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2.4.13-1

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### 2.4.13 Accidental Releases of Radioactive Liquid Effluents in Ground and Surface Waters

This subsection describes the ability of the groundwater and surface water environment to delay, disperse, dilute, or concentrate liquid effluents, as related to existing or potential future water users based on an accidental release of radioactive liquid effluent from the liquid waste management system (LWMS). A radionuclide transport analysis is conducted to predict radionuclide concentrations that might be encountered in the nearest source of potable water, located in an unrestricted area, which could be used for direct or indirect human consumption. The resulting radionuclide concentrations are compared against the effluent concentration limits (ECLs) identified in 10 CFR 20, Appendix B, Table 2, Column 2 to determine acceptability.

The analysis is performed assuming a liquid effluent release to groundwater from a generically termed LWMS tank. The source term envelopes the five reactor technologies (and six vendors) under consideration. The bounding source term presented in [Table 2.4.13-1](#) is assumed to consist of the maximum concentration for each radionuclide from each of the reactor technologies considered in the Plant Parameter Envelope. For example, the tritium concentration is derived from the AP1000 technology while the Sr-90 concentration is derived from the ESBWR technology. [Table 2.4.13-2](#) summarizes the characteristics of the LWMS tanks considered to result in the highest potential exposure concentrations when postulated to fail.

Although the mPower liquid effluent tank volume (500,000 gal) as shown in [Table 2.4.13-2](#) is the largest from the technologies under consideration, none of the radionuclides in the mPower source term have bounding concentrations. In fact, the bounding radionuclide concentrations assumed in the LWMS tank source term exceed the mPower radionuclide concentrations by at least a factor of 20. Therefore, the mPower tank volume is not selected for use in this analysis to estimate the total amount of radioactivity in the source term. The APWR technology has the second largest tank volume (120,000 gal) and has multiple radionuclides with bounding concentrations. Therefore, the APWR liquid effluent tank is selected as the bounding tank volume. Note that the failed tank volume has no impact on the screening analysis performed as part of the radionuclide transport analysis.

#### 2.4.13.1 Accident Scenario

The postulated accident scenario conservatively neglects any containment features present that would mitigate the effects of a postulated tank failure and assumes an instantaneous release from a LWMS tank, resulting in a release directly to groundwater. The postulated volume of liquid released and the associated radionuclide concentrations were selected to produce an accident scenario that would result in the most adverse contamination of groundwater, or surface water via the groundwater pathway. Source term concentrations used in this analysis are presented in Column 9 ( $C_0$ ) of [Table 2.4.13-3](#).

#### 2.4.13.2 Conceptual Model

The conceptual model of the site groundwater system is based on information presented in Appendix 2.4.12-C. The primary aquifers in the site area are the Chicot and the underlying Evangeline aquifer. Plant-specific boring information ([Reference 2.4.13-1](#)) suggests that the bottom of the Chicot aquifer is approximately 300 feet below current ground surface in the power block area and is the aquifer of interest for the accidental release scenario. The Chicot aquifer is subdivided into three saturated sandy zones at the VCS site: the "Upper Shallow" aquifer, the "Lower Shallow" aquifer, and the "Deep" aquifer. These sand units are separated by less permeable layers of clayey materials.

As part of site construction, a cooling basin of approximately 4900 acres will be constructed. Seepage from the cooling basin will alter groundwater flow patterns in the site area. Construction will also locally alter the hydrogeologic characteristics and groundwater flow patterns in the power block area. To quantify these changes, a three-dimensional, finite-difference groundwater flow model was developed. Modeling results indicate that the impoundment of surface water in the cooling basin significantly alters the potentiometric elevations and groundwater flow patterns. These changes are reflected in the modeled potentiometric surfaces for the Upper Shallow, Lower Shallow, and Deep aquifers as presented in Appendix 2.4.12-C. In particular, the potentiometric elevations in the hydrogeologic units underlying the cooling basin are increased, creating downward and radial flow away from the basin. The radial nature of the flow transitions to more uniform, northeasterly flow towards the Guadalupe River with increasing depth.

Groundwater pathways associated with an accidental release of liquid effluent from a LWMS tank were evaluated by conducting particle tracking analyses using the groundwater model for the post-construction conditions described above. Alternative groundwater pathways were established by releasing particles from the fill in the power block area for a variety of scenarios. As presented in Appendix 2.4.12-C, all of the scenarios considered indicate an accidental release of radioactive liquid effluent would result in vertically-downward transport through the backfill and horizontal transport through the Lower Shallow aquifer to the eastern property boundary with groundwater travel times of approximately 41,000 days. Scenario 4 simulates the post-construction groundwater system and includes a postulated pumping well located at the property boundary east of the power block area. As shown in [Figure 2.4.13-1](#), the particle tracking analysis for this scenario indicates the released particles would not be captured by the pumping well. However, it is conservatively assumed for the purpose of demonstrating compliance with 10 CFR 20 limits that a water-supply well at this location would capture an accidental release of liquid effluent. In this case, the travel time and pathline distance would be approximately 32,000 days and 10,500 feet, respectively, both of which are more conservative than predicted.

### 2.4.13.3 Radionuclide Transport Analysis

A radionuclide transport analysis was conducted to estimate the radionuclide concentrations that a water user might be exposed to in the event of an accidental LWMS tank failure. A screening analysis was first conducted to eliminate radionuclides that would likely decay to concentrations well below the ECLs identified in 10 CFR 20, Appendix B, Table 2, Column 2 ([Reference 2.4.13-2](#)). Further analysis, using more realistic assumptions and modeling techniques, was then performed for the remaining radionuclides when the screening results indicated radionuclide concentrations to be of potential concern.

This analysis accounts for the parent radionuclides expected to be present in a LWMS tank plus progeny radionuclides that would be generated subsequently during transport. The analysis considers all progeny in the decay chain sequences that are important for dosimetric purposes. International Commission on Radiation Protection Publication 38 ([Reference 2.4.13-3](#)) was used to identify the member for which the decay chain sequence can be truncated. For some of the radionuclides expected to be present in the LWMS tank, consideration of up to three members of the decay chain was required. The radionuclide transport analysis consists of a screening analysis followed by a two-dimensional transport analysis to account for hydrodynamic dispersion in addition to advection, radioactive decay and adsorption.

