk Ingestion[f] (pCi/year)	Dose Conversion Factor[g] (DCF) (mrem/pCi)	Dose from Fish Ingestion[h] (mrem/year)	Dose from Crustacean/ Mollusk Ingestion[i] (mrem/year)	Total Dose -- Aquatic Ingestion[j] (mrem/year)
Cs-137	4.10E-06	4.10E+03	4.00E+01	2.50E+01	0.5	0.5	5.4	0.9	4.43E+05	4.61E+04	5.00E-05	2.21E+01	2.30E+00	2.44E+01
Cs-134	8.70E-07	8.70E+02	8.70E-02	2.50E+01	0.5	0.5	5.4	0.9	9.40E+04	9.79E+03	7.33E-05	6.88E+00	7.17E-01	7.60E+00
Fe-55	1.50E-05	1.50E+01	3.00E+03	2.00E+04	0.5	0.5	5.4	0.9	1.22E+05	1.35E+05	6.07E-07	7.37E-02	8.19E-02	1.56E-01
H-3	5.10E-05	5.10E+04	9.00E-01	9.30E-01	0.5	0.5	5.4	0.9	1.24E+05	2.13E+04	6.40E-08	7.93E-03	1.37E-03	9.30E-03
Y-90	4.90E-10	4.90E-01	2.50E+01	1.00E+03	0.5	0.5	5.4	0.9	3.31E+01	2.21E+02	1.08E-05	3.56E-04	2.37E-03	2.73E-03
Sr-90	4.90E-10	4.90E-01	2.00E+00	2.00E+01	0.5	0.5	5.4	0.9	2.65E+00	4.41E+00	1.42E-04	3.77E-04	6.28E-04	1.01E-03
											TOTALS	2.91E+01	3.11E+00	3.22E+01

Notes:

(a) Concentrations from Table 2.4.13-210. No dilution in the bay is assumed.

(b) Table A-1 (saltwater) from Reference 211.

(c) Section D.2.2 in Appendix D of Reference 206.

(d) Table D.2 in Reference 206.

(e) Calculated as: [Water conc (pCi/L)] * FWR * DFf *FR

(f) Calculated as: [Water conc (pCi/L)] * CMMR * DFcm *FR

(g) "Effective" column of Table 2.2, Reference 221.

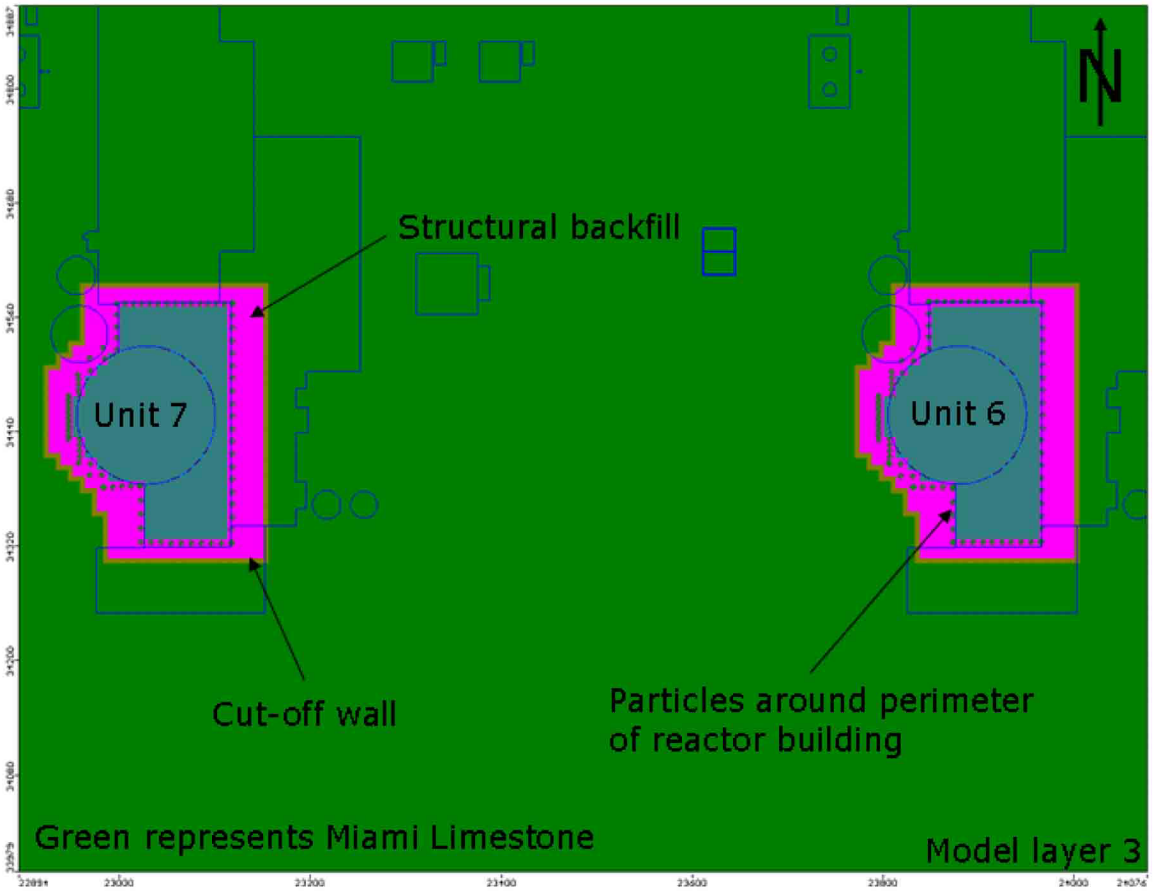
(h) Calculated as: Intake from Fish Ingestion (pCi/year) * DCF (mrem/pCi)

(i) Calculated as: Intake from Crustacean/Mollusk Ingestion (pCi/year) * DCF (mrem/pCi)

(j) Calculated as: Dose from Fish Ingestion (mrem/year) + Dose from Crustacean/Mollusk Ingestion (mrem/year)

