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Dominion®

July 29, 2009

U. S. Nuclear Regulatory Commission
Attention: Document Control Desk
Washington, D. C. 20555

Serial No. NA3-09-013RA
Docket No. 52-017
COL/BCB

DOMINION VIRGINIA POWER
NORTH ANNA UNIT 3 COMBINED LICENSE APPLICATION
RESPONSE TO REQUEST FOR ADDITIONAL INFORMATION LETTER NO. 034
(FSAR CHAPTER 2)

On March 26, 2009, the NRC requested additional information to support the review of certain portions of the North Anna Unit 3 Combined License Application (COLA). The letter contained twelve RAIs. Dominion responded to nine of the RAIs by letter dated June 17, 2009 (Serial No. NA3-09-013R). The response to one of the other three RAIs is provided in Enclosure 1 of this letter:

- RAI Question 02.04.13-4 Accidental Release Groundwater Transport Analysis

The information provided in the RAI response will be incorporated into a future submission of the North Anna Unit 3 COLA, as described in the Enclosure. Additional analysis is required to complete the responses to the two remaining RAIs from Letter No. 034 (02.05.04-12, Engineering Properties of Concrete Fill, and 02.05.04-15, Dynamic Bearing Capacity for Reactor/Fuel Buildings). These responses will be submitted by August 31, 2009.

Please contact Regina Borsh at (804) 273-2247 (regina.borsh@dom.com) if you have questions.

Very truly yours,

Eugene S. Grecheck

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NRO

COMMONWEALTH OF VIRGINIA

COUNTY OF HENRICO

The foregoing document was acknowledged before me, in and for the County and Commonwealth aforesaid, today by Eugene S. Grecheck, who is Vice President-Nuclear Development of Virginia Electric and Power Company (Dominion Virginia Power). He has affirmed before me that he is duly authorized to execute and file the foregoing document on behalf of the Company, and that the statements in the document are true to the best of his knowledge and belief.

Acknowledged before me this 29th day of July, 2009
My registration number is 7173057 and my
Commission expires: August 31, 2012

Wanda K. Marshall
Notary Public

WANDA K. MARSHALL
Notary Public
Commonwealth of Virginia
7173057
My Commission Expires Aug 31, 2012

Enclosure:

1. Response to NRC RAI Letter No. 034, RAI Question No. 02.04.13-4

Commitments made by this letter:

1. The information provided in the RAI response will be incorporated into a future submission of the North Anna Unit 3 COLA, as described in the Enclosure.
2. These responses [02.05.04-12, Engineering Properties of Concrete Fill, and 02.05.04-15, Dynamic Bearing Capacity for Reactor/Fuel Buildings] will be submitted by August 31, 2009.

cc: U. S. Nuclear Regulatory Commission, Region II
T. A. Kevern, NRC
J. T. Reece, NRC
J. J. Debiec, ODEC
R. Kingston, GEH
P. Smith, DTE

ENCLOSURE 1

Response to NRC RAI Letter Number 34

RAI Question Number 02.04.13-4

NRC RAI 02.04.13-4

The purpose of this RAI is to address the requirements of 10 CFR 20, Appendix B, which requires that radionuclides released in liquid effluents do not result in concentrations at the nearest source of potable water that exceed the concentrations listed in Table 2, column 2.

Staff request additional information demonstrating that the applicant's transport analysis constitutes a bounding analysis, i.e. an analysis that is based on the largest or smallest parameter values measured onsite, which consequently calculates the highest receptor-point radionuclide concentrations consistent with onsite measurements.

As currently presented in the FSAR, the transport analysis uses a groundwater hydraulic conductivity (to compute groundwater velocity) that is less than the maximum value observed at the site. In addition, the transport analysis uses K_d values based on literature data that, in some cases, are greater than the minimum observed site-specific values. Staff requests the results of a transport analysis that uses the maximum observed hydraulic conductivity and the minimum site-specific K_d values for comparison with the 10 CFR 20, Appendix B, Table 2 effluent concentration limits.

Dominion Response

The analysis of an accidental release of liquid effluent to groundwater, as originally presented in FSAR Section 2.4.13.1, has been revised to use the maximum observed hydraulic conductivity and minimum observed site-specific K_d values. The analysis uses the accident scenario, conceptual model, and transport analysis methodology as described in FSAR Section 2.4.13.1. The methodology, data and assumptions, analysis, and results are presented in this RAI response. Design features, intended to mitigate the effects of a postulated Liquid Waste Management System (LWMS) tank failure, are described as well.

As described in FSAR Section 2.4.13.1.3, an initial screening analysis is performed considering advection and radioactive decay only to eliminate from consideration the radionuclides that would be well below the 10 CFR 20, Appendix B, Table 2 effluent concentration limits (ECLs) under very conservative modeling assumptions (i.e., no adsorption and no dispersion). For this limiting case, activity concentrations for parent and relevant progeny radionuclides are calculated at the point where liquid effluent from a postulated accidental release from an LWMS tank would discharge from the groundwater to Lake Anna. This point has been identified to be the Lake Anna cove that will serve as the forebay for the Unit 3 makeup water intake, based on observed water table contours (FSAR Figures 2.4-207 through 2.4-214) and groundwater modeling results that reflect post-construction conditions. This portion of the lake is within the restricted area as defined in SSAR Section 2.1.1.3 and illustrated on SSAR Figure 2.1-1.

Activity concentrations for the parent and first two progeny radionuclides at the point of groundwater discharge can be calculated from FSAR Equations 2.4.13-8, -13, and -18 with time, t, being equal to the groundwater travel time. The groundwater travel time between when the LWMS tank is postulated to fail and reaching Lake Anna is calculated based on the following data:

Hydraulic conductivity (K) = 9.9 ft/d
Hydraulic gradient (dh/dx) = -0.040
Effective porosity (n_e) = 0.25
Transport distance (L) = 1000 ft

The hydraulic conductivity value represents the maximum observed value for the site, based on test data summarized in FSAR Table 2.4-16R. The other properties were established as described in FSAR 2.4.13.1.3.

Using the above values, the average linear velocity is calculated to be:

$$v = -\frac{K}{n_e}\frac{dh}{dx} = \frac{9.9}{0.25} \times 0.040 = 1.58 \text{ ft/d}$$

The groundwater travel time is then:

$$t = \frac{L}{v} = \frac{1000}{1.58} = 1.73 \text{ y}$$

Using FSAR Equations 2.4.13-8, -13, and -18, the source term concentrations were decayed for a period of 1.73 y. Results are provided in Table 1 (page 9 of this response) under the column heading "Advection and Decay" and include the groundwater concentration, C, at the point of discharge to Lake Anna and the ratio of groundwater concentration to the associated effluent concentration limit, C/ECL. Note that in calculating this ratio, values of less than 1×10^{-6} were taken to be zero. Radionuclides for which the C/ECL value is greater than or equal to 0.01 are H-3, Mn-54, Fe-55, Co-58, Co-60, Ni-63, Zn-65, Sr-89, Sr-90, Y-90, Y-91, Zr-95, Nb-95, Ru-106, Ag-110m, Cs-134, Cs-137, Ce-144, Pr-144, and Pu-239; and are taken to be the radionuclides of interest for the purposes of assessing compliance with 10 CFR 20. The C/ECL values for the remaining radionuclides are so small that they do not play a role in assessing regulatory compliance, even when summed; these radionuclides are eliminated from further consideration.

The radionuclides of interest identified above were further evaluated considering adsorption, in addition to advection and radioactive decay. The distribution coefficient, K_d, for each radionuclide was assigned its minimum site-specific value, based on data included in FSAR Table 2.4-207. Site-specific K_d values are not available for some radionuclides, including isotopes of yttrium (Y), zirconium

(Zr), niobium (Nb), praseodymium (Pr), and neptunium (Np). In the case of the yttrium isotopes, Y-90 and Y-91, the K_d value was assumed to be the same as strontium, Sr-90 and Sr-91 serving as parent radionuclides. The K_d values for Zr-95, Nb-95m, and Nb-95 were conservatively established based on data published in NUREG/CR-6697 (i.e., the 10th percentile of their distribution). For Pr-144, a daughter product of Ce-144, its K_d value was assumed to be the same as for cerium. In the case of Np-239, the parent of Pu-239, its K_d value was assumed to be the same as for plutonium. For H-3, a component of water, the K_d value is zero by definition. The K_d values used in the transport analysis are provided in Table 1.

Retardation factors for the radionuclides of interest were calculated using FSAR Equation 2.4.13-2 using the K_d values as described above, an effective porosity of 0.25, and a bulk density of 1.83 g/cm^3. The concentration of each radionuclide was then determined at the point of groundwater discharge to Lake Anna using FSAR Equations 2.4.13-8, -13, and -18, as necessary, and the appropriate initial concentration, decay rate, and retardation factor. Table 1 provides the results under the column heading "Advection, Decay, and Adsorption." As before, C/ECL values less than 1×10^{-6} were taken to be zero. Radionuclides for which the C/ECL value is greater than or equal to 0.01 are H-3, Co-60, Ni-63, Sr-90, Y-90, and Pu-239.

In interpreting the results provided in Table 1, it is important to recognize that differential transport rates result from the adsorption process. Consequently, any radionuclides associated with an accidental release of liquid effluent to the groundwater would arrive at the lake shoreline at different times. The arrival times, t_i, are calculated as

$$t_i = \frac{L}{v / R_i}$$

where: t_i = arrival time for radionuclide i; and R_i = retardation factor for radionuclide i. The duration of a liquid effluent release, τ, can be determined as

$$\tau = \frac{V_{release}}{Q_{release}}$$

where: $V_{release}$ = volume of liquid effluent released (29,600 gal. or 3957 ft^3); and $Q_{release}$ = volumetric flow rate of liquid effluent into the subsurface. Noting that $Q_{release}$ is limited by the groundwater flow rate, $Q_{release}$ can be estimated as a function of the geometry of the liquid effluent plume and the Darcy velocity. It is assumed that the liquid effluent released from the LWMS tank occupies a volume in the saturated zone in the shape of rectangular parallelepiped with a height, b, equal to the saturated thickness of the water table aquifer (26 ft), and equal length, l, and width, w. Considering that the release would occupy a fraction of

the aquifer volume equal to the effective porosity, the length and width of the plume can be calculated as 24.67 ft. The flow rate of the liquid effluent release in the subsurface can then be estimated as

$$Q_{release} = qA = -K\frac{dh}{dx}bw = 9.9 \times 0.040 \times 26 \times 24.67 = 254 \text{ ft}^3/\text{d} = 0.00294 \text{ ft}^3/\text{s}$$

Given the above, τ is calculated as

$$\tau = \frac{3957 \text{ ft}^3}{0.00294 \text{ ft}^3/\text{s}} / 86{,}400 \text{ s/d} = 15.6 \text{ d}$$

Using the radionuclide arrival times and discharge duration as described above, the sum of fractions, Σ C/ECL, is plotted as a function of time elapsed following the postulated release in Figure 1 (page 11 of this response). This plot assumes that the release is instantaneous and that transport mechanisms are limited to advection, adsorption, and decay. These results indicate that H-3 would discharge to Lake Anna 1.7 years following a release, while Sr-90 and Y-90 would discharge about 47 years following a release. In these cases, the H-3 and the Sr-90 and Y-90 concentrations would be above 10 CFR 20 limits within the restricted area. Pu-239, Co-60, and Ni-63 would discharge much later, about 69, 84, and 162 years, respectively, following a release. Pu-239, Co-60, and Ni-63 concentrations are predicted to be below 10 CFR 20 limits at their point of discharge to Lake Anna and within the restricted area. These results demonstrate that Pu-239, Co-60, and Ni-63 require no further evaluation.