#### 2.4.13.3.1 Screening Analysis

A conservative screening analysis was performed initially considering radioactive decay only. This analysis assumes that all radionuclides migrate at the same rate as groundwater and considers no adsorption or dispersion, which would otherwise result in lower radionuclide concentrations. Under these assumptions, the radionuclide concentration along a groundwater pathline can be expressed as a function of the groundwater travel time using the Bateman equations as given in Appendix B of NUREG/CR-5512, Volume 1 ([Reference 2.4.13-4](#)). The expressions for the parent, first progeny, and second progeny are as follows:

$$C_1(t) = C_{10} \exp(-\lambda_1 t) \quad (2.4.13-1)$$

$$C_2(t) = \left( \frac{d_{12} \lambda_2 C_{10}}{\lambda_2 - \lambda_1} \right) \exp(-\lambda_1 t) + \left( C_{20} - \frac{d_{12} \lambda_2 C_{10}}{\lambda_2 - \lambda_1} \right) \exp(-\lambda_2 t) \quad (2.4.13-2)$$

$$\begin{aligned}
 C_3(t) = & \left[ \frac{d_{13}\lambda_3 C_{10}}{\lambda_3 - \lambda_1} + \frac{d_{23}\lambda_2 d_{12}\lambda_3 C_{10}}{(\lambda_3 - \lambda_1)(\lambda_2 - \lambda_1)} \right] \exp(-\lambda_1 t) \\
 & + \left[ \frac{d_{23}\lambda_3 C_{20}}{\lambda_3 - \lambda_2} - \frac{d_{23}\lambda_2 d_{12}\lambda_3 C_{10}}{(\lambda_3 - \lambda_2)(\lambda_2 - \lambda_1)} \right] \exp(-\lambda_2 t) \\
 & + \left[ C_{30} - \frac{d_{13}\lambda_3 C_{10}}{\lambda_3 - \lambda_1} - \frac{d_{23}\lambda_3 C_{20}}{\lambda_3 - \lambda_2} + \frac{d_{23}\lambda_2 d_{12}\lambda_3 C_{10}}{(\lambda_3 - \lambda_1)(\lambda_3 - \lambda_2)} \right] \exp(-\lambda_3 t)
 \end{aligned}
 \tag{2.4.13-3}$$

where:

- $C_1$  = concentration of the parent radionuclide ( $\mu\text{Ci}/\text{cm}^3$ )
- $C_2$  = concentration of the first progeny radionuclide ( $\mu\text{Ci}/\text{cm}^3$ )
- $C_3$  = concentration of the second progeny radionuclide ( $\mu\text{Ci}/\text{cm}^3$ )
- $C_{10}$  = initial concentration of the parent radionuclide ( $\mu\text{Ci}/\text{cm}^3$ )
- $C_{20}$  = initial concentration of the first progeny radionuclide ( $\mu\text{Ci}/\text{cm}^3$ )
- $C_{30}$  = initial concentration of the second progeny radionuclide ( $\mu\text{Ci}/\text{cm}^3$ )
- $\lambda_1$  = radioactive decay constant for the parent radionuclide ( $\text{day}^{-1}$ )
- $\lambda_2$  = radioactive decay constant for the first progeny radionuclide ( $\text{day}^{-1}$ )
- $\lambda_3$  = radioactive decay constant for the second progeny radionuclide ( $\text{day}^{-1}$ )
- $d_{12}$  = fraction of parent radionuclide transitions that result in production of first progeny
- $d_{13}$  = fraction of parent radionuclide transitions that result in production of second progeny
- $d_{23}$  = fraction of first progeny transitions that result in production of second progeny
- $t$  = groundwater travel time (day)

Note that the radioactive decay constant is related to the radionuclide half-life as:

$$\lambda = \frac{\ln 2}{t_{1/2}}
 \tag{2.4.13-4}$$

where:

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

For the screening analysis, transport to the hypothetical, domestic water-supply well located on the northeastern site boundary was selected for analysis because this pathway has the shortest groundwater travel time and hence the least radioactive decay of the alternatives analyzed. The radionuclides assumed to be released from a LWMS tank were decayed for a period equal to the travel time from the point of release to the site boundary (32,000 days), using Equations 2.4.13-1,

2.4.13-2, or 2.4.13-3. The bounding concentrations listed in [Table 2.4.13-1](#) were used to establish the initial concentrations. Radionuclides having concentrations at the site boundary of less than 1 percent of their respective ECL were eliminated from further consideration because their concentrations would be well below their regulatory limits. As indicated in Column 11 (C/ECL) of [Table 2.4.13-3](#), H-3, Co-60, Ni-63, Sr-90, Y-90, I-129, Cs-137, and Pu-239 would exceed 1 percent of their ECL when accounting for radioactive decay and groundwater advection. The analysis was then repeated for these radionuclides to account for radioactive decay, groundwater advection and retardation as described below.

Radionuclide travel time ( $t$ ) considering advection and retardation is defined as:

$$t = \frac{Rx}{v} \quad (2.4.13-5)$$

where:

R = retardation factor

x = pathline length (feet)

v = average linear groundwater velocity (feet/year)

The retardation factor R is defined as ([Reference 2.4.13-5](#)):

$$R = 1 + \frac{\rho_b K_d}{n_e} \quad (2.4.13-6)$$

where:

$K_d$  = distribution coefficient ( $\text{cm}^3/\text{g}$ )

$n_e$  = effective porosity

$\rho_b$  = dry bulk density ( $\text{g}/\text{cm}^3$ )

The distribution coefficients for tritium (H-3) and I-129 were assigned a value of zero because there is little or no tendency for these radionuclides to adsorb. Distribution coefficient values for Co, Ni, Sr, Cs, and Pu were assigned based on laboratory analyses of soil samples obtained from the VCS site ([Reference 2.4.13-6](#)). The results of these analyses are summarized in [Table 2.4.13-4](#). The minimum  $K_d$  values determined from laboratory testing of the Lower Shallow aquifer materials were conservatively used to represent the  $K_d$  values used in this analysis.  $K_d$  values for parent radionuclides and progeny are assumed to be equal for this analysis. Total porosity was determined from the analysis of soil samples obtained from the VCS site. [Table 2.4.12-10](#) summarizes these data. The geometric mean of the total porosity for the Lower Shallow aquifer was determined to be 0.365. The effective porosity was estimated to be 80 percent of the total porosity based on [Figure 2.4.12-21](#) and a median grain size of 0.1 mm. The resulting effective porosity is 0.29. A dry



bulk density value of 96.6 pcf (1.55 g/cm<sup>3</sup>) is used in this analysis. This value represents the minimum measured value for the Lower Shallow aquifer as presented in Table 2.4.12-10. Calculated retardation factors are presented in Column 13 (R) of Table 2.4.13-3.

When repeating the screening analysis to account for radionuclide retardation, only H-3 and I-129 concentrations exceed 1 percent of their ECL as shown in Column 15 (C/ECL) of Table 2.4.13-3. Given the I-129 concentration is less than 4 percent of its ECL, only H-3 is retained for further analysis. As shown in Table 2.4.13-3, H-3 exceeds its ECL by a factor of 7.31.