PTN COL 2.4-5

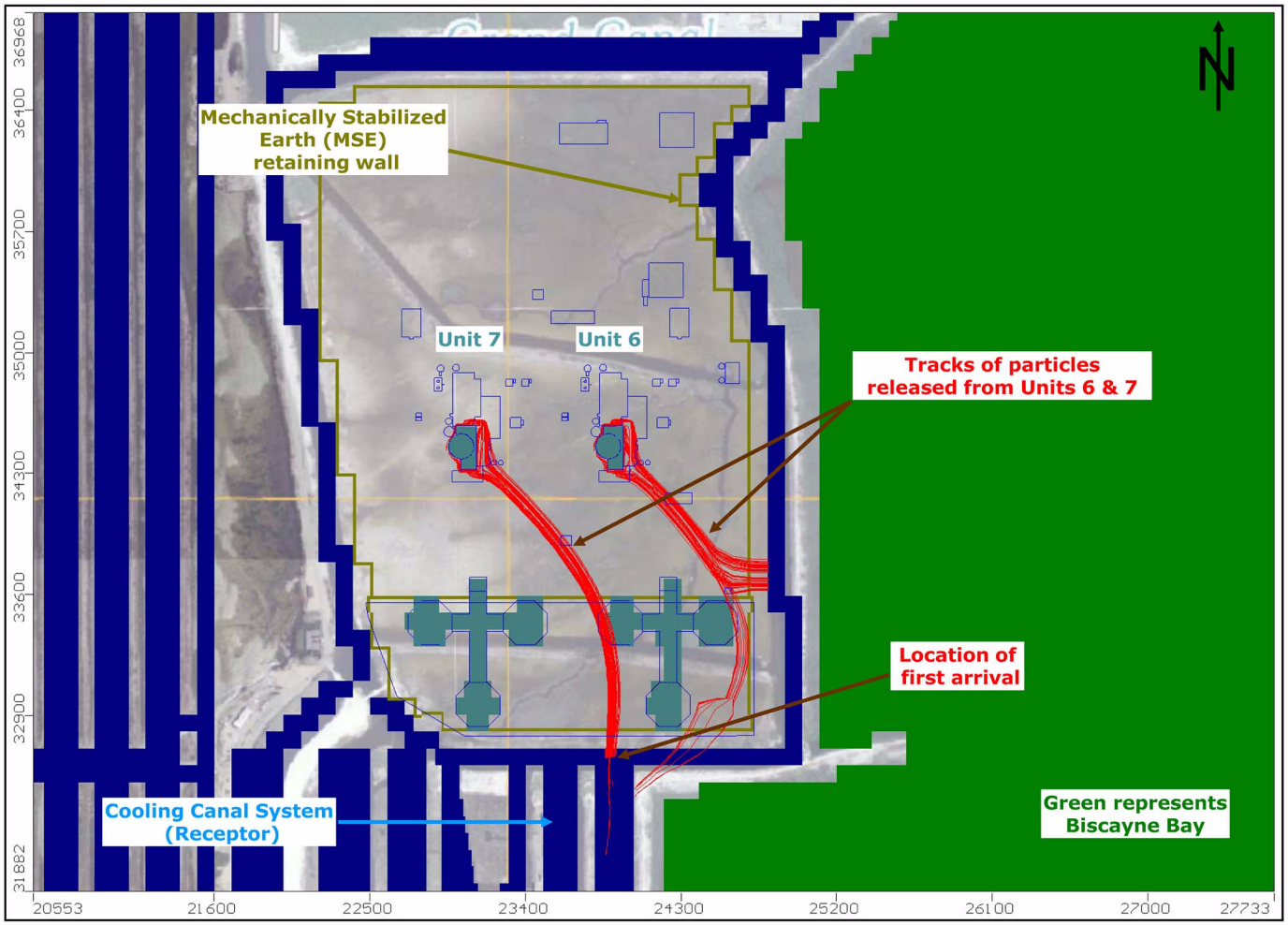
Figure 2.4.13-201 MODPATH Particle Starting Locations



Note: Horizontal and vertical axes represent model coordinates in feet. Model origin at easting 852766, northing 362512 (in State Plane Coordinates, North American Datum of 1983/Adjustment of 1990, Florida East, Zone 0901, U.S. feet)

PTN COL 2.4-5

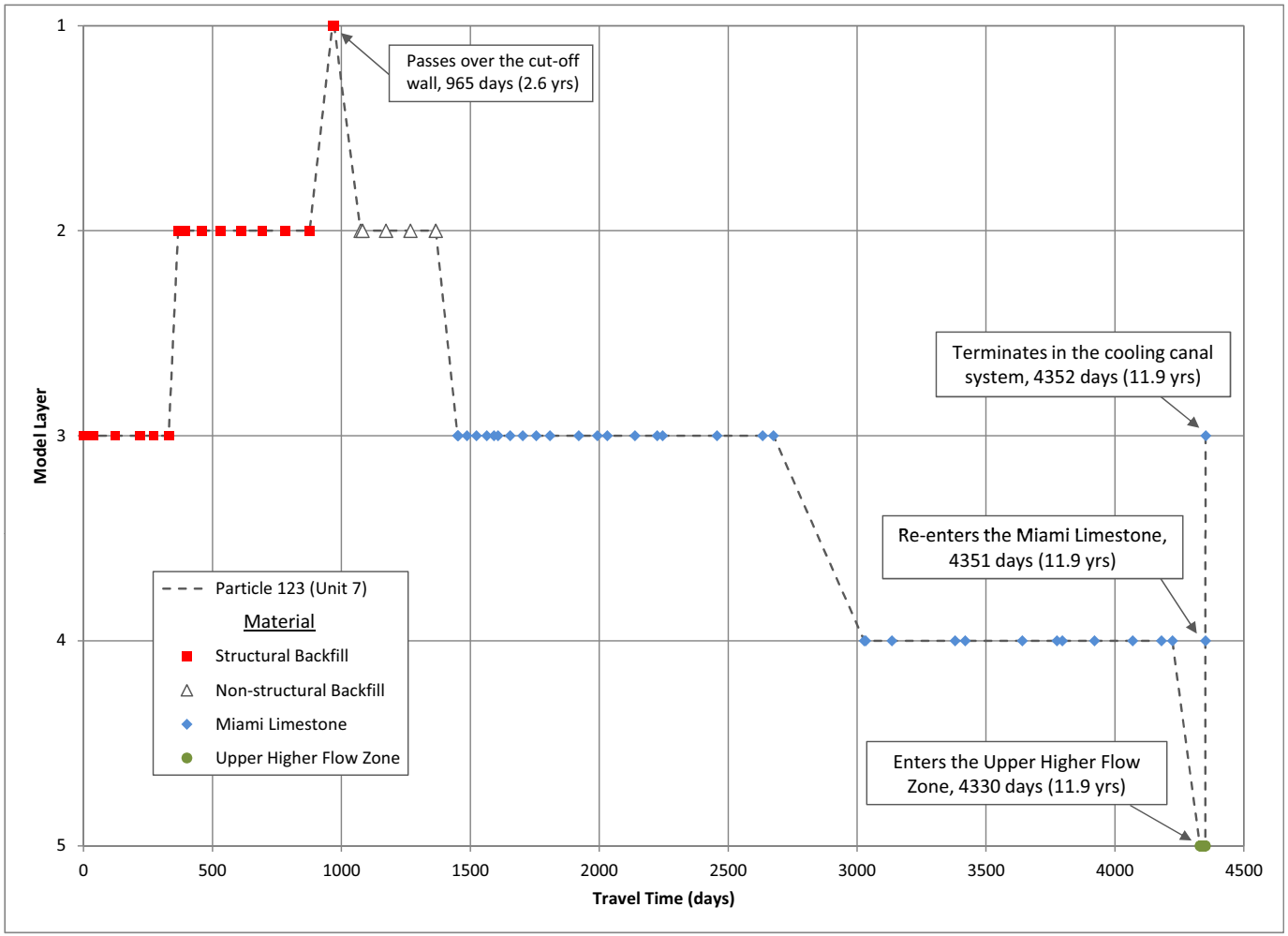
Figure 2.4.13-202 MODPATH Particle Tracking Case 1 Plan View (IWF-On, RCW-Off)