The results presented in Table 1 and Figure 1 indicate that H-3, Sr-90, and Y-90 need to be further evaluated to determine compliance with 10 CFR 20, Appendix B, Table 2 limits, which apply to the nearest source of potable water located in an unrestricted area. This evaluation requires consideration of surface water pathways, which in turn are determined by the status of plant operation. Because of its mobility, a release of H-3 would likely enter the surface water within the operational lifetime of Unit 3 (up to 60 years), whereas the less mobile Sr-90 and Y-90 could enter the surface water either during Unit 3 operation or after the plant has been shutdown, depending on when an accidental release might occur. As described in FSAR Section 2.4.13.2, any constituent in the groundwater discharging to Lake Anna during plant operation is expected to be: (1) entrained, mixed, and diluted with surface water in the cove that comprises the Unit 3 intake forebay; (2) subsequently abstracted from the cove by the water-supply intake for Unit 3, introduced into the closed-cycle circulating water system, and circulated through wet cooling towers; and (3) discharged with the cooling tower blowdown to the discharge canal. If Unit 3 were not operating, constituents in groundwater discharging to Lake Anna would simply be mixed and diluted with surface water in the cove. Note that this cove is isolated from the rest of Lake Anna by a berm

and is connected hydraulically with the lake by a set of culverts as shown in FSAR Figure 2.4-204.

For the scenario in which the plant is operating (where H-3, Sr-90, and Y-90 are of interest), radionuclide concentrations in the discharge canal can be estimated by diluting the volume of liquid effluent released into the volume of the discharge canal and accounting for the radioactive decay that would occur during groundwater transport. This approach assumes that Units 1 & 2 are not operating, which is conservative because it ignores the large volume of circulating water discharged from Units 1 & 2 that would otherwise be available for dilution. Assuming fully mixed conditions and no hydraulic interaction with the Waste Heat Treatment Facility, the sum of fractions can be calculated as

$$\sum \frac{C_{discharge}}{ECL} = \frac{V_{release}}{V_{discharge}} \sum \frac{C}{ECL}$$

where: $C_{discharge}$ = radionuclide concentration in the discharge canal (restricted area); C = radionuclide concentration of the groundwater discharging to surface water (Table 1); and $V_{discharge}$ = volume of water in the discharge canal. The discharge canal is 3850 ft long with a bottom width of 100 ft, side slopes of 2.5:1, and an invert elevation of 227 ft NGVD 29 (ESP-ER Section 3.4.2.2). Given these characteristics, the discharge canal volume can be calculated as

$$V_{discharge} = AL = (b + zy)yL$$

where: A = cross sectional area; b = bottom width; z = side slope; y = depth; and L = channel length. For a lake elevation of 250 ft NGVD 29, the volume of the discharge canal is calculated using the equation for $V_{discharge}$ as follows:

$$V_{discharge} = [100 + 2.5(23)](23)(3850) = 13{,}947{,}000 \text{ ft}^3$$

Applying the equation above to H-3 and Sr-90 and Y-90 yields the following:

H-3: $$\sum \frac{C_{discharge}}{ECL} = \frac{3957}{13{,}947{,}000} \times 2.39 = 0.00068 < 1$$

S-90/Y-90: $$\sum \frac{C_{discharge}}{ECL} = \frac{3957}{13{,}947{,}000} \times (390 + 27.9) = 0.12 < 1$$

For the scenario in which the plant is not operating (where Sr-90 and Y-90 are of interest), a bounding estimate of the sum of fractions in the unrestricted area of Lake Anna can be determined by calculating the radionuclide concentration in the isolated cove of Lake Anna that receives the effluent release via groundwater

discharge. Assuming fully mixed conditions, this concentration can be calculated as

$$\sum \frac{C_{cove}}{ECL} = \frac{V_{release}}{V_{cove}} \sum \frac{C}{ECL}$$

where: C_{cove} = radionuclide concentration in the Lake Anna cove (restricted area); and V_{cove} = volume of water in cove (3,929,000 ft^3 assuming a 250 ft NGVD 29 water surface elevation). This value is considered bounding because any water leaving the cove would have to mix with additional surface water prior to entering the unrestricted area. Applying this equation to Sr-90 and Y-90 gives

$$\text{S-90/Y-90:} \quad \sum \frac{C_{cove}}{ECL} = \frac{3957}{3{,}929{,}000} \times (390 + 27.9) = 0.42 < 1$$

The results presented above demonstrate that use of the maximum observed hydraulic conductivity and minimum site-specific K_d values result in sum of fraction values less than one (unity) during plant operation and after the plant has been shut down. Therefore, it is concluded that the requirements of 10 CFR 20 are met under these limiting conditions that combine maximum hydraulic conductivity and minimum distribution coefficients.

Note that the above analysis embodies a number of conservative assumptions regarding the LWMS tank failure mechanism and subsequent transport in the groundwater and surface water environments. The key conservatisms in the analysis are identified and described below.

1. The accidental release analysis assumes an instantaneous release to the groundwater. This assumption is very conservative because it requires simultaneous failure of the LWMS tank, steel-lined tank cubicles of the radwaste building, and reinforced walls and basemat of the radwaste building, all of which are seismically designed.

2. The LWMS tank being evaluated, an equipment drain collection tank located on the lowest level of the radwaste building, is about 26 ft below the water table. If a failure as described above were to occur, groundwater would flow into the lower levels of the radwaste building, precluding the release of liquid effluents out of the building. The building interior would have to be flooded to an elevation greater than or equal to the water table before a release to the groundwater could occur. Based on the nominal dimensions of the radwaste building (65.0 m by 32.8 m), about 477,315 ft^3 of water would be required to fill the building interior to the water table elevation, assuming 80 percent of the volume is susceptible to water flooding. This would dilute the radioactive source term by a factor of about 120 (477,315 / 3957) from that used in the present analysis.

3. Longitudinal and transverse hydrodynamic dispersion during groundwater transport is not accounted for in the transport analysis. Hydrodynamic dispersion would act to attenuate radionuclide concentrations in the groundwater, which would result in surface water concentrations lower than those predicted.

4. The maximum observed hydraulic conductivity and the minimum site-specific K_d values are used for the groundwater transport analysis, which represents a highly unlikely combination. This in turn yields very conservative (lower duration) groundwater transport times that underestimate radioactive decay. The use of more realistic hydraulic conductivity and K_d values (e.g., geometric mean values) would result in longer groundwater travel times, more radioactive decay, and lower groundwater and surface water concentrations.

In addition to the above, it should be noted that the Unit 3 design incorporates special design features to mitigate the consequences of a failure of a tank as described in FSAR Section 2.4.13. In particular, compartments in the radwaste building containing high level liquid radwaste are steel-lined up to a height capable of containing the release of all liquid radwaste in the compartment. These design features are durable and passive and require no operator intervention. Steel liners are cited in BTP 11-6 as design features considered acceptable for mitigating the consequences of LWMS tank failures. However, no credit has been taken in the analysis described above or in FSAR Section 2.4.13 for these design features mitigating the consequences of an accidental release of liquid effluent from a LWMS tank.

Finally, it is noted that compliance with 10 CFR 20.1406(a) requires an onsite monitoring program, as an integral part of the radiological environmental monitoring program. Implementation of the program will provide early detection and quantification of any leaks and spills and maintain a current baseline of radiological and hydrogeological parameters. Given that groundwater travel times for the radionuclides of interest conservatively range from 1.7 to 47 years, there would be ample time to monitor groundwater conditions and to perform remediation, if needed, to ensure compliance with 10 CFR 20 limits.

Proposed COLA Revision

FSAR Section 2.4.13 will be revised as shown in the attached mark-up to incorporate the above response.

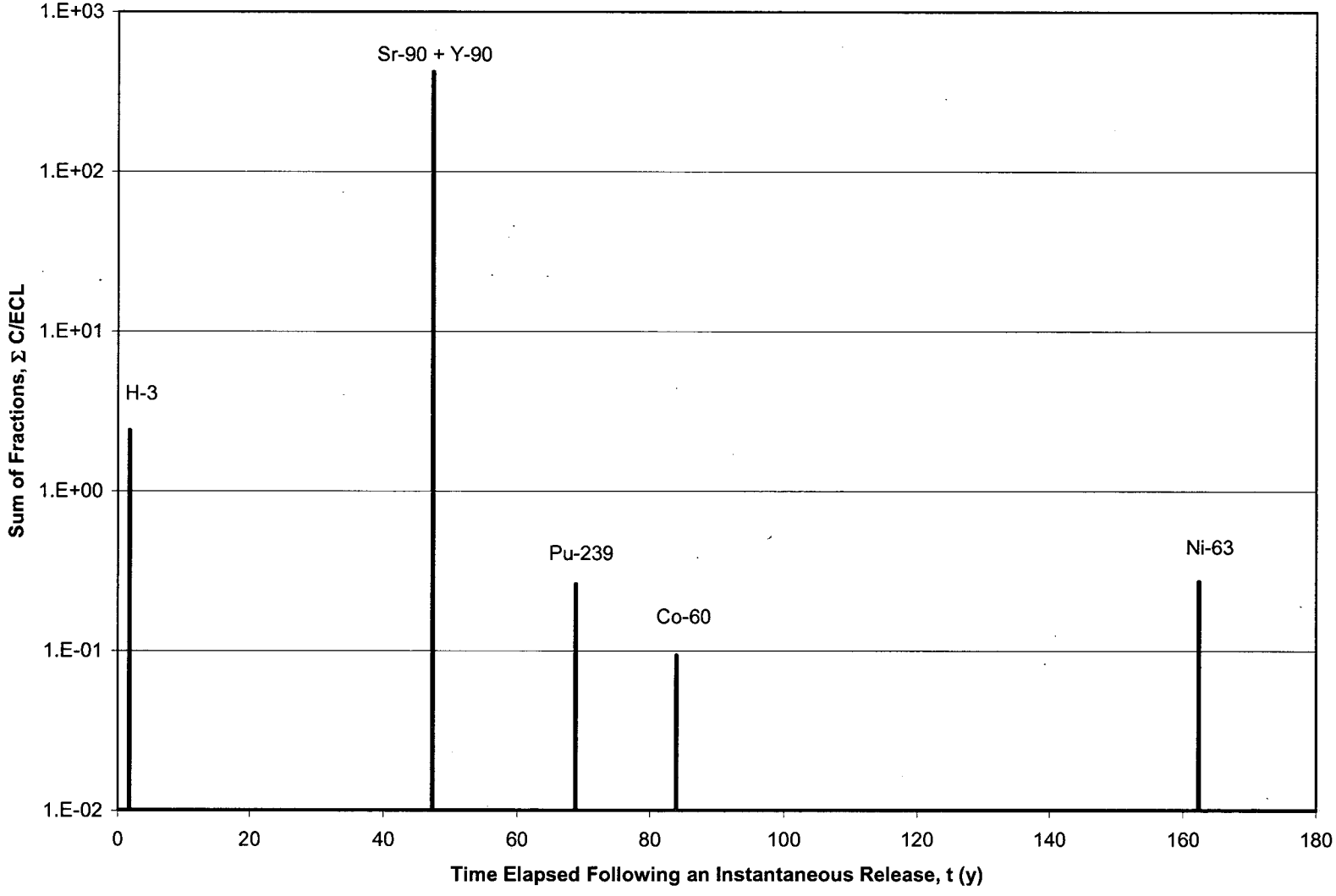
Table 1: Groundwater Concentrations at Point of Discharge to Lake Anna