### 2.4.13.3.2 Two-Dimensional Transport

Tritium is further analyzed to account for longitudinal and transverse dispersion in groundwater. The effects of dispersion were analyzed using the analytical solution of the two-dimensional advection-dispersion equation presented by Codell and Duguid, Equation 4.33 in Reference 2.4.13-7. The solution assumes an instantaneous release of activity  $M$  uniformly distributed over width  $w$  and thickness  $b$ . Using this method, the concentration,  $C$ , at the location of a hypothetical well ( $x$  = pathline length) at time  $t$  is calculated as a function of the total initial radionuclide activity,  $M$  as:

$$C(x,t) = \frac{M}{n_e R} X_1 Y_2 Z_2 \quad (2.4.13-7)$$

where  $X_1$ ,  $Y_2$ , and  $Z_2$  are given by the expressions:

$$X_1 = \frac{1}{\sqrt{4\pi D_L t/R}} \exp\left[-\frac{(x - vt/R)^2}{4D_L t/R} - \lambda t\right] \quad (2.4.13-8)$$

$$Y_2 = \frac{1}{2w} \left\{ \operatorname{erf}\left[\frac{(w/2+y)}{\sqrt{4D_T t/R}}\right] + \operatorname{erf}\left[\frac{(w/2-y)}{\sqrt{4D_T t/R}}\right] \right\} \quad (2.4.13-9)$$

$$Z_2 = \frac{1}{b} \quad (2.4.13-10)$$

in which  $w$  is the conceptualized width of the contaminant slug in the aquifer,  $y$  is the lateral position with respect to the center of the pathline (i.e., distance to the left or right, assume  $y = 0$ ),  $b$  is the saturated thickness of the aquifer, and  $M$  is the released activity, which is equal to the activity concentration of each nuclide in the effluent times the postulated volume of the effluent release (96,000 gal, i.e., 80 percent of the limiting tank volume [Reference 2.4.13-8]).

The dispersion coefficients are estimated as (Reference 2.4.13-5):

$$D_L = \alpha_L v \quad (2.4.13-11)$$

$$D_T = \alpha_T v \quad (2.4.13-12)$$

where  $\alpha_L$  is the longitudinal dispersivity and  $\alpha_T$  is the transverse dispersivity. The longitudinal dispersivity may be estimated as (Reference 2.4.13-9):

$$\alpha_L = 0.83(\log x)^{2.414} \quad (2.4.13-13)$$

Note that Equation 2.4.13-13 assumes that both  $\alpha_L$  and  $x$  (pathline length) are in units of meters. Using site-specific values for  $x$  and  $v$ , the longitudinal dispersivity and the longitudinal coefficient of hydrodynamic dispersion are obtained as  $\alpha_L = 56.2$  feet and  $D_L = 18.5$  feet<sup>2</sup>/day. The average linear groundwater velocity ( $v = 0.33$  feet/day) is derived from the pathline length (10,500 feet) divided by the groundwater travel time (32,000 days). The transverse dispersivity is estimated to be one tenth of the longitudinal dispersivity, based on Reference 2.4.13-10, which indicates the ratio of longitudinal to transverse dispersivity ranges from 5 to 24.

The volume of the aquifer that would be occupied by the release is estimated by dividing the release volume (approximately 12,800 feet<sup>3</sup> [96,000 gal]) by the effective porosity (0.29). This results in an estimated volume of approximately 44,300 feet<sup>3</sup> in the aquifer.

The shape of the resulting contaminant slug is assumed to be square in plan view and to extend vertically throughout the entire saturated thickness of the Lower Shallow aquifer, estimated to be approximately 10 feet. The area of the contaminant slug in plan view is then estimated by dividing the volume by the 10 feet representative saturated thickness,  $b$ . Consistent with the assumption that the contaminant slug is square in plan view, the cross-sectional width,  $w$ , is equal to the square root of the planar area ( $w$  is approximately 66 feet). Note that Equation 2.4.13-7 is relatively insensitive to the assumed source width  $w$ .

The peak H-3 concentration calculated with Equation 2.4.13-7 is  $1.6 \times 10^{-5}$   $\mu\text{Ci}/\text{cm}^3$  with a resulting C/ECL ratio of 0.02. The sum of fractions (C/ECL) for H-3 (0.02), and I-129 (0.036), is approximately 0.06. All other radionuclides in the source term decay to near-zero values and do not significantly contribute to the dose at the site boundary.

#### 2.4.13.4 Compliance with 10 CFR 20

The radionuclide transport analysis presented above demonstrates that all of the radionuclides that could potentially be released to groundwater would be individually below their ECLs at the site boundary for the most conservative of the alternative pathways. 10 CFR 20, Appendix B, Table 2, imposes additional requirements when the identity and concentration of each radionuclide in a mixture are known. In this case, the ratio present in the mixture and the concentration otherwise established in 10 CFR 20 Appendix B for the specific radionuclide not in a mixture must be determined. The sum of such ratios for all of the radionuclides in the mixture may not exceed "1" (i.e., "unity"). The sum of fractions at this compliance point was determined to be 0.06. This value is below

unity and demonstrates compliance with the 10 CFR 20 limit at the nearest potential potable water supply in an unrestricted area.

#### 2.4.13.5 Releases to Surface Water

With the exception of the mPower technology, there are no LWMS outdoor tanks, and therefore no accident scenario could result in the release of LWMS effluent directly to surface water.

In the case of the mPower technology, the limiting tank is located outdoors within the power block area. Assuming the mPower tank fails, the released liquid would be retained by the dike that encloses the tank. The released liquid would enter the subsurface and migrate vertically through the backfill and horizontally through the Lower Shallow aquifer to the northeastern site boundary. This groundwater pathway has been analyzed in [Subsection 2.4.13.3](#) assuming bounding radionuclide concentrations and complies with 10 CFR 20 requirements. The mPower source term has relatively low radionuclide concentrations. All but three of the mPower radionuclide source term concentrations (H-3, Rb-88, and Ru-106) are below their ECLs. Additionally, the bounding radionuclide concentrations assumed for a release to groundwater exceed mPower concentrations by at least a factor of 20. A failure of the mPower outdoor tank and release of liquid effluent to the environment would therefore comply with 10 CFR 20 requirements.