Notes: Model layer 1 shown. Pathlines represent projections onto model layer 1 for all particles released.
Horizontal and vertical axes represent model coordinates in feet. Model origin at easting 852766, northing 362512 (in State Plane Coordinates, North American Datum of 1983/Adjustment of 1990, Florida East, Zone 0901, U.S. feet)

PTN COL 2.4-5

Figure 2.4.13-203 MODPATH Particle Tracking - Case Layer 1 with Time



PTN COL 2.4-5

Figure 2.4.13-204 MODPATH Particle Tracking - Case 1 Distance with Time

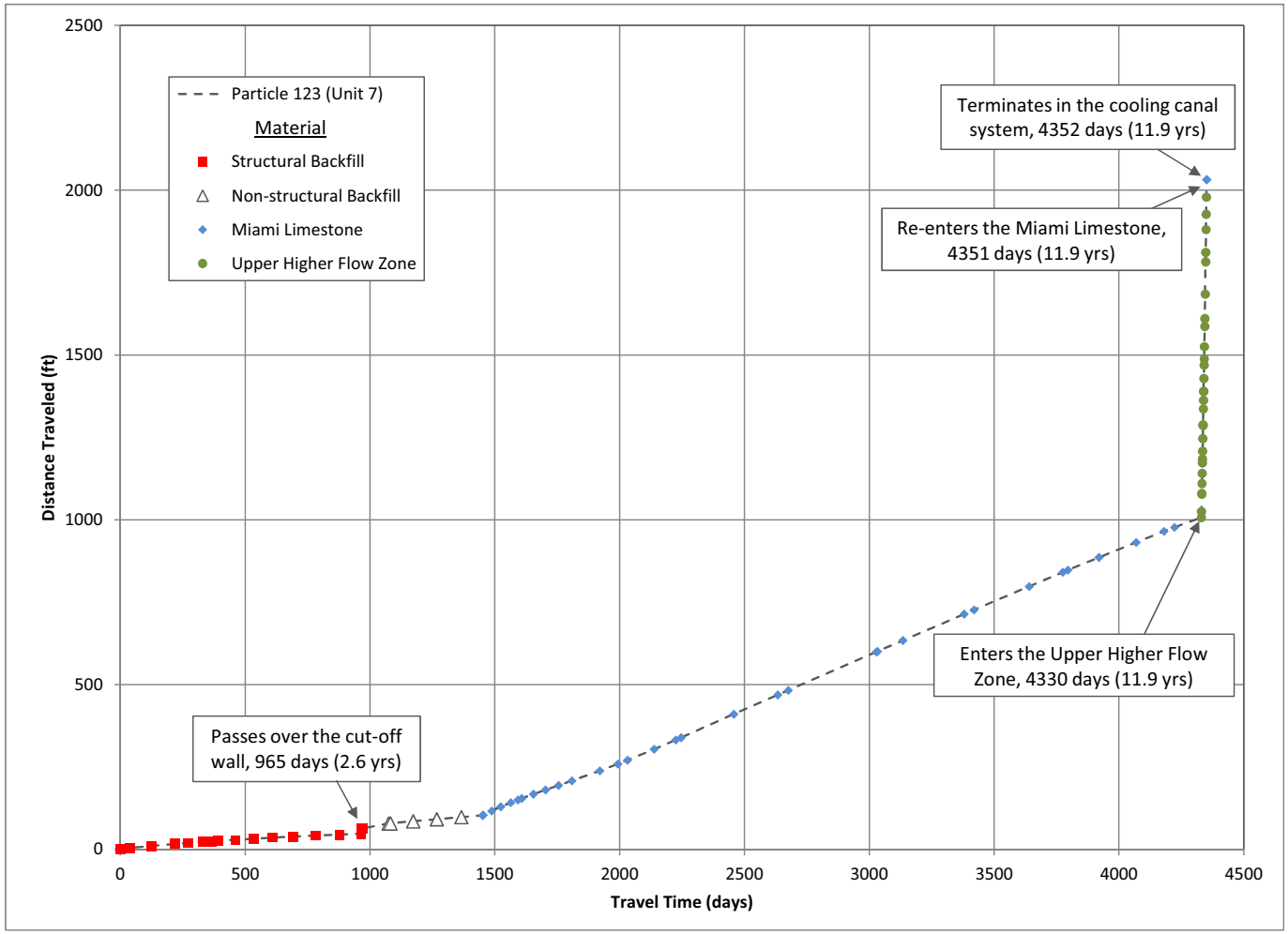
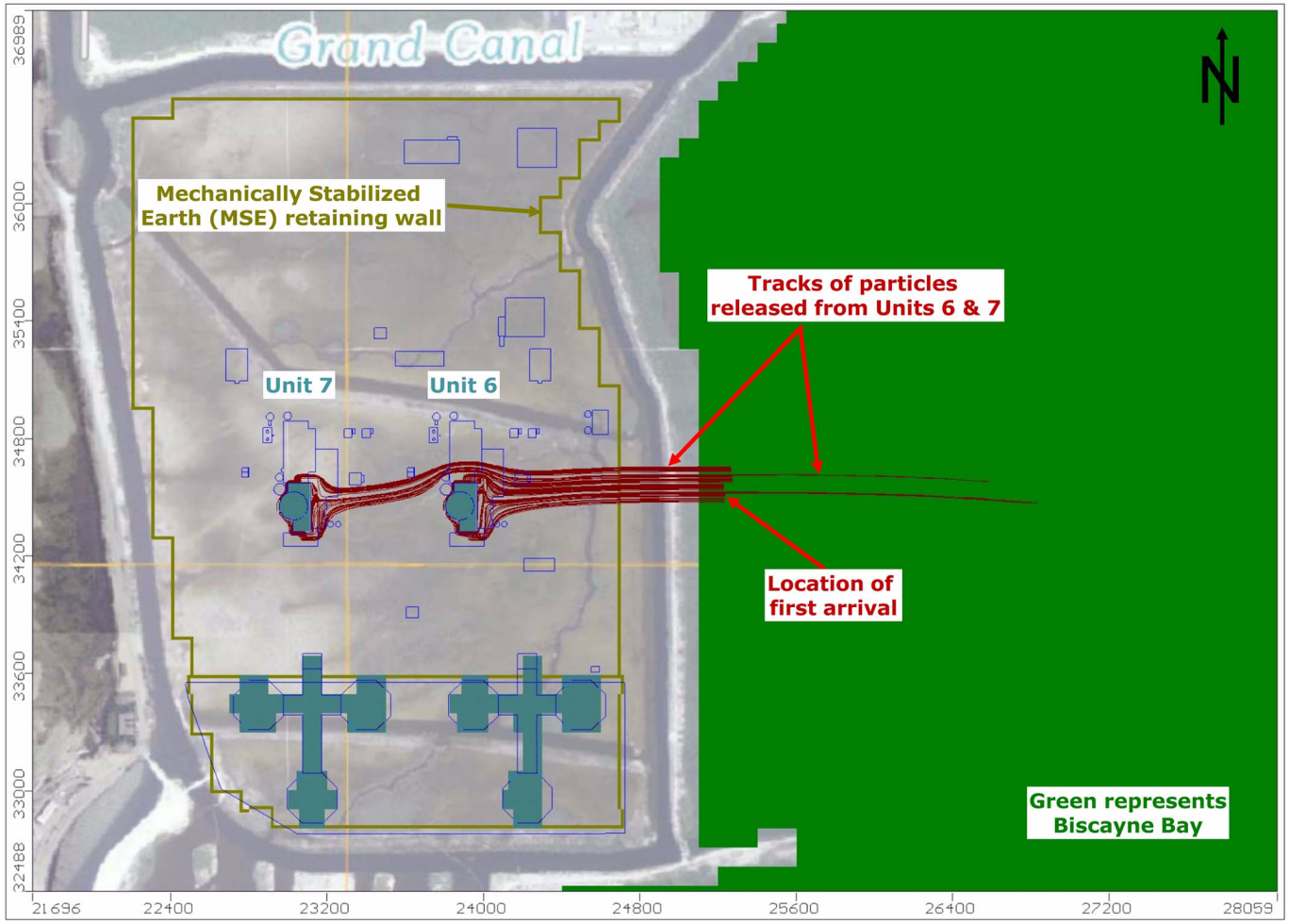