Source Term Characteristics										Advection and Decay					Advection, Decay, and Adsorption			
Parent Radio-nuclide	Progeny in Chain	Half-life[1] (days)	Branching Fraction[1] d_{12}	d_{13}	d_{23}	Decay Rate[2] ($days^{-1}$)	ECL[3] ($\mu Ci/cm^3$)	Collection Tank Conc[4] (MBq/m^3)	Collection Tank Conc ($\mu Ci/cm^3$)	K_1	K_2	K_3	Ground Water Conc[5] ($\mu Ci/cm^3$)	Ground Water Conc / ECL	Distribution Coefficient (cm^3/g)	Retardation Factor[6]	Ground Water Conc[7] ($\mu Ci/cm^3$)	Ground Water Conc / ECL
H-3		4.51E+03				1.54E-04	1.00E-03	9.73E+01	2.63E-03	2.63E-03			2.39E-03	2.39E+00	0	1.0	2.39E-03	2.39E+00
Na-24		6.25E-01				1.11E+00	5.00E-05	4.74E+01	1.28E-03	1.28E-03			1.09E-307	0.00E+00				
P-32		1.43E+01				4.85E-02	9.00E-06	1.98E+01	5.35E-04	5.35E-04			2.75E-17	0.00E+00				
Cr-51		2.77E+01				2.50E-02	5.00E-04	2.61E+03	7.05E-02	7.05E-02			9.72E-09	1.94E-05				
Mn-54		3.13E+02				2.21E-03	3.00E-05	9.83E+01	2.66E-03	2.66E-03			6.56E-04	2.19E+01	4.5	33.9	6.81E-24	0.00E+00
Mn-56		1.07E-01				6.48E+00	7.00E-05	7.59E+01	2.05E-03	2.05E-03			0.00E+00	0.00E+00				
Fe-55		9.86E+02				7.03E-04	1.00E-04	3.08E+03	8.32E-02	8.32E-02			5.34E-02	5.34E+02	4504	32943.3	0.00E+00	0.00E+00
Fe-59		4.45E+01				1.56E-02	1.00E-05	3.82E+01	1.03E-03	1.03E-03			5.54E-08	5.54E-03				
Co-58		7.08E+01				9.79E-03	2.00E-05	1.76E+02	4.76E-03	4.76E-03			9.84E-06	4.92E-01	6.5	48.5	2.41E-133	0.00E+00
Co-60		1.93E+03				3.59E-04	3.00E-06	6.25E+02	1.69E-02	1.69E-02			1.35E-02	4.49E+03	6.5	48.5	2.80E-07	9.35E-02
Ni-63		3.51E+04				1.97E-05	1.00E-04	3.24E+00	8.76E-05	8.76E-05			8.65E-05	8.65E-01	12.7	93.9	2.72E-05	2.72E-01
Cu-64		5.29E-01				1.31E+00	2.00E-04	5.92E+01	1.60E-03	1.60E-03			0.00E+00	0.00E+00				
Zn-65		2.44E+02				2.84E-03	5.00E-06	2.65E+03	7.16E-02	7.16E-02			1.19E-02	2.38E+03	11.8	87.3	7.17E-70	0.00E+00
Rb-89		1.06E-02				6.54E+01	9.00E-04	1.25E+00	3.38E-05	3.38E-05			0.00E+00	0.00E+00	3.6	27.3		
	Sr-89	5.05E+01	1.0000			1.37E-02	8.00E-06	1.43E+02	3.86E-03	-7.09E-09	3.86E-03		6.67E-07	8.33E-02	3.6	27.3	5.44E-106	0.00E+00
Sr-90		1.06E+04				6.54E-05	5.00E-07	2.23E+01	6.03E-04	6.03E-04			5.78E-04	1.16E+03	3.6	27.3	1.95E-04	3.90E+02
	Y-90	2.67E+00	1.0000			2.60E-01	7.00E-06	6.95E-01	1.88E-05	6.03E-04	-5.84E-04		5.78E-04	8.26E+01	3.6	27.3	1.95E-04	2.79E+01
Sr-91		3.96E-01				1.75E+00	2.00E-05	5.68E+01	1.54E-03	1.54E-03			0.00E+00	0.00E+00	3.6	27.3		
	Y-91m	3.45E-02	0.5780			2.01E+01	2.00E-03			9.72E-04	-9.72E-04		0.00E+00	0.00E+00	3.6	27.3		
	Y-91	5.85E+01		0.4220	1.0000	1.18E-02	8.00E-06	6.28E+01	1.70E-03	-1.10E-05	5.74E-07	1.71E-03	9.63E-07	1.20E-01	3.6	27.3	2.79E-92	0.00E+00
Sr-92		1.13E-01				6.14E+00	4.00E-05	3.25E+01	8.78E-04	8.78E-04			0.00E+00	0.00E+00				
	Y-92	1.48E-01	1.0000			4.68E+00	4.00E-05	2.67E+01	7.22E-04	-2.83E-03	3.55E-03		0.00E+00	0.00E+00				
Y-93		4.21E-01				1.65E+00	2.00E-05	5.98E+01	1.62E-03	1.62E-03			0.00E+00	0.00E+00				
Zr-95		6.40E+01				1.08E-02	2.00E-05	1.34E+01	3.62E-04	3.62E-04			3.89E-07	1.94E-02	6.13	45.8	2.67E-140	0.00E+00
	Nb-95m	3.61E+00	0.0070			1.92E-01	3.00E-05			2.69E-06	-2.69E-06		2.88E-09	9.61E-05	6.13	45.8		
	Nb-95	3.52E+01		0.9930	1.0000	1.97E-02	3.00E-05	8.76E+00	2.37E-04	8.05E-04	3.07E-07	-5.69E-04	8.62E-07	2.87E-02	6.13	45.8	5.95E-140	0.00E+00
Mo-99		2.75E+00				2.52E-01	2.00E-05	2.07E+02	5.59E-03	5.59E-03			4.37E-72	0.00E+00				
	Tc-99m	2.51E-01	0.8760			2.76E+00	1.00E-03	1.72E+01	4.65E-04	5.39E-03	-4.93E-03		4.22E-72	0.00E+00				
Ru-103		3.93E+01				1.76E-02	3.00E-05	2.39E+01	6.46E-04	6.46E-04			9.43E-09	3.14E-04				
	Rh-103m	3.90E-02	0.9970			1.78E+01	6.00E-03	2.33E-02	6.30E-07	6.45E-04	-6.44E-04		9.41E-09	1.57E-06				
Ru-106		3.68E+02				1.88E-03	3.00E-06	8.17E+00	2.21E-04	2.21E-04			6.72E-05	2.24E+01	272	1990.4	0.00E+00	0.00E+00
	Rh-106	3.45E-04	1.0000			2.01E+03	NA[8]	2.95E-05	7.97E-10	2.21E-04	-2.21E-04		6.72E-05					
Ag-110m		2.50E+02				2.77E-03	6.00E-06	2.67E+00	7.22E-05	7.22E-05			1.25E-05	2.09E+00	2.5	19.3	1.58E-19	0.00E+00
	Ag-110	2.85E-04	0.0133			2.43E+03	NA[8]			9.60E-07	-9.60E-07		1.67E-07					
Te-129m		3.36E+01				2.06E-02	7.00E-06	4.29E+01	1.16E-03	1.16E-03			2.56E-09	3.66E-04				
	Te-129	4.83E-02	0.6500			1.44E+01	4.00E-04		0.00E+00	7.55E-04	-7.55E-04		1.67E-09	4.17E-06				
Te-131m		1.25E+00				5.55E-01	8.00E-06	4.85E+00	1.31E-04	1.31E-04			1.21E-156	0.00E+00				
	Te-131	1.74E-02	0.2220			3.98E+01	8.00E-05			2.95E-05	-2.95E-05		2.72E-157	0.00E+00				
	I-131	8.04E+00		0.7780	1.0000	8.62E-02	1.00E-06	6.89E+02	1.86E-02	-2.42E-05	6.40E-08	1.86E-02	4.30E-26	0.00E+00				
Te-132		3.26E+00				2.13E-01	9.00E-06	1.21E+00	3.27E-05	3.27E-05			1.66E-63	0.00E+00				
	I-132	9.58E-02	1.0000			7.24E+00	1.00E-04	6.58E+01	1.78E-03	3.37E-05	1.74E-03		1.71E-63	0.00E+00				
I-133		8.67E-01				7.99E-01	7.00E-06	5.51E+02	1.49E-02	1.49E-02			9.45E-222	0.00E+00				
	Xe-133m	2.19E+00	0.0290			3.17E-01	NA[8]			-2.83E-04	2.83E-04		3.94E-91					
	Xe-133	5.25E+00		0.9710	1.0000	1.32E-01	NA[8]			-2.81E-03	-2.03E-04	3.01E-03	1.76E-39					
I-134		3.65E-02				1.90E+01	4.00E-04	4.38E+01	1.18E-03	1.18E-03			0.00E+00	0.00E+00				

Source Term Characteristics										Advection and Decay					Advection, Decay, and Adsorption			
Parent Radio-nuclide	Progeny in Chain	Half-life[1] (days)	Branching Fraction[1]			Decay Rate[2] ($days^{-1}$)	ECL[3] ($\mu Ci/cm^3$)	Collection Tank Conc[4] (MBq/m^3)	Collection Tank Conc ($\mu Ci/cm^3$)	K_1	K_2	K_3	Ground Water Conc[5] ($\mu Ci/cm^3$)	Ground Water Conc / ECL	Distribution Coefficient (cm^3/g)	Retardation Factor[6]	Ground Water Conc[7] ($\mu Ci/cm^3$)	Ground Water Conc / ECL
			d_{12}	d_{13}	d_{23}													
I-135		2.75E-01				2.52E+00	3.00E-05	2.19E+02	5.92E-03	5.92E-03			0.00E+00	0.00E+00				
	Xe-135m	1.06E-02	0.1540			6.53E+01	NA[8]			9.48E-04	-9.48E-04		0.00E+00					
	Xe-135	3.79E-01		0.8460	1.0000	1.83E+00	NA[8]			-1.57E-02	2.73E-05	1.57E-02	0.00E+00					
Cs-134		7.53E+02				9.21E-04	9.00E-07	7.36E+01	1.99E-03	1.99E-03			1.11E-03	1.24E+03	64.9	475.7	1.76E-123	0.00E+00
Cs-136		1.31E+01				5.29E-02	6.00E-06	7.25E+00	1.96E-04	1.96E-04			6.09E-19	0.00E+00				
Cs-137		1.10E+04				6.30E-05	1.00E-06	2.09E+02	5.65E-03	5.65E-03			5.43E-03	5.43E+03	64.9	475.7	3.42E-11	3.42E-05
	Ba-137m	1.77E-03	0.9460			3.91E+02	NA[8]	3.71E-03	1.00E-07	5.34E-03	-5.34E-03		5.14E-03					
Cs-138		2.24E-02				3.09E+01	4.00E-04	5.62E+00	1.52E-04	1.52E-04			0.00E+00	0.00E+00				
Ba-140		1.27E+01				5.46E-02	8.00E-06	1.75E+02	4.73E-03	4.73E-03			5.14E-18	0.00E+00				
	La-140	1.68E+00	1.0000			4.13E-01	9.00E-06	2.62E+01	7.08E-04	5.45E-03	-4.74E-03		5.92E-18	0.00E+00				
Ce-141		3.25E+01				2.13E-02	3.00E-05	2.97E+01	8.03E-04	8.03E-04			1.14E-09	3.80E-05				
Ce-144		2.84E+02				2.44E-03	3.00E-06	7.86E+00	2.12E-04	2.12E-04			4.55E-05	1.52E+01	329.1	2408.0	0.00E+00	0.00E+00
	Pr-144m	5.07E-03	0.0178			1.37E+02	NA[8]			3.78E-06	-3.78E-06		8.10E-07					
	Pr-144	1.20E-02		0.9822	0.9990	5.78E+01	6.00E-04	1.03E-03	2.78E-08	2.12E-04	2.76E-06	-2.15E-04	4.55E-05	7.58E-02	329.1	2408.0	0.00E+00	0.00E+00
W-187		9.96E-01				6.96E-01	3.00E-05	1.15E+01	3.11E-04	3.11E-04			4.84E-195	0.00E+00				
Np-239		2.36E+00				2.94E-01	2.00E-05	7.17E+02	1.94E-02	1.94E-02			5.76E-83	0.00E+00	5.3	39.8		
	Pu-239	8.79E+06	1.0000			7.89E-08	2.00E-08			-5.20E-09	5.20E-09		5.20E-09	2.60E-01	5.3	39.8	5.19E-09	2.60E-01

[1] Obtained from ICRP Publication 38.
[2] Calculated using FSAR Equation 2.4.13-4.
[3] Obtained from 10 CFR 20, Appendix B, Table 2, Column 2.
[4] Obtained from DCD Table 12.2-13a.
[5] Calculated using FSAR Equations 2.4.13-8, 2.4.13-13, or 2.4.13-18 depending on position in decay chain and assuming no retardation.
[6] Calculated using FSAR Equation 2.4.13-2.
[7] Calculated using FSAR Equations 2.4.13-8, 2.4.13-13, or 2.4.13-18 depending on position in decay chain.
[8] ECL is not available.