#### 2.4.13.6 References

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- 2.4.13-2 10 CFR 20, Appendix B, available at: <http://www.nrc.gov/reading-rm/doc-collections/cfr/part020/appb/>.
- 2.4.13-3 International Commission on Radiation Protection (ICRP), *Radionuclide Transformations — Energy and Intensity of Emissions*, ICRP Publication 38, Volumes 11-13, Pergamon Press, New York, 1983.
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- 2.4.13-8 U.S. Nuclear Regulatory Commission, *Postulated Radioactive Releases Due to Liquid-Containing Tank Failures*, NUREG-0800, Branch Technical Position 11-6, March 2007.
- 2.4.13-9 Xu, M., and Eckstein, Y., *Use of Weighted Least-Squares Method in Evaluation of the Relationship Between Dispersivity and Field-scale, Ground Water*, v. 33, No. 6, 1995.
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**Table 2.4.13-1 (Sheet 1 of 2)**  
**Bounding Source Term Concentrations**

Nuclide	Toshiba ABWR (µCi/mL)	GEH ABWR (µCi/mL)	mPower (µCi/mL)	AP1000 (µCi/mL)	APWR (µCi/mL)	ESBWR (µCi/mL)	Bounding Concentration (µCi/mL)	Bounding Technology
H-3	1.0E-02	1.0E-02	4.8E-02	1.0E+00	7.8E-01	2.6E-03	1.0E+00	AP1000
Na-24	3.5E-02	7.5E-03	3.5E-06	NA	7.1E-03	1.4E-03	3.5E-02	Toshiba ABWR
P-32	6.5E-04	2.1E-03	NA	NA	NA	5.9E-04	2.1E-03	GEH ABWR
Cr-51	2.0E-02	8.1E-02	1.7E-07	1.3E-03	5.3E-03	7.8E-02	8.1E-02	GEH ABWR
Mn-54	4.3E-04	1.2E-03	8.9E-08	6.8E-04	3.3E-03	2.9E-03	3.3E-03	APWR
Mn-56	1.8E-01	7.5E-03	NA	1.7E-01	NA	2.2E-03	1.8E-01	Toshiba ABWR
Fe-55	3.2E-03	1.8E-02	6.7E-08	5.1E-04	2.5E-03	9.1E-02	9.1E-02	ESBWR
Fe-59	1.2E-04	4.5E-04	1.7E-08	1.3E-04	5.5E-04	1.1E-03	1.1E-03	ESBWR
Co-58	8.6E-04	3.3E-03	2.6E-07	1.9E-03	8.9E-03	5.2E-03	8.9E-03	APWR
Co-60	2.8E-03	7.2E-03	3.0E-08	2.2E-04	1.1E-03	1.9E-02	1.9E-02	ESBWR
Ni-63	7.3E-03	1.8E-05	NA	NA	NA	9.6E-05	7.3E-03	Toshiba ABWR
Cu-64	1.0E-01	1.9E-02	NA	NA	NA	1.7E-03	1.0E-01	Toshiba ABWR
Zn-65	1.2E-03	3.6E-03	2.8E-08	NA	1.1E-03	7.9E-02	7.9E-02	ESBWR
Kr-83m	NA	NA	NA	8.7E-02	NA	NA	8.7E-02	AP1000
Br-83	NA	NA	NA	1.6E-02	NA	NA	1.6E-02	AP1000
Br-84	NA	NA	2.1E-06	8.2E-03	NA	NA	8.2E-03	AP1000
Kr-85m	NA	NA	NA	4.1E-01	NA	NA	4.1E-01	AP1000
Kr-88	NA	NA	NA	7.3E-01	NA	NA	7.3E-01	AP1000
Rb-88	NA	NA	1.3E-03	7.3E-01	4.9E-03	NA	7.3E-01	AP1000
Rb-89	2.1E-02	8.4E-05	NA	3.3E-02	NA	3.4E-05	3.3E-02	AP1000
Sr-89	4.1E-04	1.5E-03	7.8E-09	5.3E-04	2.6E-04	4.2E-03	4.2E-03	ESBWR
Sr-90	5.2E-05	1.3E-04	6.7E-10	2.4E-05	2.5E-05	6.6E-04	6.6E-04	ESBWR
Sr-91	1.4E-02	2.1E-03	7.8E-08	8.2E-04	1.0E-04	1.7E-03	1.4E-02	Toshiba ABWR
Sr-92	3.8E-02	1.6E-03	NA	2.0E-04	NA	9.2E-04	3.8E-02	Toshiba ABWR
Y-90	5.2E-05	1.3E-04	NA	6.3E-06	NA	2.1E-05	1.3E-04	GEH ABWR
Y-91	5.7E-03	6.0E-04	2.9E-10	6.8E-05	2.7E-05	1.9E-03	5.7E-03	Toshiba ABWR
Y-91m	NA	NA	5.8E-08	4.5E-04	6.4E-05	NA	4.5E-04	AP1000
Y-92	2.2E-02	1.2E-03	NA	1.6E-04	NA	7.6E-04	2.2E-02	Toshiba ABWR
Y-93	1.4E-02	2.0E-03	3.4E-07	5.3E-05	4.6E-04	1.7E-03	1.4E-02	Toshiba ABWR
Zr-95	1.2E-03	1.2E-04	2.2E-08	7.8E-05	7.5E-04	4.0E-04	1.2E-03	Toshiba ABWR
Nb-95	1.2E-03	1.1E-04	1.6E-08	7.8E-05	6.3E-04	2.6E-04	1.2E-03	Toshiba ABWR
Mo-99	6.5E-03	6.0E-03	3.9E-07	1.0E-01	3.2E-03	6.1E-03	1.0E-01	AP1000
Tc-99m	6.5E-03	6.0E-03	4.2E-07	9.7E-02	3.1E-03	5.1E-04	9.7E-02	AP1000
Ru-103	2.7E-03	2.9E-04	4.2E-07	6.8E-05	1.4E-02	7.1E-04	1.4E-02	APWR
Rh-103m	2.7E-03	2.9E-04	NA	6.8E-05	1.2E-02	6.9E-07	1.2E-02	APWR
Ru-106	5.2E-04	5.4E-05	5.0E-06	NA	1.9E-01	2.4E-04	1.9E-01	APWR
Rh-106	5.2E-04	5.4E-05	NA	2.2E-05	1.9E-01	8.8E-10	1.9E-01	APWR
Ag-110m	5.8E-06	1.7E-05	7.2E-08	1.9E-04	2.7E-03	7.9E-05	2.7E-03	APWR