Figure 2.4.13-205 MODPATH Particle Tracking Case 3 Plan View (IWF-Off, RCW-Off)

PTN COL 2.4-5



Notes: Model layer 1 shown. Pathlines represent projections onto model layer 1 for all particles released.
Horizontal and vertical axes represent model coordinates in feet. Model origin at easting 852766, northing 362512 (in State Plane Coordinates, North American Datum of 1983/Adjustment of 1990, Florida East, Zone 0901, U.S. feet)

Figure 2.4.13-206 MODPATH Particle Tracking - Case 3 Layer with Time

PTN COL 2.4-5

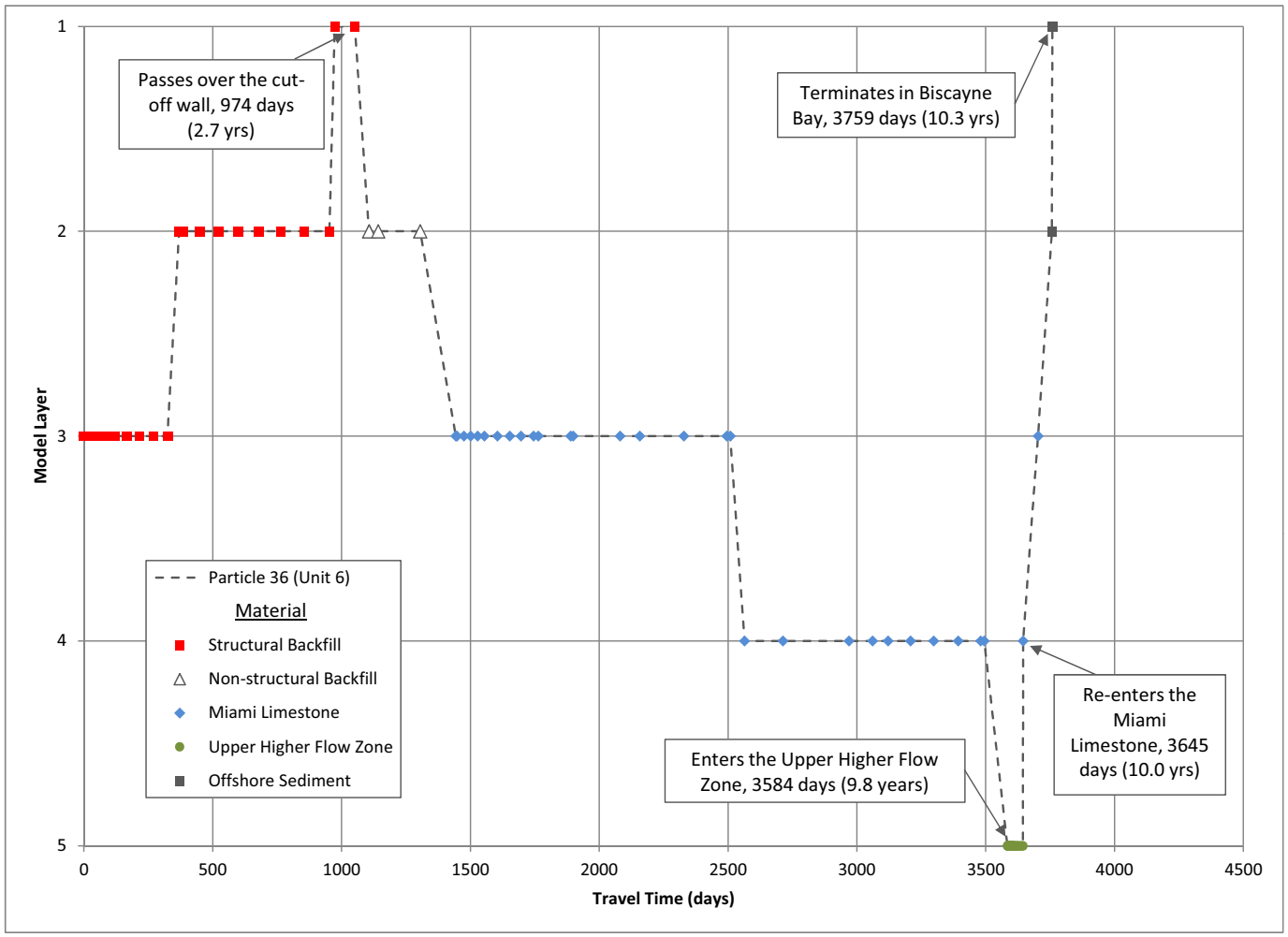


Figure 2.4.13-207 MODPATH Particle Tracking - Case 3 Distance with Time

PTN COL 2.4-5

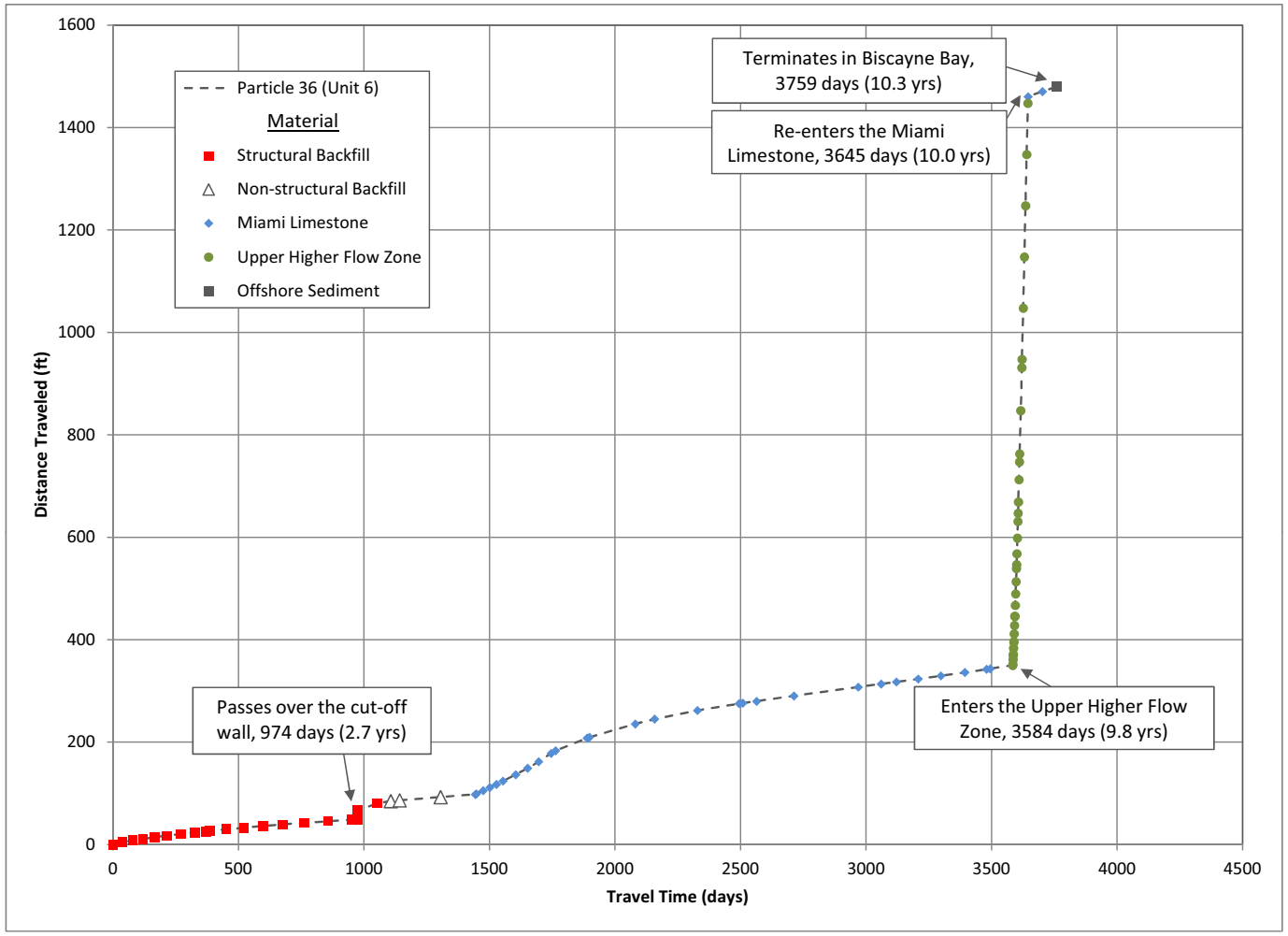


Figure 2.4.13-208 Measured K_d Values for Cesium (includes Replicate Measurements)