Figure 1: Sum of Fractions as a Function of Time for Groundwater Discharged to Lake Anna



Markup of North Anna COLA

The attached markup represents Dominion's good faith effort to show how the COLA will be revised in a future COLA submittal in response to the subject RAI. However, the same COLA content may be impacted by revisions to the ESBWR DCD, responses to other COLA RAIs, other COLA changes, plant design changes, editorial or typographical corrections, etc. As a result, the final COLA content that appears in a future submittal may be somewhat different than as presented herein.

were selected to produce an accident scenario that leads to the most adverse contamination of groundwater, or surface water via the groundwater pathway.

Radwaste tanks outside of containment are located on the levels B1F and B2F of the radwaste building as shown on DCD Figure 1.2-25. The radwaste tanks having the largest volumes include the three equipment drain collection tanks and the equipment drain sample tank, all in the lowest level, B2F. Each of these tanks has a volume of 140 m^3 (37,000 gal) according to DCD Tables 12.2-13a and 12.2-13b.

Estimates of activity concentrations in various liquid radwaste tanks are provided in DCD Tables 12.2-13a through 12.2-13g. Of these tanks, the limiting tank in terms of radionuclide activity is the Equipment Drain Collection Tank, and its activity is provided in DCD Table 12.2-13a. Values are also provided in Table 2.4-206.

The accident scenario assumes that one of the equipment drain collection tanks ruptures and its contents are released to the groundwater. Note that this accident scenario is extremely conservative because the radwaste building is seismically designed in accordance with RG 1.143, Class RW-IIa, as described in DCD Section 12.2.1.4. Also, the concrete in each tank cubicle is provided with a steel liner, as described in Section 11.2.2.3, to prevent any potential liquid releases to the environment.

2.4.13.1.2 **Model**

Figure 2.4-217 illustrates the model used to evaluate an accidental release of radioactive liquid effluent to groundwater, or to surface water via the groundwater pathway. The key elements and assumptions embodied in the model are described and discussed below.

As indicated above, one of the equipment drain collection tanks is assumed to be the source of the release, with each tank having a capacity of 140 m^3 (37,000 gal) and radionuclide concentrations as given in DCD Table 12.2-13a. These tanks are located on the lowest level of the radwaste building (level B2F), which has a floor elevation of 244 ft msl. One of the tanks is postulated to rupture, and 80 percent of the liquid volume (112 m^3 or 29,600 gal) is assumed to be released following the guidance provided in BTP 11-6. Following tank rupture, it is conservatively assumed that a pathway is created that allows the entire 112 m^3 to enter the groundwater (unconfined aquifer) instantaneously.

The assumption of instantaneous release to the groundwater following tank rupture is very conservative because it requires failure of the floor drain system, plus it ignores the barriers presented by the basemat and the steel liners incorporated into the tank cubicles of the radwaste building, which is seismically designed. It should also be recognized that level B2F of the radwaste building is well below the water table. Piezometric head contour maps presented in Figure 2.4-207 through Figure 2.4-214 indicate that the ambient water table in the vicinity of the radwaste building is about 270 ft msl, or 26 ft above the floor elevation. If the basemat or exterior walls of the radwaste building and associated steel liners were to fail simultaneously, groundwater would flow into the radwaste building, precluding the release of liquid effluents out of the building. Only if the interior of the radwaste building was flooded to a level higher than the surrounding groundwater would there be a pathway for liquid effluents to be released out of the building and to the groundwater. Hence, the assumption of an accidental release of liquid effluents from the radwaste building to groundwater is extremely conservative, given the design features of the radwaste building intended to prevent an accidental release and the hydrogeologic conditions at the site.

With the postulated instantaneous release of the contents of an equipment drain collection tank to groundwater, radionuclides enter the unconfined aquifer and migrate with the groundwater in the direction of decreasing hydraulic head. Hydraulic head contour maps for the unconfined aquifer presented in Figure 2.4-207 through Figure 2.4-214 indicate that the groundwater pathway from the radwaste building is north-northeast toward Lake Anna, a groundwater discharge area. In particular, the hydrogeologic data suggest that the groundwater pathway terminates in the cove used for the Unit 3 intake from Lake Anna. The flow path is assumed to be a straight line between the radwaste building and the south edge of the cove, a distance of about 305 m (1000 ft) based on Figure 2.1-201. As indicated in Section 2.4.12.1.2, groundwater flow occurs in both the saprolite and underlying, shallow bedrock. During saturated zone transport, radionuclide concentrations of the liquid released to the groundwater are reduced by the processes of adsorption, hydrodynamic dispersion, and radioactive decay. As described in Section 2.4.12.1.3, there is an existing water-supply well in the power block area (Well No. 2 on Figure 2.4-215). This well will be closed and grouted to accommodate the construction of Unit 3. There are no other

existing water-supply or monitoring wells between the postulated release point and Lake Anna.

Lake Anna serves as a groundwater discharge area for the unconfined aquifer. The radionuclides associated with a liquid release would enter the surface water system via Lake Anna. ~~As noted above, the~~ The portion of Lake Anna closest to the release point is the cove that ~~is used for the water supply intake for Unit 3. This cove was created to construct the intakes for two units (an earlier Unit 3 and a Unit 4) that were not completed~~ was created for the abandoned Units 3 and 4. ~~The~~ As shown in Figure 2.4-204, the water-supply intake for Unit 3 is located at the end of the cove, which ~~serves as the forebay for Unit 3's water supply intake. This cove~~ is physically separated from the rest of the lake by a cofferdam, ~~. Openings in the cofferdam are provided to convey water from the North Anna Reservoir to the water supply intake~~ but hydraulically connected to the lake by a set of culverts. ~~This~~ The intake provides make-up water to the normal plant circulating water and service water cooling systems, and supplies water to the ~~potable,~~ station water system for demineralized~~,~~ water and fire protection use.~~water systems. The make-up water flow rates are about 1.42 m^3/s (50 cfs) and about 0.96 m^3/s (34 cfs) in the energy conservation and maximum water conservation modes, respectively. Under normal operating conditions~~ Because flow through the cove is induced when Unit 3 is operating, the subsequent surface water pathways for any radionuclides discharged with the groundwater to the cove depends on the operating status of the plant.

During the operational lifetime of Unit 3 (up to 60 years), any contaminated groundwater discharging to the cove ~~is entrained, mixed, and diluted with surface water in the Unit 3 intake forebay area and subsequently~~ would be abstracted from the ~~cove~~ lake by the water-supply intake for Unit 3. Any radionuclides introduced into the make-up water systems ~~are either circulated through the closed cycle, wet cooling towers associated with the normal plant circulating water and service water cooling systems, or enter the potable, demineralized, and fire protection systems. Volatile radionuclides in the circulating water passing through wet cooling towers are lost to the atmosphere. Non volatile radionuclides concentrate in the circulating water due to evaporative losses and are~~ ultimately would be discharged with the cooling tower blowdown to the discharge canal. ~~The~~ This blowdown discharge~~, about 0.34 m^3/s (12 cfs) in energy conservation mode and~~

~~about 0.25 m^3/s in maximum water conservation mode, mixes in~~ would be mixed and diluted with surface water in the discharge canal. ~~with 120 m^3/s (4246 cfs) of circulating water from Units 1 and 2 as illustrated in SSAR Figure 2.4-13~~. ~~Radionuclides transported by the flow in the discharge canal then pass through the WHTF, enter~~ The discharge canal is hydraulically connected to the WHTF, which in turn discharges to the North Anna Reservoir through Dike 3. ~~, and~~ Any radionuclides released from the discharge canal would undergo additional mixing and dilution in the ~~reservoir (SSAR Figure 2.4-13).~~ WHTF as well as the North Anna Reservoir ~~Most of the flow and associated dissolved radionuclide constituents are then recirculated upstream to the water intakes for Units 1, 2 and 3, while a relatively small fraction of the flow discharges~~ prior to discharge from the North Anna Dam to the North Anna River.

If Unit 3 were not operating, any contaminated groundwater discharging to Lake Anna would simply be mixed and diluted with surface water in the cove. Because the cove is isolated from the rest of the lake by the cofferdam and connected by culverts, hydraulic interaction between the two surface water bodies would occur only when there are changes in lake level or during runoff events.

As described in SSAR Section 2.1.1.3, the liquid effluent release limits for Unit 3 apply at the end of the discharge canal, which is designated as the release point to unrestricted areas in the context of 10 CFR 20. This would be the compliance point if Unit 3 were operating. As noted in ESP-ER Table 2.3-4, the Doswell Water Treatment Plant is the nearest and only municipal water system currently supplied from the North Anna River. The treatment plant is about 20 miles downstream of the North Anna Dam and near the confluence with the Little River.

2.4.13.1.3 **Radionuclide Transport Analysis**

A radionuclide transport analysis has been conducted to estimate the radionuclide concentrations that might expose existing and future water users based on an instantaneous release of the radioactive liquid from an equipment drain collection tank. Analysis of liquid effluent release commences with a screening model, using demonstratively conservative assumptions and coefficients. Radionuclide concentrations resulting from the screening analysis are then compared against the effluent concentration limits (ECLs) identified in 10 CFR 20, Appendix B, Table 2, Column 2, to determine acceptability. Further analysis, using more realistic modeling techniques, is conducted~~, as necessary, after the~~

~~screening results for each step are available~~ for the radionuclides of interest as identified in the screening analysis.

a. **Methodology**

This analysis accounts for the parent radionuclides assumed present in the radwaste tank plus progeny radionuclides that are generated subsequently during transport. The analysis considered all progeny in the decay chain sequences that are important for dosimetric purposes. International Commission on Radiation Protection (ICRP) Publication 38 (Reference 2.4-211) was used to identify the member for which the decay chain sequence can be truncated. For some of the radionuclides assumed present in an equipment drain collection tank, consideration of up to three members of the decay chain sequence was required. The derivation of the equations governing the transport of the parent and progeny radionuclides follows.

Transport of the parent radionuclide along a groundwater pathline is governed by the advection-dispersion-reaction equation (Reference 2.4-212), which is given as [equations and associated citations renumbered to 2.4.13-1 through 2.4.13-19]:

$$R\frac{\partial C}{\partial t} = D\frac{\partial^2 C}{\partial x^2} - v\frac{\partial C}{\partial x} - \lambda RC \qquad (2.4.13\text{-}1)$$

where: C = radionuclide concentration in terms of atom density; R = retardation factor; D = coefficient of longitudinal hydrodynamic dispersion; ~~v~~ v = average linear velocity; and λ = radioactive decay constant. The retardation factor is defined from the relationship:

$$R = 1 + \frac{\rho_b K_d}{n_e} \qquad (2.4.13\text{-}2)$$

where: ρ_b = bulk density; K_d = distribution coefficient; and n_e = effective porosity. The average linear velocity is determined using Darcy's law, which is:

$$v = -\frac{K}{n_e}\frac{dh}{dx} \qquad (2.4.13\text{-}3)$$

where: K = hydraulic conductivity; and dh/dx = hydraulic gradient. The radioactive decay constant can be written as:

$$\lambda = \frac{\ln 2}{t_{1/2}} \qquad (2.4.13\text{-}4)$$

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

Using the method of characteristics approach described in Reference 2.4-213, the material derivative of concentration can be written as:

$$\frac{dC}{dt} = \frac{\partial C}{\partial t} + \frac{dx}{dt}\frac{\partial C}{\partial x} \qquad (2.4.13\text{-}5)$$

Conservatively neglecting hydrodynamic dispersion, the characteristic equations for Equation 2.4.13-1 can be expressed as follows:

$$\frac{dC}{dt} = -\lambda C \qquad (2.4.13\text{-}6)$$

$$\frac{dx}{dt} = \frac{v}{R} \qquad (2.4.13\text{-}7)$$

The solutions of the system of equations comprising Equation 2.4.13-6 and Equation 2.4.13-7 can be obtained by integration to yield the characteristic curves of Equation 2.4.13-1. For the parent radionuclide, the equations representing the characteristic curves can be obtained as:

$$C_1 = C_{10}\exp(-\lambda_1 t) \qquad (2.4.13\text{-}8)$$

$$t = R_1 L / v \qquad (2.4.13\text{-}9)$$

where: C_1 = activity concentration of the parent radionuclide; C_{10} = initial activity concentration of the parent radionuclide; λ_1 = radioactive decay constant for the parent radionuclide; R_1 = retardation factor for the parent radionuclide; and L = groundwater pathline length.