**Table 2.4.13-1 (Sheet 2 of 2)**  
**Bounding Source Term Concentrations**

Nuclide	Toshiba ABWR (µCi/mL)	GEH ABWR (µCi/mL)	mPower (µCi/mL)	AP1000 (µCi/mL)	APWR (µCi/mL)	ESBWR (µCi/mL)	Bounding Concentration (µCi/mL)	Bounding Technology
Ag-110	NA	NA	NA	NA	3.6E-05	NA	3.6E-05	APWR
Te-127m	NA	NA	NA	3.7E-04	NA	NA	3.7E-04	AP1000
I-129	NA	NA	NA	7.3E-09	NA	NA	7.3E-09	AP1000
Te-129m	1.4E-04	5.4E-04	1.1E-08	1.3E-03	3.4E-04	1.3E-03	1.3E-03	ESBWR/AP1000
Te-129	NA	NA	2.9E-06	1.8E-03	6.4E-04	NA	1.8E-03	AP1000
Te-131m	3.2E-04	1.4E-04	9.9E-08	3.2E-03	3.9E-04	1.4E-04	3.2E-03	AP1000
Te-131	NA	NA	1.0E-06	2.1E-03	1.4E-04	NA	2.1E-03	AP1000
Te-132	9.8E-05	3.3E-05	1.0E-07	3.8E-02	9.7E-04	3.6E-05	3.8E-02	AP1000
Te-134	NA	NA	NA	5.3E-03	NA	NA	5.3E-03	AP1000
I-130	NA	NA	NA	5.3E-03	NA	NA	5.3E-03	AP1000
I-131	1.6E-02	3.6E-02	1.2E-07	3.4E-01	2.5E-03	4.1E-02	3.4E-01	AP1000
I-132	1.4E-01	5.1E-03	6.6E-06	4.6E-01	2.8E-03	2.9E-03	4.6E-01	AP1000
I-133	1.1E-01	3.3E-02	1.8E-06	6.3E-01	5.1E-03	3.1E-02	6.3E-01	AP1000
I-134	2.4E-01	3.3E-03	1.3E-05	1.1E-01	1.4E-03	1.6E-03	2.4E-01	Toshiba ABWR
I-135	1.5E-01	1.6E-02	4.9E-06	3.8E-01	4.2E-03	1.1E-02	3.8E-01	AP1000
Xe-133m	NA	NA	NA	8.2E-01	NA	NA	8.2E-01	AP1000
Xe-133	NA	NA	NA	5.8E+01	NA	NA	5.8E+01	AP1000
Xe-135m	NA	NA	NA	8.2E-02	NA	NA	8.2E-02	AP1000
Xe-135	NA	NA	NA	1.7E+00	NA	NA	1.7E+00	AP1000
Cs-134	8.9E-05	4.8E-04	6.5E-08	3.3E-01	4.1E-04	2.2E-03	3.3E-01	AP1000
Cs-136	5.9E-05	1.8E-04	1.5E-06	4.8E-01	6.3E-03	2.2E-04	4.8E-01	AP1000
Cs-137	2.4E-04	1.3E-03	1.2E-07	2.4E-01	5.9E-04	6.2E-03	2.4E-01	AP1000
Cs-138	4.1E-02	3.6E-04	NA	1.8E-01	NA	1.5E-04	1.8E-01	AP1000
Xe-138	NA	NA	NA	1.2E-01	NA	NA	1.2E-01	AP1000
Ba-137m	NA	NA	1.2E-07	2.3E-01	1.1E-04	1.1E-07	2.3E-01	AP1000
Ba-140	1.3E-03	3.9E-03	7.4E-07	4.8E-04	1.8E-02	5.2E-03	1.8E-02	APWR
La-140	3.6E-02	3.9E-03	1.6E-06	1.5E-04	2.4E-02	7.8E-04	3.6E-02	Toshiba ABWR
Ce-141	3.9E-03	4.2E-04	8.4E-09	7.8E-05	2.6E-04	8.8E-04	3.9E-03	Toshiba ABWR
Ce-143	NA	NA	1.8E-07	6.8E-05	7.9E-04	NA	7.9E-04	APWR
Ce-144	5.1E-04	5.1E-05	2.2E-07	5.8E-05	8.3E-03	2.3E-04	8.3E-03	APWR
Pr-143	5.1E-04	3.0E-05	NA	7.3E-05	4.0E-04	NA	5.1E-04	Toshiba ABWR
Pr-144	1.0E-05	NA	NA	5.8E-05	8.3E-03	3.1E-08	8.3E-03	APWR
W-187	1.0E-03	3.3E-04	1.7E-07	NA	5.5E-04	3.4E-04	1.0E-03	Toshiba ABWR
Np-239	2.7E-02	2.0E-02	1.4E-07	NA	9.7E-04	2.1E-02	2.7E-02	Toshiba ABWR

NA — Not Applicable

**Table 2.4.13-2  
 LWMS Tank Characteristics for Each Technology**

	<b>Toshiba ABWR</b>	<b>GEH ABWR</b>	<b>mPower</b>	<b>AP1000</b>	<b>APWR</b>	<b>ESBWR</b>
<b>Tank</b>	Low Conductivity Waste (LCW) Collection Tank	Low Conductivity Waste (LCW) Sample Tank	Refueling Water Storage Tank (RWST)	Liquid Radwaste System (WLS) Effluent Holdup Tank	Holdup Tank	Equipment Drain Collection Tank
<b>Location</b>	Radwaste Building	Radwaste Building	Outdoor	Auxiliary Building	Auxiliary Building	Radwaste Building
<b>Volume (gal)</b>	37,000	27,750 <sup>(a)</sup>	500,000	28,000	120,000 <sup>(b)</sup>	37,000

- (a) The GEH ABWR source term is based on the highest radionuclide concentrations from either the LCW Sample Tank or the LCW Collection Tank. The LCW Sample Tank volume is larger than the LCW Collection Tank volume, therefore the LCW Sample Tank volume is selected for use in this analysis for added conservatism.
- (b) The APWR source term is based on the highest radionuclide concentrations from either the Boric Acid Tank or the Holdup Tank. The Holdup Tank volume is larger than the Boric Acid Tank volume, therefore the Holdup Tank volume is selected for use in this analysis for added conservatism.