PTN COL 2.4-5

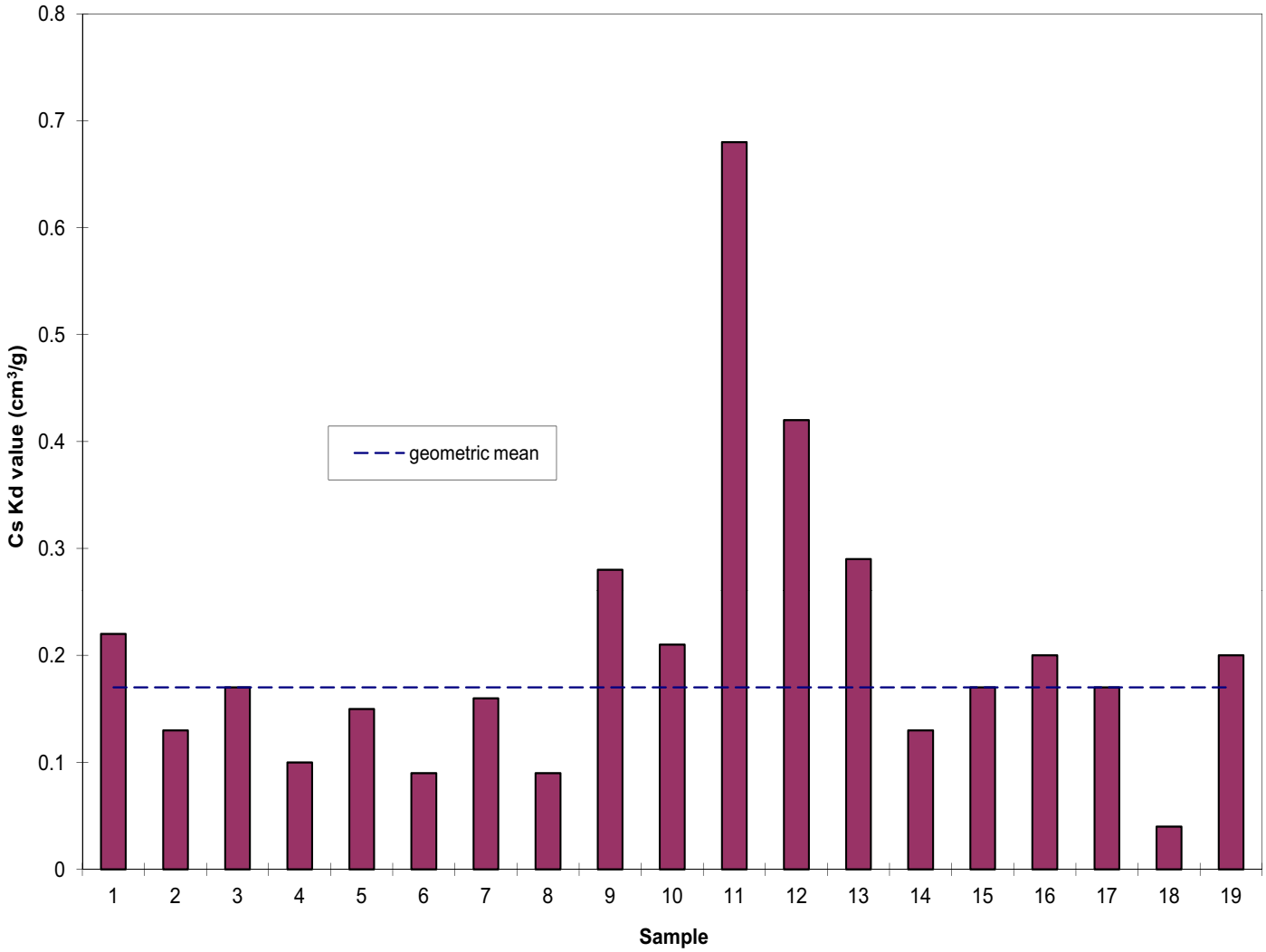


Figure 2.4.13-209 Histogram of Measured Cs K_d Values