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

$$R_2\frac{\partial C_2}{\partial t} = D\frac{\partial^2 C_2}{\partial x^2} - v\frac{\partial C_2}{\partial x} + d_{12}\lambda_1 R_1 C_1 - \lambda_2 R_2 C_2 \qquad (2.4.13\text{-}10)$$

where: subscript 2 denotes the first progeny radionuclide; and d_{12} = fraction of parent radionuclide transitions that result in production of progeny radionuclide. The characteristic equations for Equation 2.4.13-10, assuming $R_1 \approx R_2$ and again conservatively neglecting hydrodynamic dispersion, can be derived as:

$$\cancel{\frac{dC_2}{dt} = d_{12}\lambda_1 C_1 - \lambda_2 C_2} \qquad \boxed{\frac{dC_2}{dt} = d_{12}\lambda_1 C_1 - \lambda_2 C_2} \qquad (2.4.13\text{-}11)$$

$$\frac{dx}{dt} = \frac{v}{R_2} \qquad (2.4.13\text{-}12)$$

~~where: $\lambda_1' = \lambda_1 R_1 / R_2$.~~ Recognizing that Equation 2.4.13-11 is formally similar to Equation B.43 of Reference 2.4-214, these equations can be integrated to yield an expression for the activity concentration of the first progeny radionuclide:

$$\cancel{C_2 = K_1 \exp(-\lambda_1' t) + K_2 \exp(-\lambda_2 t)} \qquad (2.4.13\text{-}13)$$

$$\boxed{C_2 = K_1 \exp(-\lambda_1 t) + K_2 \exp(-\lambda_2 t)}$$

$$t = R_2 L / v \qquad (2.4.13\text{-}14)$$

for which:

$$\cancel{K_1 = \frac{d_{12}\lambda_2 C_{10}}{\lambda_2 - \lambda_1'}} \qquad \boxed{K_1 = \frac{d_{12}\lambda_2 C_{10}}{\lambda_2 - \lambda_1}}$$

$$\cancel{K_2 = C_{20} - \frac{d_{12}\lambda_2 C_{10}}{\lambda_2 - \lambda_1'}} \qquad \boxed{K_2 = C_{20} - \frac{d_{12}\lambda_2 C_{10}}{\lambda_2 - \lambda_1}}$$

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

$$R_3 \frac{\partial C_3}{\partial t} = D \frac{\partial^2 C_3}{\partial x^2} - v \frac{\partial C_3}{\partial x} + d_{13}\lambda_1 R_1 C_1 + d_{23}\lambda_2 R_2 C_2 - \lambda_3 R_3 C_3 \qquad (2.4.13\text{-}15)$$

where: subscript 3 denotes the second progeny radionuclide; d_{13} = fraction of parent radionuclide transitions that result in production of second progeny radionuclide; and d_{23} = fraction of first progeny radionuclide transitions that result in production of second progeny radionuclide. The characteristic equations for Equation 2.4.13-15, assuming $R_1 \approx R_2 \approx R_3$ and again conservatively neglecting hydrodynamic dispersion, can be derived as

$$\cancel{\frac{dC_3}{dt} = d_{13}\lambda_1' C_1 + d_{23}\lambda_2' C_2 - \lambda_3 C_3} \qquad (2.4.13\text{-}16)$$

$$\boxed{\frac{dC_3}{dt} = d_{13}\lambda_1 C_1 + d_{23}\lambda_2 C_2 - \lambda_3 C_3}$$

$$\frac{dx}{dt} = \frac{v}{R_3} \qquad (2.4.13\text{-}17)$$

~~where: $\lambda_1' = \lambda_1 R_1 / R_3$; and $\lambda_2' = \lambda_2 R_2 / R_3$.~~ Considering the formal similarity of Equation 2.4.13-16 to Equation B.54 of Reference 2.4-214, Equation 2.4.13-16 and Equation 2.4.13-17 can be integrated to yield an

expression for the activity concentration of the second progeny radionuclide:

$$\cancel{C_3 = K_1 \exp(-\lambda_1' t) + K_2 \exp(-\lambda_2' t) + K_3 \exp(-\lambda_3 t)} \qquad (2.4.13\text{-}18)$$

$$\boxed{C_3 = K_1 \exp(-\lambda_1 t) + K_2 \exp(-\lambda_2 t) + K_3 \exp(-\lambda_3 t)}$$

$$t = R_3 L / v \qquad (2.4.13\text{-}19)$$

for which:

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

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

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

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

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

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

~~To estimate the radionuclide concentrations in groundwater discharging to Lake Anna, Equation 2.4.13-8, Equation 2.4.13-13, and Equation 2.4.13-18 were applied as appropriate along the groundwater pathline that would originate at the radwaste building and terminate at the Lake Anna shoreline. The analysis was performed sequentially as described below.~~

b. ~~**Transport Considering Radioactive Decay Only**~~ **Screening Analysis**

~~An initial~~ Using the methodology developed above, a screening analysis was performed considering advection and radioactive decay only to eliminate from consideration those radionuclides in the source term that would be well below the 10 CFR 20, Appendix B, Table 2 ECLs under very conservative modeling assumptions (i.e., no adsorption and no dispersion). For this limiting case, activity concentrations for parent and relevant progeny radionuclides were calculated at the point where liquid effluent from a postulated accidental release from an equipment drain collection tank would discharge from the groundwater to Lake Anna. This

point has been identified to be the Lake Anna cove that will serve as the forebay for the Unit 3 makeup water intake, as discussed previously. This portion of the lake is within the restricted area as defined in SSAR Section 2.1.1.3 and illustrated on SSAR Figure 2.1-1. Activity concentrations for the parent and first two progeny radionuclides at the point of groundwater discharge can be calculated from Equations 2.4.13-8, 2.4.13-13, and 2.4.13-18 with time, *t*, being equal to the groundwater travel time. ~~This analysis assumed that all radionuclides migrate at the same rate as groundwater and considered no adsorption and retardation, which would otherwise result in lower radionuclide concentrations. The concentrations of the radionuclides assumed to be released from an equipment drain collection tank were decayed for a period equal to the groundwater travel time from the point of release to Lake Anna, using Equation 2.4.13-8, Equation 2.4.13-13, or Equation 2.4.13-18 as appropriate with $R_1 = R_2 = R_3 = 1$. Any radionuclide having a concentration of less than 0.01 times its ECL was eliminated from consideration because its concentration would be well below its regulatory limit. Any radionuclide having a concentration greater than or equal to 0.01 times its ECL was retained for further evaluation.~~

~~Evaluating transport considering radioactive decay only requires an estimate of the groundwater travel time.~~ The groundwater travel time between the ~~radwaste building and~~ point of the postulated release and the point of discharge to Lake Anna ~~has been estimated using the following site specific hydrogeologic characteristics~~ is calculated based on the following data:

Hydraulic conductivity, K = ~~3.4~~ 9.9 ft/d~~ay~~

Hydraulic gradient, dh/dx = –0.040 ~~ft/ft~~

Effective porosity, n_e = 0.25

Transport distance, L = 1000 ft

~~Note that the hydraulic conductivity (3.4 ft/day) was established as a site characteristic in the SSAR based on hydraulic testing of 13 observation wells completed in the water table aquifer, with the 3.4 ft/day value being the maximum of the 13 observations. Subsequently, three additional observation wells were installed and tested as part of the Unit 3 subsurface investigation, increasing the total number of hydraulic conductivity observations to 16 for the saprolite material. Table 2.4-16R summarizes these data. A review of these observations indicates that 14~~

~~out of the 16 values (87.5 percent) are less than or equal to 3.4 ft/day. Because a value of 3.4 ft/day is greater than 87.5 percent of the observed data, it is considered to be a conservative value. The two values that exceed 3.4 ft/day include those observed at OW-945 (3.8 ft/day) and OW-946 (9.9 ft/day), which are located 2000 to 2500 ft upgradient from the radwaste building (see Figure 2.4-206). These values are not representative of the hydrogeologic conditions along the groundwater pathway between the radwaste building and Lake Anna. Hence, the 3.4 ft/day value established as site characteristic is conservative and is considered appropriate for assessing an accidental release of liquid effluent to the groundwater.~~

The hydraulic conductivity value represents the maximum observed value for the site, based on test data summarized in Table 2.4-16R. The hydraulic gradient and effective porosity were established as described in Section 2.4.12.1.2.

~~Using the above~~ Based on these values, ~~in~~ Equation 2.4.13-3~~,~~ is used to calculate the average linear velocity ~~is calculated to be~~ as:

$$v = -\frac{K}{n_e}\frac{dh}{dx} = \frac{\overset{9.9}{\cancel{3.4}}}{0.25} \times 0.040 = \overset{1.58}{\cancel{0.544}}\ \text{ft/d}\cancel{\text{ay}}$$

~~The~~ Using Equation 2.4.13-9, the groundwater travel time is then:

$$t = L/v = 1000/\overset{1.58}{\cancel{0.54}} = \overset{1.73}{\cancel{1840\ \text{days} = 5.03}}\ \text{years}$$

~~Using~~ Taking $R_1=R_2=R_3=1$ and using Equations 2.4.13-8, ~~Equation 2.4.13-13, or Equation 2.4.13-18~~ 2.4.13-13, and 2.4.13-18, as appropriate ~~with R = 1, the initial~~, the source term concentrations were decayed for a period of ~~5.03~~1.73 years. Radioactive decay data and decay chain specifications were taken from ~~NUREG/CR-5512, Vol. 1, Table E.1 (Reference 2.4-214). Radioactive decay data for some of the shorter-lived radionuclides were obtained from~~ ICRP Publication 38 (Reference 2.4-211). Results are provided in Table 2.4-206, under the column heading "Advection and Decay" and include the groundwater concentration, *C*, at the point of discharge to Lake Anna and ~~summarizes the results and identifies those radionuclides for which~~ the ratio of groundwater concentration to the associated effluent concentration limit, *C*/ECL. ~~would exceed 0.01. These~~ Ratios of less than 1×10^{-6} were taken to be zero. Radionuclides for which the *C*/ECL value is greater than

or equal to 0.01 include H-3, Mn-54, Fe-55, Co-58, Co-60, Ni-63, Zn-65, Sr-89, Sr-90, Y-90, Y-91, Zr-95, Nb-95, Ru-106, Ag-110m, Cs-134, Cs-137, Ce-144, Pr-144, and Pu-239, and are considered to be the radionuclides of interest for the purpose of assessing compliance with 10 CFR 20. The *C*/ECL values for the remaining radionuclides are so small that they do not play a role in assessing regulatory compliance, even when summed; these radionuclides were eliminated from further consideration.

c. ~~**Transport Considering Radioactive Decay and Adsorption**~~ **Groundwater Pathway**

~~Radionuclides retained from the screening analysis (H-3, Mn-54, Fe-55, Co-60, Ni-63, Zn-65, Sr-90, Y-90, Ru-106, Ag-110m, Cs-134, Cs-137, Ce-144, and Pu-239)~~ The radionuclides of interest identified above were further evaluated ~~and screened~~ considering adsorption ~~and retardation~~ in addition to advection and radioactive decay. Distribution coefficient~~s for these elements were assigned using literature values. In particular~~, K_d values were ~~selected assuming the literature data to be log normally distributed and selecting the 10th percentile of the distribution to conservatively assign a value for the radionuclide transport analysis. NUREG/CR-6697 (Reference 2.4-215), Attachment C, Table 3.9-1 is used to assign the mean and standard deviation for each of the distributions. In the case of Y-90, no data were available to assign a K_d value for yttrium. Instead, adsorption characteristics for yttrium were assumed to be similar to that of scandium, as these two elements lie adjacent in the periodic table. The K_d value for Y-90 was then estimated as the 10th percentile of the distribution for scandium using the mean and standard deviation from NUREG/CR-6697~~ determined by laboratory analysis of site soil samples (Reference 2.4-219).