**Table 2.4.13-3 (Sheet 1 of 3)**  
**Results of Screening Level Radionuclide Transport Analysis**

Parent Radionuclide (1)	Progeny in Chain (2)	Radionuclide Characteristics						C <sub>0</sub> (μCi/cm <sup>3</sup> ) (9)	Radioactive Decay		Radioactive Decay + Retardation			
		t <sub>1/2</sub> (days) (3)	d <sub>12</sub> (4)	d <sub>13</sub> (5)	d <sub>23</sub> (6)	λ (days <sup>-1</sup> ) (7)	ECL (μCi/cm <sup>3</sup> ) (8)		C (μCi/cm <sup>3</sup> ) (10)	C/ECL (11)	K <sub>d</sub> (cm <sup>3</sup> /g) (12)	R (13)	C (μCi/cm <sup>3</sup> ) (14)	C/ECL (15)
H-3	—	4.51E+03	—	—	—	1.54E-04	1.00E-03	1.00E+00	7.31E-03	7.31E+00	0.00	1.0	7.31E-03	7.31E+00
Na-24	—	6.25E-01	—	—	—	1.11E+00	5.00E-05	3.50E-02	0.00E+00	0.00E+00	—	—	—	—
P-32	—	1.43E+01	—	—	—	4.85E-02	9.00E-06	2.10E-03	0.00E+00	0.00E+00	—	—	—	—
Cr-51	—	2.77E+01	—	—	—	2.50E-02	5.00E-04	8.10E-02	0.00E+00	0.00E+00	—	—	—	—
Mn-54	—	3.13E+02	—	—	—	2.21E-03	3.00E-05	3.30E-03	5.52E-34	0.00E+00	—	—	—	—
Mn-56	—	1.07E-01	—	—	—	6.48E+00	7.00E-05	1.80E-01	0.00E+00	0.00E+00	—	—	—	—
Fe-55	—	9.86E+02	—	—	—	7.03E-04	1.00E-04	9.10E-02	1.55E-11	0.00E+00	—	—	—	—
Fe-59	—	4.45E+01	—	—	—	1.56E-02	1.00E-05	1.10E-03	3.72E-220	0.00E+00	—	—	—	—
Co-58	—	7.08E+01	—	—	—	9.79E-03	2.00E-05	8.90E-03	7.77E-139	0.00E+00	—	—	—	—
Co-60	—	1.93E+03	—	—	—	3.59E-04	3.00E-06	1.90E-02	1.94E-07	6.46E-02	65.70	352.2	0.00E+00	0.00E+00
Ni-63	—	3.51E+04	—	—	—	1.98E-05	1.00E-04	7.30E-03	3.88E-03	3.88E+01	26.30	141.6	9.35E-42	0.00E+00
Cu-64	—	5.29E-01	—	—	—	1.31E+00	2.00E-04	1.00E-01	0.00E+00	0.00E+00	—	—	—	—
Zn-65	—	2.44E+02	—	—	—	2.84E-03	5.00E-06	7.90E-02	2.62E-41	0.00E+00	—	—	—	—
Br-83	—	9.96E-02	—	—	—	6.96E+00	9.00E-04	1.60E-02	0.00E+00	0.00E+00	—	—	—	—
—	Kr-83m	7.63E-02	0.9998	—	—	9.09E+00	NA	8.70E-02	0.00E+00	—	—	—	—	—
Br-84	—	2.21E-02	—	—	—	3.14E+01	4.00E-04	8.20E-03	0.00E+00	0.00E+00	—	—	—	—
Kr-88	—	1.18E-01	—	—	—	5.86E+00	NA	7.30E-01	0.00E+00	—	—	—	—	—
—	Rb-88	1.24E-02	1.0000	—	—	5.61E+01	4.00E-04	7.30E-01	0.00E+00	0.00E+00	—	—	—	—
Rb-89	—	1.06E-02	—	—	—	6.54E+01	9.00E-04	3.30E-02	0.00E+00	0.00E+00	—	—	—	—
—	Sr-89	5.05E+01	1.0000	—	—	1.37E-02	8.00E-06	4.20E-03	7.45E-194	0.00E+00	—	—	—	—
Sr-90	—	1.06E+04	—	—	—	6.54E-05	5.00E-07	6.60E-04	8.14E-05	1.63E+02	5.83	32.2	3.92E-33	0.00E+00
—	Y-90	2.67E+00	1.0000	—	—	2.60E-01	7.00E-06	1.30E-04	8.14E-05	1.16E+01	5.83	32.2	3.92E-33	0.00E+00
Sr-91	—	3.96E-01	—	—	—	1.75E+00	2.00E-05	1.40E-02	0.00E+00	0.00E+00	—	—	—	—
—	Y-91m	3.45E-02	0.5780	—	—	2.01E+01	2.00E-03	4.50E-04	0.00E+00	0.00E+00	—	—	—	—
—	Y-91	5.85E+01	—	0.4220	1.0000	1.18E-02	8.00E-06	5.70E-03	1.25E-167	0.00E+00	—	—	—	—
Sr-92	—	1.13E-01	—	—	—	6.14E+00	4.00E-05	3.80E-02	0.00E+00	0.00E+00	—	—	—	—
—	Y-92	1.48E-01	1.0000	—	—	4.68E+00	4.00E-05	2.20E-02	0.00E+00	0.00E+00	—	—	—	—
Y-93	—	4.21E-01	—	—	—	1.65E+00	2.00E-05	1.40E-02	0.00E+00	0.00E+00	—	—	—	—
Zr-95	—	6.40E+01	—	—	—	1.08E-02	2.00E-05	1.20E-03	3.67E-154	0.00E+00	—	—	—	—