PTN COL 2.4-5

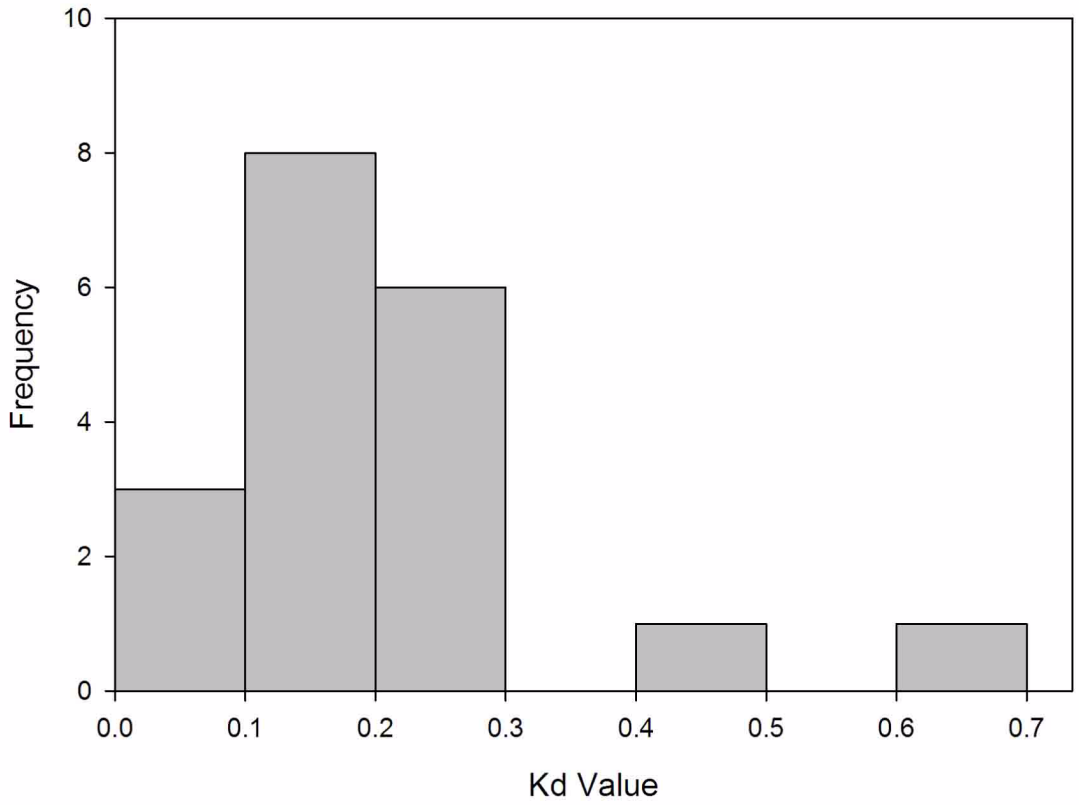
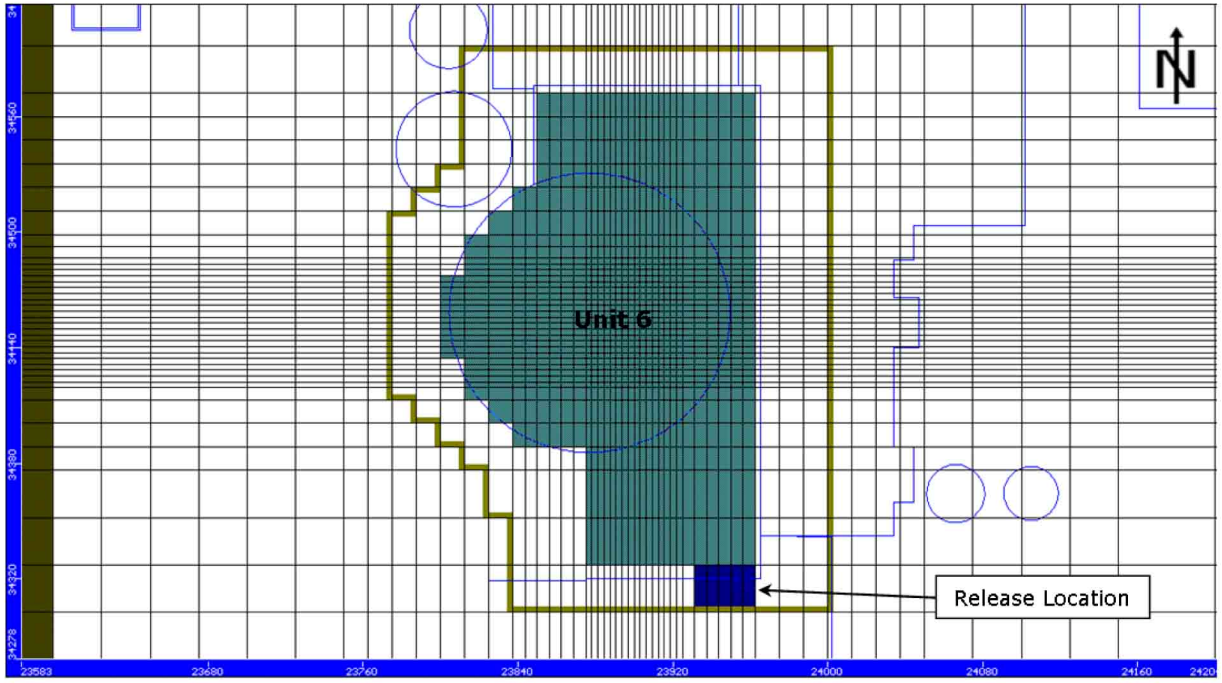