~~To assess the validity of the Kd values derived from NUREG/CR-6697 as described above, site-specific Kd~~ For the purpose of assessing 10 CFR 20 compliance, each radionuclide was assigned its minimum site-specific K_d value as obtained by laboratory testing. Site-specified K_d values were determined for Mn, Fe, Co, Ni, Zn, Sr, Ru, Ag, Cs, Ce, and Pu for 20 saprolite and weathered rock samples. These samples were obtained from borings B-901, B-904, B-913, B-917, B-919, B-920, B-928, B-929, B-931, B-932, B-949, and B-951, the locations of which are shown on Figures 2.5-221 and 2.5-222. K_d values for these samples were determined using the batch method in accordance with ASTM D 4646-03

at Savannah River National Laboratory using site water obtained from the unconfined aquifer. ~~Table 2.4-207 summarizes the results along with the values estimated from NUREG/CR-6697. Comparing the site-specific Kd values against those assumed in the transport analysis indicates the following:~~ The results are summarized in Table 2.4-207. Site-specific K_d values are not available for some radionuclides, including isotopes of yttrium (Y), zirconium (Zr), niobium (Nb), praseodymium (Pr), and neptunium (Np). In the case of the yttrium isotopes, Y-90 and Y-91, the K_d value was assumed to be the same as strontium, Sr-90 and Sr-91 serving as parent radionuclides. The K_d values for Zr-95, Nb-95m, and Nb-95 were conservatively assigned the 10th percentile of their distribution based on data published in NUREG/CR-6697 (Reference 2.4-215). For Pr-144, a daughter product of Ce-144, its K_d value was assumed to be the same as for cerium. In the case of Np-239, the parent of Pu-239, its K_d value was assumed to be the same as for plutonium. For H-3, a component of water, the K_d value is zero by definition. The K_d values used in the transport analysis are provided in Table 2.4-206.

- ~~The Kd values assumed for 6 elements (Fe, Zn, Sr, Ru, Cs, Ce) are less than the minimum observed values.~~
- ~~The Kd values assumed for 2 elements (Mn, Co) are bounded by the 1 percentile of the observed data.~~
- ~~The Kd values assumed for 2 elements (Ag, Pu) are bounded by the 10th percentile of the observed data.~~
- ~~The Kd value assumed for 1 element (Ni) is bounded by the 25th percentile of the observed data.~~

~~Based on the above comparison, the Kd values derived from NUREG/CR-6697 are conservative relative to the site-specific values. The literature values were therefore retained for the transport analysis.~~

Retardation factors for the radionuclides of interest were calculated using Equation 2.4.13-2 with the K_d values ~~the distribution coefficients established~~ as described above, an effective porosity of 0.25, and a bulk density of 1.83 g/cm^3. The bulk density was estimated using a soil grain specific gravity of 2.65 and total porosity of 0.31, ~~as described in~~ which were determined on a site-specific basis (Section 2.4.12.1.2). The concentration ~~for~~ of each radionuclide was then determined at the point of groundwater discharge to Lake Anna using ~~Equation~~

Equations 2.4.13-8, ~~or Equation~~ 2.4.13-13, and 2.4.13-18, as necessary, and the appropriate initial concentration, decay rate, and retardation factor. ~~Results are summarized in Table 2.4-208 and indicate that groundwater concentration to ECL ratios for H-3, Sr-90, Y-90, and Pu-239 would exceed 0.01.~~ Table 2.4-206 provides the results under the column heading "Advection, Decay, and Adsorption." As before for the groundwater concentration (*C*) to ECL ratios, *C*/ECL values less than 1×10^{-6} were taken to be zero. Radionuclides for which the *C*/ECL value is greater than or equal to 0.01 include H-3, Co-60, Ni-63, Sr-90, Y-90, and Pu-239.

In interpreting the results provided in Table 2.4-206, it is important to recognize that differential transport rates result from the adsorption process. Consequently, any radionuclides associated with an accidental release of liquid effluent to the groundwater could arrive at the lake shoreline at different times. The arrival time of a given radionuclide, t_i, is calculated as:

$$t_i = \frac{L}{v / R_i} \qquad (2.4.13\text{-}20)$$

where: t_i = arrival time for radionuclide i; and R_i = retardation factor for radionuclide i. The duration of a liquid effluent release, τ_i, can be determined as:

$$\tau_i = \frac{V_{release}}{Q_{release}} \qquad (2.4.13\text{-}21)$$

where: $V_{release}$ = volume of liquid effluent released (29,600 gal or 3957 ft^3); and $Q_{release}$ = volumetric flow rate of liquid effluent in the subsurface. Noting that $Q_{release}$ is limited by the groundwater flow rate, $Q_{release}$ can be estimated as a function of the geometry of the liquid effluent plume and the Darcy velocity. It is assumed that the liquid effluent released from the failed tank occupies a volume in the saturated zone in the shape of rectangular parallelepiped with a height, b, equal to the saturated thickness of the water table aquifer (26 ft), and equal length, l, and width, w. Considering that the release would occupy a fraction of the aquifer volume equal to the effective porosity, the length and width of the plume can be calculated as 24.67 ft. The flow rate of the liquid effluent release in the subsurface can then be estimated as:

$$Q_{release} = qA = -K\frac{dh}{dx}bw = 9.9 \times 0.040 \times 26 \times 24.67 = 254\ \text{ft}^3/\text{d} = 0.00294\ \text{ft}^3/\text{s}$$

Given the above, τ is calculated from Equation 2.4.13-21 as:

$$\tau = \frac{3957\ \text{ft}^3}{0.00294\ \text{ft}^3/\text{s}} / 86{,}400\ \text{s/d} = 15.6\ \text{d}$$

Using the radionuclide arrival times and discharge durations as described above, the sum of fractions, Σ *C*/ECL, is plotted as a function of time elapsed following the postulated release in Figure 2.4-218 for the hydraulic conductivity and distribution coefficient values assigned as described above. This plot assumes that the release is instantaneous and that transport mechanisms are limited to advection, adsorption, and decay. These results indicate that H-3 would discharge to Lake Anna 1.7 years following a release, while Sr-90 and Y-90 would discharge about 47 years following a release. In these cases, the H-3 and the Sr-90 and Y-90 concentrations would be above 10 CFR 20 limits within the restricted area. Pu-239, Co-60, and Ni-63 would discharge much later, about 69, 84, and 162 years, respectively, following a release. Pu-239, Co-60, and Ni-63 concentrations are predicted to be below 10 CFR 20 limits at their point of discharge to Lake Anna and within the restricted area. These results demonstrate that Pu-239, Co-60, and Ni-63 require no further evaluation.

d. ~~**Transport Considering Radioactive Decay, Adsorption, and Dilution**~~ **Surface Water Pathways**

~~As discussed in Section 2.4.13.1.2, the H-3, Sr-90, Y-90, and Pu-239 isotopes discharging with the groundwater to Lake Anna are entrained, mixed, and diluted in the surface water, flow of which is induced by the water supply intake for Unit 3. A dilution factor was estimated to account for the mixing and dilution as described below.~~

~~The total radionuclide flux in the groundwater was calculated using NUREG-0868 (Reference 2.4-216), Equation 3.23 as a basis. Conservatively ignoring hydrodynamic dispersion, this equation can be restated as:~~

$$F_{GW} = n_e v C_{GW} A \qquad (2.4.13\text{-}21)$$

~~where: F_{GW} = total radionuclide flux in groundwater; C_{GW} = radionuclide concentration in the groundwater; A = cross-sectional area normal to the direction of groundwater flow; and the other terms are as defined previously. The cross-sectional area of the plume is conservatively assumed to extend over the entire saturated thickness of the unconfined~~

~~aquifer and the entire length of the radwaste building. The saturated thickness is taken to extend from the water table to the top of the Zone III-IV, slightly weathered to moderately weathered rock. In the vicinity of the radwaste building, Figure 2.4-207 through Figure 2.4-214 indicate a water table elevation of about 82.30 m (270 ft) msl, while Table 2.5-208 indicates the Zone III-IV top of rock elevation to be 74.37 m (244 ft) msl. These values result in a saturated thickness of about 7.92 m (26 ft). DCD Figure 1.2-25 indicates the radwaste building to be 65 m (213 ft) in length normal to the direction of groundwater flow. The assumption that the plume extends the entire length of the building is conservative because the characteristic dimensions of the sources from which a release is postulated are a relatively small fraction of the 65 m length. The cross-sectional area is then the product of 26 ft and 213 ft, or 5540 ft^2.~~

~~The total radionuclide flux in the surface water of Lake Anna, induced by pumping from the water supply intake for Unit 3, is calculated as:~~

$$F_{SW} = QC_{SW} \qquad (2.4.13\text{-}22)$$

~~where: F_{SW} = total radionuclide flux in surface water; Q = surface water flow rate; and C_{SW} = radionuclide concentration in the surface water. This approach for calculating the radionuclide flux in surface water is justified, considering that any radionuclides released to the groundwater would likely discharge to the Unit 3 intake forebay area, which has been isolated from the rest of the lake and from which the water intake for Unit 3 will obtain water. The surface water flow is determined by the water supply requirements for Unit 3, which total 1.42 m^3/s (50 cfs) when running in the energy conservation mode and 0.96 m^3/s (34 cfs) in the maximum water conservation mode. There are times of the year when the combination wet and dry cooling towers used for normal plant cooling could function in a completely dry mode, particularly during cold weather. Under these conditions, no make-up water is required for the normal plant circulating water system, which comprises most of the total demand. However, these conditions are expected to persist for relatively short durations and are not representative of transport conditions over longer time scales.~~

~~Because the total radionuclide flux must be conserved, radionuclide concentrations in the surface water are estimated by equating Equation 2.4.13-21 and Equation 2.4.13-22 and solving for C_{SW}:~~

$$C_{SW} = \frac{n_e vA}{Q} C_{GW} \quad \text{(2.4.13-23)}$$

where the quantity $n_e vA/Q$ defines the dilution factor. Assuming for conservatism that the plant is operating in the maximum water conservation mode, the dilution factor is calculated using the previously defined values for n_e, v, A, and Q to be:

$$\frac{n_e vA}{Q} = \frac{0.25 \times 0.54/86{,}400 \times 5540}{34} = 2.56 \times 10^{-4}$$

This dilution factor is applied to the H-3, Sr-90, Y-90, and Pu-239 concentrations reported in Table 2.4-209 to account for dilution in addition to radioactive decay and adsorption. Table 2.4-210 summarizes the resulting concentrations, which represent the concentrations in the surface water withdrawn by the water supply intake for Unit 3. It is seen that the concentrations of each of these radionuclides are below their respective ECLs.

Most of the 0.96 m^3/s (34 cfs) withdrawn from Lake Anna is used as make-up water to replenish evaporative losses from cooling towers that are part of closed-cycle cooling systems. As discussed in Section 2.4.13.1.2, the non-volatile radionuclides concentrate in the circulating water by a factor of about four, prior to being discharged to the discharge canal. Even then, concentrations are well below ECLs. It should also be noted that radionuclides released in cooling tower blowdown discharge would mix with circulating water discharge from Units 1 and 2 (up to 120.2 m^3/s (4246 cfs)) as long as these units are operating. If Units 1 and 2 are shutdown, a minimum of 15.04 m^3/s (531 cfs) will continue to be circulated to provide adequate dilution for normal plant releases. These flows from Units 1 and 2 would further dilute the radionuclides discharged from Unit 3, which is not accounted for in Table 2.4-209.