**Table 2.4.13-3 (Sheet 2 of 3)**  
**Results of Screening Level Radionuclide Transport Analysis**

Parent Radionuclide (1)	Progeny in Chain (2)	Radionuclide Characteristics						C <sub>0</sub> (μCi/cm <sup>3</sup> ) (9)	Radioactive Decay		Radioactive Decay + Retardation			
		t <sub>1/2</sub> (days) (3)	d <sub>12</sub> (4)	d <sub>13</sub> (5)	d <sub>23</sub> (6)	λ (days <sup>-1</sup> ) (7)	ECL (μCi/cm <sup>3</sup> ) (8)		C (μCi/cm <sup>3</sup> ) (10)	C/ECL (11)	K <sub>d</sub> (cm <sup>3</sup> /g) (12)	R (13)	C (μCi/cm <sup>3</sup> ) (14)	C/ECL (15)
—	Nb-95m	3.61E+00	0.0070	—	—	1.92E-01	3.00E-05	0.00E+00	2.72E-156	0.00E+00	—	—	—	—
—	Nb-95	3.52E+01	—	0.9930	1.0000	1.97E-02	3.00E-05	1.20E-03	8.15E-154	0.00E+00	—	—	—	—
Mo-99	—	2.75E+00	—	—	—	2.52E-01	2.00E-05	1.00E-01	0.00E+00	0.00E+00	—	—	—	—
—	Tc-99m	2.51E-01	0.8760	—	—	2.76E+00	1.00E-03	9.70E-02	0.00E+00	0.00E+00	—	—	—	—
Ru-103	—	3.93E+01	—	—	—	1.76E-02	3.00E-05	1.40E-02	1.08E-247	0.00E+00	—	—	—	—
—	Rh-103m	3.90E-02	0.9970	—	—	1.78E+01	6.00E-03	1.20E-02	1.08E-247	0.00E+00	—	—	—	—
Ru-106	—	3.68E+02	—	—	—	1.88E-03	3.00E-06	1.90E-01	1.31E-27	0.00E+00	—	—	—	—
—	Rh-106	3.45E-04	1.0000	—	—	2.01E+03	NA	1.90E-01	1.31E-27	—	—	—	—	—
Ag-110m	—	2.50E+02	—	—	—	2.77E-03	6.00E-06	2.70E-03	7.93E-42	0.00E+00	—	—	—	—
—	Ag-110	2.85E-04	0.0133	—	—	2.43E+03	NA	3.60E-05	1.06E-43	—	—	—	—	—
Te-127m	—	1.09E+02	—	—	—	6.36E-03	9.00E-06	3.70E-04	1.56E-92	0.00E+00	—	—	—	—
—	Te-127	3.90E-01	0.9760	—	—	1.78E+00	1.00E-04	0.00E+00	1.53E-92	0.00E+00	—	—	—	—
Te-129m	—	3.36E+01	—	—	—	2.06E-02	7.00E-06	1.30E-03	2.62E-290	0.00E+00	—	—	—	—
—	Te-129	4.83E-02	0.6500	—	—	1.44E+01	4.00E-04	1.80E-03	1.71E-290	0.00E+00	—	—	—	—
I-129	—	5.73E+09	—	—	—	1.21E-10	2.00E-07	7.30E-09	7.30E-09	3.65E-02	0.00	1.0	7.30E-09	3.65E-02
Te-131m	—	1.25E+00	—	—	—	5.55E-01	8.00E-06	3.20E-03	0.00E+00	0.00E+00	—	—	—	—
—	Te-131	1.74E-02	0.2220	—	—	3.98E+01	8.00E-05	2.10E-03	0.00E+00	0.00E+00	—	—	—	—
—	I-131	8.04E+00	—	0.7780	1.0000	8.62E-02	1.00E-06	3.40E-01	0.00E+00	0.00E+00	—	—	—	—
Te-132	—	3.26E+00	—	—	—	2.13E-01	9.00E-06	3.80E-02	0.00E+00	0.00E+00	—	—	—	—
—	I-132	9.58E-02	1.0000	—	—	7.24E+00	1.00E-04	4.60E-01	0.00E+00	0.00E+00	—	—	—	—
Te-134	—	2.90E-02	—	—	—	2.39E+01	3.00E-04	5.30E-03	0.00E+00	0.00E+00	—	—	—	—
—	I-134	3.65E-02	1.0000	—	—	1.90E+01	4.00E-04	2.40E-01	0.00E+00	0.00E+00	—	—	—	—
I-130	—	5.15E-01	—	—	—	1.35E+00	2.00E-05	5.30E-03	0.00E+00	0.00E+00	—	—	—	—
I-133	—	8.67E-01	—	—	—	7.99E-01	7.00E-06	6.30E-01	0.00E+00	0.00E+00	—	—	—	—
—	Xe-133m	2.19E+00	0.0290	—	—	3.17E-01	NA	8.20E-01	0.00E+00	—	—	—	—	—
—	Xe-133	5.25E+00	—	0.9710	1.0000	1.32E-01	NA	5.80E+01	0.00E+00	—	—	—	—	—
I-135	—	2.75E-01	—	—	—	2.52E+00	3.00E-05	3.80E-01	0.00E+00	0.00E+00	—	—	—	—
—	Xe-135m	1.06E-02	0.1540	—	—	6.53E+01	NA	8.20E-02	0.00E+00	—	—	—	—	—
—	Xe-135	3.79E-01	—	0.8460	1.0000	1.83E+00	NA	1.70E+00	0.00E+00	—	—	—	—	—
Cs-134	—	7.53E+02	—	—	—	9.21E-04	9.00E-07	3.30E-01	5.32E-14	0.00E+00	—	—	—	—

**Table 2.4.13-3 (Sheet 3 of 3)**  
**Results of Screening Level Radionuclide Transport Analysis**

Parent Radionuclide (1)	Progeny in Chain (2)	Radionuclide Characteristics						C <sub>0</sub> (μCi/cm <sup>3</sup> ) (9)	Radioactive Decay		Radioactive Decay + Retardation			
		t <sub>1/2</sub> (days) (3)	d <sub>12</sub> (4)	d <sub>13</sub> (5)	d <sub>23</sub> (6)	λ (days <sup>-1</sup> ) (7)	ECL (μCi/cm <sup>3</sup> ) (8)		C (μCi/cm <sup>3</sup> ) (10)	C/ECL (11)	K <sub>d</sub> (cm <sup>3</sup> /g) (12)	R (13)	C (μCi/cm <sup>3</sup> ) (14)	C/ECL (15)
Cs-136	—	1.31E+01	—	—	—	5.29E-02	6.00E-06	4.80E-01	0.00E+00	0.00E+00	—	—	—	—
Cs-137	—	1.10E+04	—	—	—	6.30E-05	1.00E-06	2.40E-01	3.20E-02	3.20E+04	38.00	204.1	4.39E-180	0.00E+00
—	Ba-137m	1.77E-03	0.9460	—	—	3.91E+02	NA	2.30E-01	3.02E-02	—	—	—	—	—
Xe-138	—	1.02E-02	—	—	—	6.79E+01	NA	1.20E-01	0.00E+00	—	—	—	—	—
—	Cs-138	2.24E-02	1.0000	—	—	3.09E+01	4.00E-04	1.80E-01	0.00E+00	0.00E+00	—	—	—	—
Ba-140	—	1.27E+01	—	—	—	5.46E-02	8.00E-06	1.80E-02	0.00E+00	0.00E+00	—	—	—	—
—	La-140	1.68E+01	1.0000	—	—	4.13E-01	9.00E-06	3.60E-02	0.00E+00	0.00E+00	—	—	—	—
Ce-141	—	3.25E+01	—	—	—	2.13E-02	3.00E-05	3.90E-03	1.56E-299	0.00E+00	—	—	—	—
Ce-143	—	1.38E+01	—	—	—	5.04E-01	2.00E-05	7.90E-04	0.00E+00	0.00E+00	—	—	—	—
—	Pr-143	1.36E+01	1.0000	—	—	5.11E-02	2.00E-05	5.10E-04	0.00E+00	0.00E+00	—	—	—	—
Ce-144	—	2.84E+02	—	—	—	2.44E-03	3.00E-06	8.30E-03	1.00E-36	0.00E+00	—	—	—	—
—	Pr-144m	5.07E-03	0.0178	—	—	1.37E+02	NA	0.00E+00	1.78E-38	—	—	—	—	—
—	Pr-144	1.20E-02	—	0.9822	0.9990	5.78E+01	6.00E-04	8.30E-03	1.00E-36	0.00E+00	—	—	—	—
W-187	—	9.96E-01	—	—	—	6.96E-01	3.00E-05	1.00E-03	0.00E+00	0.00E+00	—	—	—	—
Np-239	—	2.36E+00	—	—	—	2.94E-01	2.00E-05	2.70E-02	0.00E+00	0.00E+00	433.00	2315.3	0.00E+00	0.00E+00
—	Pu-239	8.79E+06	1.0000	—	—	7.89E-08	2.00E-08	0.00E+00	7.23E-09	3.62E-01	433.00	2315.3	2.10E-11	1.05E-03

Notes:

Yellow highlighting indicates C/ECL ratios exceed 0.01.