Figure 2.4.13-210 MT3DMS Release Location for Cs-137

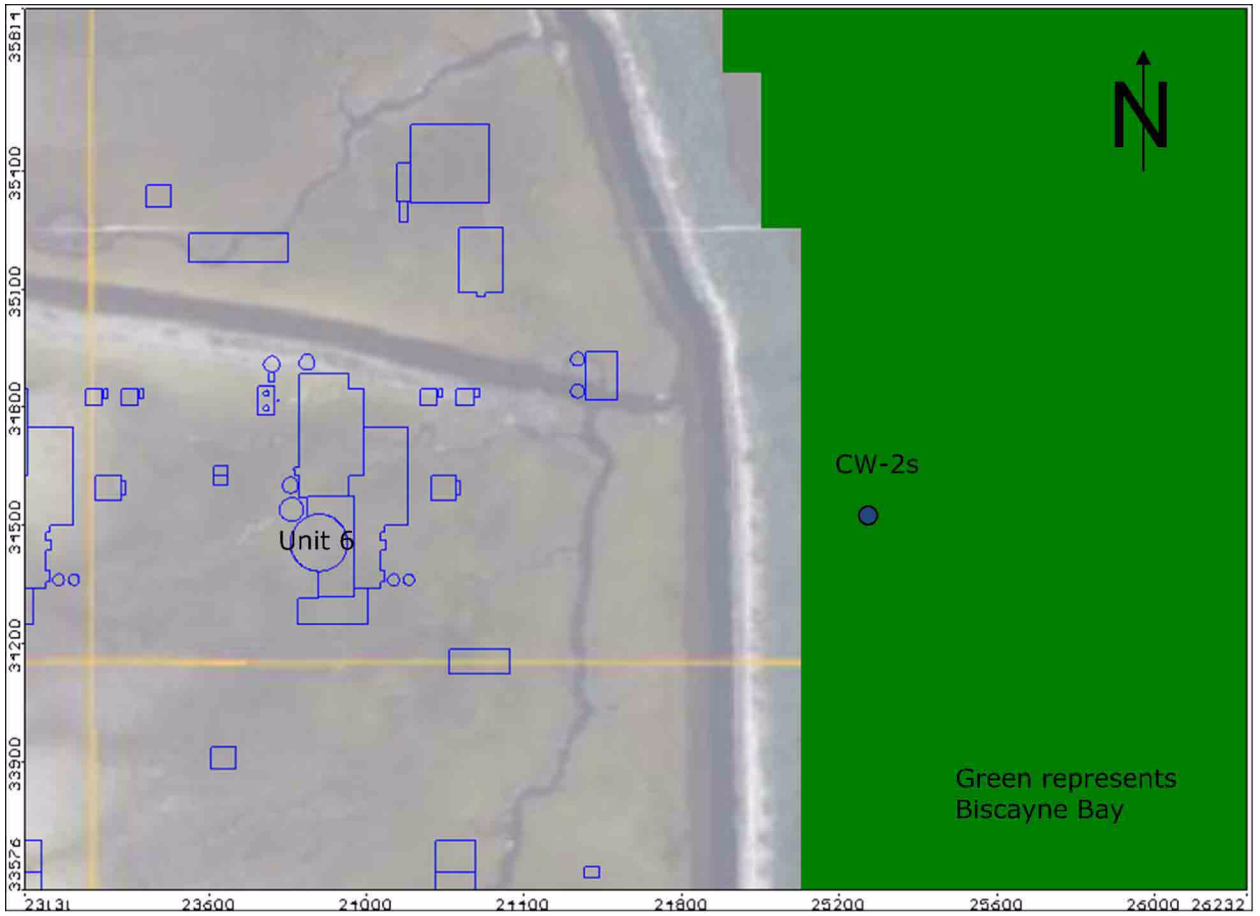
PTN COL 2.4-5



Notes: Horizontal and vertical axes represent model coordinates in feet. Model origin at easting 852766, northing 362512 (in State Plane Coordinates, North American Datum of 1983/Adjustment of 1990, Florida East, Zone 0901, U.S. feet)
Dark blue cells show release location for Cs-137 in model layer 3. Other radionuclides may include additional cells or fewer cells for release area (depending on distribution coefficient). Green-blue shading indicates no-flow area of building. Yellow-green boundary around building indicates excavation cut-off wall. Dark brown cells on western edge indicate area is inactive to transport.