As described in Section 2.4.13.1.2, there is an atmospheric pathway associated with the accidental release of liquid effluents to groundwater, which entails the release of tritium to the atmosphere, as water vapor, from the evaporation of cooling water from the Unit 3 wet cooling towers. Table 2.4-209 indicates a tritium concentration of 5.08×10^{-7} $\mu Ci/cm^3$ (508 pCi/l) for surface water withdrawn as makeup water to the circulating water system and contributed by the accidental release. This value is about one twentieth the 9417 pCi/l value evaluated previously in

~~FEIS Appendix H.3 (Reference 2.4-217). The FEIS determined that the doses associated with a concentration of 9417 pCi/l were insignificant when compared to the maximally exposed individual (MEI) dose from atmospheric releases from the stacks of Unit 3. Because the predicted concentration of 508 pCi/l is about a factor of twenty less than 9417 pCi/l, the dose associated with this atmospheric pathway is also insignificant.~~

The results presented in Table 2.4-206 and Figure 2.4-218 indicate that H-3, Sr-90, and Y-90 need to be further evaluated to determine compliance with 10 CFR 20, Appendix B, Table 2 limits, which apply to the nearest source of potable water located in an unrestricted area. This evaluation requires consideration of surface water pathways, which in turn are determined by the status of plant operation. Because of its mobility, a release of H-3 would likely enter the surface water within the operational lifetime of Unit 3 (up to 60 years), whereas the less mobile Sr-90 and Y-90 could enter the surface water either during Unit 3 operation or after the plant has been shutdown, depending on when an accidental release might occur. As described previously, any constituent in the groundwater discharging to Lake Anna during plant operation is expected to be: 1) entrained, mixed, and diluted with surface water in the cove that comprises the Unit 3 intake forebay; 2) subsequently abstracted from the cove by the water-supply intake for Unit 3, introduced into the closed-cycle circulating water system, and circulated through wet cooling towers; and 3) discharged with the cooling tower blowdown to the discharge canal. If Unit 3 were not operating, constituents in groundwater discharging to Lake Anna would simply be mixed and diluted with surface water in the cove. Note that this cove is isolated from the rest of Lake Anna by a cofferdam and is connected hydraulically with the lake by a set of culverts as shown in Figure 2.4-204.

For the scenario in which the plant is operating (where H-3, Sr-90, and Y-90 are of interest), radionuclide concentrations in the discharge canal can be estimated by diluting the volume of liquid effluent released into the volume of the discharge canal and accounting for the radioactive decay that would occur during groundwater transport. This approach assumes that Units 1 and 2 are not operating, which is conservative because it ignores the large volume of circulating water discharged from Units 1 and 2 that would otherwise be available for dilution. Assuming fully mixed

conditions and no hydraulic interaction with the WHTF, the sum of fractions can be calculated as:

$$\sum \frac{C_{discharge}}{ECL} = \frac{V_{release}}{V_{discharge}} \sum \frac{C}{ECL} \qquad (2.4.13\text{-}22)$$

where: $C_{discharge}$ = radionuclide concentration in the discharge canal (restricted area); $V_{discharge}$ = volume of water in the discharge canal; and C = radionuclide concentration of the groundwater discharging to surface water (Table 2.4-206). The discharge canal is 3850 ft long and has a trapezoidal cross-section with a bottom width of 100 ft, side slopes of 2.5:1, and an invert elevation of 227 ft NGVD 29 (ESP-ER Section 3.4.2.2). Given these characteristics, the discharge canal volume can be calculated as:

$$V_{discharge} = AL = (b + zy)yL \qquad (2.4.13\text{-}23)$$

where: A = cross sectional area; b = bottom width; z = side slope; y = depth; and L = channel length. For a lake elevation of 250 ft NGVD 29, the volume of the discharge canal is calculated using Equation 2.4.13-23 as follows:

$$V_{discharge} = [100 + 2.5(23)](23)(3850) = 13{,}947{,}000 \text{ ft}^3$$

Applying Equation 2.4.13-22 to H-3 and Sr-90 and Y-90 then yields the following for a lake elevation of 250 ft NGVD 29:

H-3: $$\sum \frac{C_{discharge}}{ECL} = \frac{3957}{13{,}947{,}000} \times 2.39 = 0.00068 < 1$$

S-90/Y-90: $$\sum \frac{C_{discharge}}{ECL} = \frac{3957}{13{,}947{,}000} \times (390 + 27.9) = 0.12 < 1$$

For the scenario in which the plant is not operating (where Sr-90 and Y-90 are of interest), a bounding estimate of the sum of fractions in the unrestricted area of Lake Anna can be determined by calculating the radionuclide concentration in the isolated cove of Lake Anna that receives the effluent release via groundwater discharge. Assuming fully mixed conditions and no hydraulic interaction with the main lake, this concentration can be calculated as:

$$\sum \frac{C_{cove}}{ECL} = \frac{V_{release}}{V_{cove}} \sum \frac{C}{ECL} \qquad (2.4.13\text{-}24)$$

where: C_{cove} = radionuclide concentration in the Lake Anna cove (restricted area); V_{cove} = volume of water in cove (3,929,000 ft^3 assuming a 250 ft NGVD 29 water surface elevation); and C = radionuclide concentration of the groundwater discharging to surface water (Table 2.4-206). This value is considered bounding because any water leaving the cove would have to mix with additional surface water prior to entering the unrestricted area. Applying Equation 2.4.13-24 to Sr-90 and Y-90 gives:

$$\text{S-90/Y-90: } \sum \frac{C_{cove}}{ECL} = \frac{3957}{3{,}929{,}000} \times (390 + 27.9) = 0.42 < 1$$

The results presented above demonstrate that use of the maximum observed hydraulic conductivity and minimum site-specific K_d values result in sum of fraction values less than one (unity) within the restricted area, both during plant operation and after the plant has been shut down. Because 10 CFR 20 limits are met within the restricted area, the same limits will be achieved with even greater margin in unrestricted areas as a consequence of additional mixing and dilution. Therefore, it is concluded that the requirements of 10 CFR 20 are met under these limiting conditions that combine maximum hydraulic conductivity and minimum distribution coefficients.

2.4.13.1.4 **Compliance with 10 CFR 20**

~~The radionuclide transport analysis presented above demonstrates that each of the radionuclides that could be accidentally released to groundwater would be individually below its ECL. However, 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").~~

~~This sum of fractions approach was applied to the radionuclide concentrations conservatively estimated as described in Section 2.4.13.1.3. Results are summarized in Table 2.4-210. The ratios for the mixture sum to 5.64×10^{-2}. This value is multiplied by a factor of four to account for concentration of radionuclides in circulating water due to evaporative losses, which results in a value of 2.26×10^{-1}. This value is below unity and demonstrates that an accidental release of radioactive~~

~~liquid effluent in groundwater complies with the 10 CFR 20 limits at the entrance of the discharge canal. The 2.26×10^{-1} value is bounding because the 0.25 m^3/s (9 cfs) of blowdown discharge would be diluted with a minimum of 15.04 m^3/s (531 cfs) of flow from Units 1 and 2 within the discharge canal and prior to the end of the canal, which is designated as the release point to unrestricted areas.~~

A conservative analysis of a postulated, accidental release of liquid effluents in groundwater has been conducted. The analysis was performed using demonstratively conservative coefficients and assumptions, and physical conditions likely to give the most adverse dispersion of liquid effluent. In addition, no credit was taken for design features considered acceptable for mitigating the consequences of an accidental release of liquid effluent from a LWMS tank. It is concluded that an accidental release of liquid from an ESBWR equipment drain collection tank to groundwater would result in radionuclide concentrations in the nearest potable water supply, located in an unrestricted area, that are below the 10 CFR 20 limits.

2.4.13.2 Surface Water

The purpose of this section is to provide a conservative analysis of a postulated, accidental release of radioactive liquid effluents to the surface water at the Unit 3 site. The key assumptions and accident scenario are described. The dilution analysis is presented along with various plant operating scenarios. The bounding case is identified. The radionuclide concentrations to which a water user might be exposed are compared against the regulatory limits for the bounding case.

2.4.13.2.1 Assumptions

The key assumptions adopted in this analysis area are as follows:

- The accidental release of radioactive liquid effluents to surface water results from a failure of the CST.
- The radionuclide inventory for the CST is based on 80 percent of the volume capacity of that tank as recommended in BTP 11-6. Based on the CST capacity of 4885 m^3 (172,512 ft^3) given in DCD Table 9.2-10, the volume of liquid released is 3908 m^3 (138,010 ft^3).

2.4-208 Virginia Department of Environmental Quality (DEQ), Annual Report of Water Withdrawals For the Period: January 1, 2006 to December 31, 2006. January 31, 2007.

2.4-209 Schlumberger Water Services (SWS), Visual MODFLOW Pro Version 4.3, User's Manual, Waterloo, Ontario, Canada, 2008.

2.4-210 Branch Technical Position 11-6, Postulated Radioactive Releases Due to Liquid-Containing Tank Failures, NUREG-0800, U. S. Nuclear Regulatory Commission, March 2007.

2.4-211 International Commission on Radiation Protection (ICRP), Radionuclide Transformations - Energy and Intensity of Emissions, ICRP Publication 38, Volumes 11-13, Pergamon Press, New York, 1983.

2.4-212 Javandel, I., Doughty, C., and C. F. Tsang, Groundwater Transport: Handbook of Mathematical Models, Water Resources Monograph 10, American Geophysical Union, 1984.

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2.4-214 Kennedy, W. E., and Strenge, D. L., Residual Radioactive Contamination From Decommissioning, NUREG/CR-5512, Volume 1, Pacific Northwest Laboratory, October 1992.

2.4-215 Yu, C., LePoire, D., E. Gnanapragasam, J. Arnish, S. Kamboj, B. M. Biwer, J. J. Cheng, A. Zielen, and S. Y. Chen, Development of Probabilistic RESRAD 6.0 and RESRAD-BUILD 3.0 Computer Codes, NUREG/CR-6697, Argonne National Laboratory, November 2000.

2.4-216 ~~Goddell, R. B., K. T. Key, and G. Whelan, A Collection of Mathematical Models for Dispersion in Surface Water and Groundwater, NUREG 0868, U. S. Nuclear Regulatory Commission, June 1982.~~ [Deleted]

2.4-217 ~~Environmental Impact Statement for an Early Site Permit (ESP) at the North Anna ESP Site, NUREG 1811, Vol. 1, December 2006.~~ [Deleted]

2.4-218 Updated Final Safety Analysis Report, North Anna Power Station, Revision 38.

2.4-219 Kaplan, D. I., Distribution Coefficients for the Combined Construction and Operation License (COL) Applications at the North Anna Site, WSRC-TR-2007-00430, Rev. 2, Savannah River National Laboratory, December 2007.