C/ECL ratios less than 1 x 10<sup>-6</sup> are taken to be zero.

NA — ECL is not available.

Dashed cells "—" indicate the information is not applicable.

Radionuclide concentrations with C/ECL ratios of less than 0.01 in Column 11 are not carried forward to the second stage of the screening analysis. These cells (i.e. Columns 12-15) are therefore dashed "—."

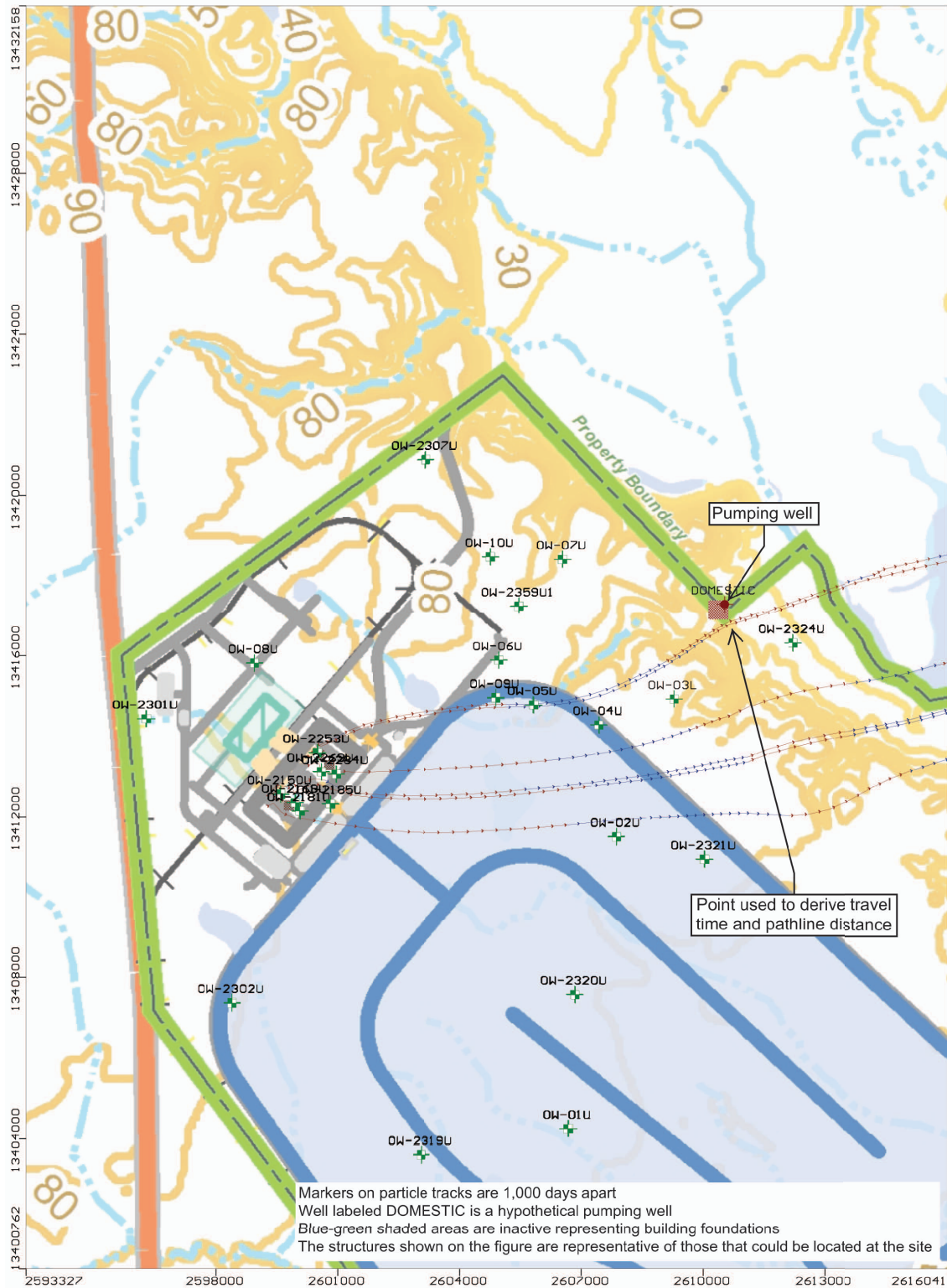
**Table 2.4.13-4  
Distribution Coefficients for Upper Shallow, Lower Shallow, and Deep Aquifers**

Boring	Sample	Zone	Material <sup>(a)</sup>	Distribution Coefficient (cm <sup>3</sup> /g)					
				Fe	Co	Ni	Sr	Cs	Pu
B-2150 <sup>(b)</sup>	SS-15	Upper	SC	1159	272	236	94.7	837	1025
B-2169	SS-13	Upper	SP-SM	3199	86.6	375	259	1349	862
B-2169	SS-15	Upper	SP	650	91.5	70.9	82	163	1326
B-2181	SS-14	Upper	SP-SC	1289	254	181	62.6	171	1283
B-2253	SS-15	Upper	SP	1164	129	139	53.7	192	728
B-2270	SS-16	Upper	CL	2314	142	86.2	29.2	449	885
B-2284 <sup>(b)</sup>	SS-16	Upper	SP-SC	2050	102	72.9	50.1	159	1119
B-2301	SS-14	Upper	SP	1332	91.2	43.3	12.8	87.7	1515
B-2307	SS-15	Upper	SP	1411	272	166	66.2	673	557
B-2317	SS-15	Upper	SP-SM	4716	608	264	108	1189	669
B-2349	SS-18	Upper	SP-SC	3907	134	80.4	137	213	1141
B-2150	SS-20	Lower	SP-SM	1763	146	244	194	38	898
B-2181	SS-19	Lower	SP-SC	1561	204	135	45	265	433
B-2253	SS-20	Lower	SP	1655	89.3	55	16.3	83.2	848
B-2270	SS-21	Lower	SP	3681	65.7	26.3	5.83	63.9	1002
B-2284	SS-20	Lower	SP-SC	1602	107	83.2	24.4	158	1217
B-2317	SS-23	Lower	SP	3535	138	163	219	120	1251
B-2349	SS-23	Lower	SP-SC	1909	75.1	59.1	87	113	1346
B-2301	SS-26	Deep	SP	1215	49.3	56	16.6	32.9	928
B-2307	SS-26	Deep	SP	2081	39.2	23.3	23.6	43	1031

(a) Material types based on the Unified Soil Classification System:

- SC — sandy clay
- SP — poorly graded sand
- SM — silty sand
- CL — low plasticity clay

(b) Triplicate samples—average value used.



**Figure 2.4.13-1 Particle Tracking Results from Post-Construction Model Simulation for Scenario 4**