Figure 2.4.13-211 MT3DMS Concentration Well Location (CW-2s)

PTN COL 2.4-5



Note: Horizontal and vertical axes represent model coordinates in feet. Model origin at easting 852766, northing 362512 (in State Plane Coordinates, North American Datum of 1983/Adjustment of 1990, Florida East, Zone 0901, U.S. feet)

Figure 2.4.13-212 MT3DMS Model Layer 1 Concentration Histories at Well CW-2s

PTN COL 2.4-5

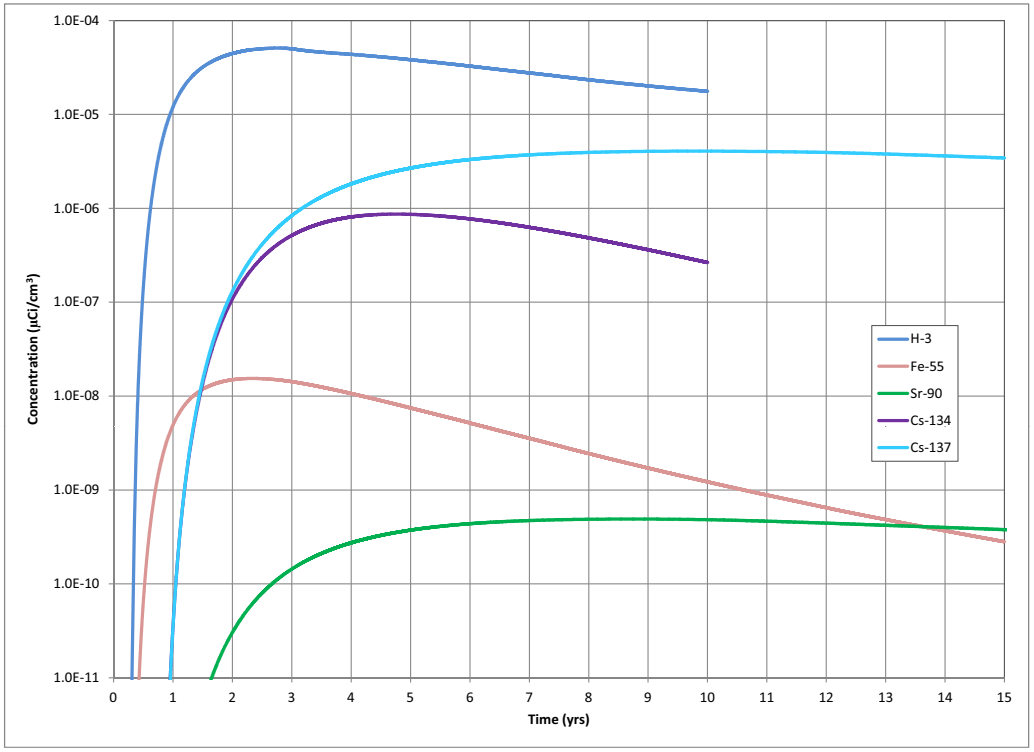
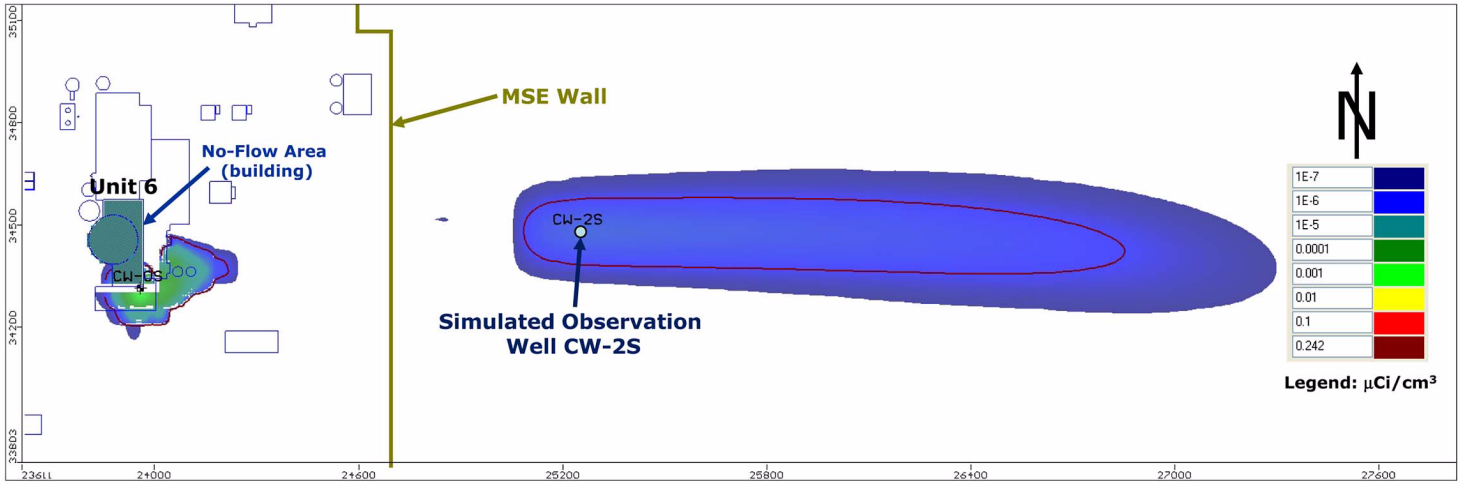


Figure 2.4.13-213 MT3DMS Plume Map for Cs-137 in Model Layer 1 at 10 Years

PTN COL 2.4-5



Notes: Dark red contour line shows Effluent Concentration Limit of 1.0E-06 uCi/cm^3. Plume concentrations less than 1.0E-07 uCi/cm^3 are not shown. The offshore portion of plume in model layer 1 occurs from upward migration of main plume from lower layers. Plume migration in layer 1 is affected by the water table elevation, MSE wall, perimeter canal, and relatively low permeability muck.
Horizontal and vertical axes represents model coordinates in feet. Model origin at easting 852766, northing 362512 (in State Plane Coordinates, North American Datum of 1983/Adjustment of 1990, Florida East, Zone 0901, U.S. feet)

Figure 2.4.13-214 Dose Time Series

PTN COL 2.4-5