NAPS COL 2.0-24-A

Table 2.4-206 ~~Results of Groundwater Transport Analysis Considering Radioactive Decay Only~~ Groundwater Concentrations at Point of Discharge to Lake Anna

~~Parent Radionuclide~~	~~Progeny in Chain~~	~~Half-life[4] (days)~~	~~Branching Fraction[4]~~ d_{12}	d_{13}	d_{23}	~~Decay Rate[2] ($days^{-1}$)~~	~~Collection Tank Conc[3] (MBq/m^3)~~	~~Collection Tank Conc ($\mu Ci/cm^3$)~~	~~Ground Water Conc[4] ($\mu Ci/cm^3$)~~	~~ECL[5] ($\mu Ci/cm^3$)~~	~~Ground Water Conc / ECL~~
~~H-3~~	-	~~4.51E+03~~	-	-	-	~~1.54E-04~~	~~9.73E+01~~	~~2.63E-03~~	~~2.0E-03~~	~~1.00E-03~~	~~1.98E+00~~
~~Na-24~~	-	~~6.25E-01~~	-	-	-	~~1.11E+00~~	~~4.74E+01~~	~~1.28E-03~~	~~0.0E+00~~	~~5.00E-05~~	~~0.00E+00~~
~~P-32~~	-	~~1.43E+01~~	-	-	-	~~4.85E-02~~	~~1.98E+01~~	~~5.35E-04~~	~~1.1E-42~~	~~9.00E-06~~	~~1.20E-37~~
~~Cr-51~~	-	~~2.77E+01~~	-	-	-	~~2.50E-02~~	~~2.61E+03~~	~~7.05E-02~~	~~7.4E-22~~	~~5.00E-04~~	~~1.49E-18~~
~~Mn-54~~	-	~~3.13E+02~~	-	-	-	~~2.21E-03~~	~~9.83E+01~~	~~2.66E-03~~	~~4.5E-05~~	~~3.00E-05~~	~~1.51E+00~~
~~Mn-56~~	-	~~1.07E-01~~	-	-	-	~~6.48E+00~~	~~7.59E+01~~	~~2.05E-03~~	~~0.0E+00~~	~~7.00E-05~~	~~0.00E+00~~
~~Fe-55~~	-	~~9.86E+02~~	-	-	-	~~7.03E-04~~	~~3.08E+03~~	~~8.32E-02~~	~~2.3E-02~~	~~1.00E-04~~	~~2.29E+02~~
~~Fe-59~~	-	~~4.45E+01~~	-	-	-	~~1.56E-02~~	~~3.82E+01~~	~~1.03E-03~~	~~3.8E-16~~	~~1.00E-05~~	~~3.79E-11~~
~~Co-58~~	-	~~7.08E+01~~	-	-	-	~~9.79E-03~~	~~1.76E+02~~	~~4.76E-03~~	~~7.3E-11~~	~~2.00E-05~~	~~3.63E-06~~
~~Co-60~~	-	~~1.93E+03~~	-	-	-	~~3.59E-04~~	~~6.25E+02~~	~~1.69E-02~~	~~8.7E-03~~	~~3.00E-06~~	~~2.91E+03~~
~~Ni-63~~	-	~~3.51E+04~~	-	-	-	~~1.97E-05~~	~~3.24E+00~~	~~8.76E-05~~	~~8.4E-05~~	~~1.00E-04~~	~~8.44E-01~~
~~Cu-64~~	-	~~5.29E-01~~	-	-	-	~~1.31E+00~~	~~5.92E+01~~	~~1.60E-03~~	~~0.0E+00~~	~~2.00E-04~~	~~0.00E+00~~
~~Zn-65~~	-	~~2.44E+02~~	-	-	-	~~2.84E-03~~	~~2.65E+03~~	~~7.16E-02~~	~~3.9E-04~~	~~5.00E-06~~	~~7.73E+01~~
~~Rb-89~~	-	~~1.06E-02~~	-	-	-	~~6.54E+01~~	~~1.25E+00~~	~~3.38E-05~~	~~0.0E+00~~	~~9.00E-04~~	~~0.00E+00~~
-	~~Sr-89~~	~~5.05E+01~~	~~1.0000~~	-	-	~~1.37E-02~~	~~1.43E+02~~	~~3.86E-03~~	~~4.3E-14~~	~~8.00E-06~~	~~5.33E-09~~
~~Sr-90~~	-	~~1.06E+04~~	-	-	-	~~6.54E-05~~	~~2.23E+01~~	~~6.03E-04~~	~~5.3E-04~~	~~5.00E-07~~	~~1.07E+03~~
-	~~Y-90~~	~~2.67E+00~~	~~1.0000~~	-	-	~~2.60E-01~~	~~6.95E-01~~	~~1.88E-05~~	~~5.3E-04~~	~~7.00E-06~~	~~7.64E+01~~
~~Sr-91~~	-	~~3.96E-01~~	-	-	-	~~1.75E+00~~	~~5.68E+01~~	~~1.54E-03~~	~~0.0E+00~~	~~2.00E-05~~	~~0.00E+00~~
-	~~Y-91m~~	~~3.45E-02~~	~~0.5780~~	-	-	~~2.01E+01~~	-	-	~~0.0E+00~~	~~2.00E-03~~	~~0.00E+00~~

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Table 2.4-206 ~~Results of Groundwater Transport Analysis Considering Radioactive Decay Only~~ Groundwater Concentrations at Point of Discharge to Lake Anna

~~Parent Radionuclide~~	~~Progeny in Chain~~	~~Half-life[1] (days)~~	~~Branching Fraction[1]~~ d_{12}	d_{13}	d_{23}	~~Decay Rate[2] ($days^{-1}$)~~	~~Collection Tank Conc[3] (MBq/m^3)~~	~~Collection Tank Conc ($\mu Ci/cm^3$)~~	~~Ground Water Conc[4] ($\mu Ci/cm^3$)~~	~~ECL[5] ($\mu Ci/cm^3$)~~	~~Ground Water Conc / ECL~~
-	~~Y 91~~	~~5.85E+01~~		~~0.4220~~	~~1.0000~~	~~1.18E-02~~	~~6.28E+01~~	~~1.70E-03~~	~~5.9E-13~~	~~8.00E-06~~	~~7.42E-08~~
~~Sr 92~~	-	~~1.13E-01~~	-	-	-	~~6.14E+00~~	~~3.25E+01~~	~~8.78E-04~~	~~0.0E+00~~	~~4.00E-05~~	~~0.00E+00~~
-	~~Y 92~~	~~1.48E-01~~	~~1.0000~~	-	-	~~4.68E+00~~	~~2.67E+01~~	~~7.22E-04~~	~~0.0E+00~~	~~4.00E-05~~	~~0.00E+00~~
~~Y 93~~	-	~~4.21E-01~~	-	-	-	~~1.65E+00~~	~~5.98E+01~~	~~1.62E-03~~	~~0.0E+00~~	~~2.00E-05~~	~~0.00E+00~~
~~Zr 95~~	-	~~6.40E+01~~	-	-	-	~~1.08E-02~~	~~1.34E+01~~	~~3.62E-04~~	~~8.2E-13~~	~~2.00E-05~~	~~4.09E-08~~
-	~~Nb 95m~~	~~3.61E+00~~	~~0.0070~~	-	-	~~1.92E-01~~	-	-	~~6.1E-15~~	~~3.00E-05~~	~~2.02E-10~~
-	~~Nb 95~~	~~3.52E+01~~	-	~~0.9930~~	~~1.0000~~	~~1.97E-02~~	~~8.76E+00~~	~~2.37E-04~~	~~1.8E-12~~	~~3.00E-05~~	~~6.06E-08~~
~~Mo 99~~	-	~~2.75E+00~~	-	-	-	~~2.52E-01~~	~~2.07E+02~~	~~5.59E-03~~	~~3.3E-204~~	~~2.00E-05~~	~~1.67E-199~~
-	~~Tc 99m~~	~~2.51E-01~~	~~0.8760~~	-	-	~~2.76E+00~~	~~1.72E+01~~	~~4.65E-04~~	~~3.2E-204~~	~~1.00E-03~~	~~3.23E-201~~
~~Ru 103~~	-	~~3.93E+01~~	-	-	-	~~1.76E-02~~	~~2.39E+01~~	~~6.46E-04~~	~~5.4E-18~~	~~3.00E-05~~	~~1.79E-13~~
-	~~Rh 103m~~	~~3.90E-02~~	~~0.9970~~	-	-	~~1.78E+01~~	~~2.33E-02~~	~~6.30E-07~~	~~5.4E-18~~	~~6.00E-03~~	~~8.93E-16~~
~~Ru 106~~	-	~~3.68E+02~~	-	-	-	~~1.88E-03~~	~~8.17E+00~~	~~2.21E-04~~	~~6.9E-06~~	~~3.00E-06~~	~~2.31E+00~~
-	~~Rh 106~~	~~3.45E-04~~	~~1.0000~~	-	-	~~2.01E+03~~	~~2.95E-05~~	~~7.97E-10~~	~~6.9E-06~~	~~NA[6]~~	-
~~Ag 110m~~	-	~~2.50E+02~~	-	-	-	~~2.77E-03~~	~~2.67E+00~~	~~7.22E-05~~	~~4.4E-07~~	~~6.00E-06~~	~~7.36E-02~~
-	~~Ag 110~~	~~2.85E-04~~	~~0.0133~~	-	-	~~2.43E+03~~	-	-	~~5.9E-09~~	~~NA[6]~~	-
~~Te 129m~~	-	~~3.36E+01~~	-	-	-	~~2.06E-02~~	~~4.29E+01~~	~~1.16E-03~~	~~3.9E-20~~	~~7.00E-06~~	~~5.62E-15~~
-	~~Te 129~~	~~4.83E-02~~	~~0.6500~~	-	-	~~1.44E+01~~	-		~~2.6E-20~~	~~4.00E-04~~	~~6.41E-17~~
~~Te 131m~~	-	~~1.25E+00~~	-	-	-	~~5.55E-01~~	~~4.85E+00~~	~~1.31E-04~~	~~0.0E+00~~	~~8.00E-06~~	~~0.00E+00~~
-	~~Te 131~~	~~1.74E-02~~	~~0.2220~~	-	-	~~3.98E+01~~	-	-	~~0.0E+00~~	~~8.00E-05~~	~~0.00E+00~~

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Table 2.4-206 ~~Results of Groundwater Transport Analysis Considering Radioactive Decay Only~~ Groundwater Concentrations at Point of Discharge to Lake Anna

~~Parent Radionuclide~~	~~Progeny in Chain~~	~~Half-life[4] (days)~~	~~Branching Fraction[4]~~ d_{12}	d_{13}	d_{23}	~~Decay Rate[2] ($days^{-1}$)~~	~~Collection Tank Conc[3] (MBq/m^3)~~	~~Collection Tank Conc ($\mu Ci/cm^3$)~~	~~Ground Water Conc[4] ($\mu Ci/cm^3$)~~	~~ECL[5] ($\mu Ci/cm^3$)~~	~~Ground Water Conc / ECL~~
-	~~I-131~~	~~8.04E+00~~	-	~~0.7780~~	~~1.0000~~	~~8.62E-02~~	~~6.89E+02~~	~~1.86E-02~~	~~2.8E-71~~	~~1.00E-06~~	~~2.78E-65~~
~~Te-132~~	-	~~3.26E+00~~	-	-	-	~~2.13E-01~~	~~1.21E+00~~	~~3.27E-05~~	~~5.9E-175~~	~~9.00E-06~~	~~6.56E-170~~
-	~~I-132~~	~~9.58E-02~~	~~1.0000~~	-	-	~~7.24E+00~~	~~6.58E+01~~	~~1.78E-03~~	~~6.1E-175~~	~~1.00E-04~~	~~6.08E-171~~
~~I-133~~	-	~~8.67E-01~~	-	-	-	~~7.99E-01~~	~~5.51E+02~~	~~1.49E-02~~	~~0.0E+00~~	~~7.00E-06~~	~~0.00E+00~~
-	~~Xe-133m~~	~~2.19E+00~~	~~0.0290~~	-	-	~~3.17E-01~~	-	-	~~3.5E-257~~	~~NA[6]~~	-
-	~~Xe-133~~	~~5.25E+00~~	-	~~0.9710~~	~~1.0000~~	~~1.32E-01~~	-	-	~~9.5E-109~~	~~NA[6]~~	-
~~I-134~~	-	~~3.65E-02~~	-	-	-	~~1.90E+01~~	~~4.38E+01~~	~~1.18E-03~~	~~0.0E+00~~	~~4.00E-04~~	~~0.00E+00~~
~~I-135~~	-	~~2.75E-01~~	-	-	-	~~2.52E+00~~	~~2.19E+02~~	~~5.92E-03~~	~~0.0E+00~~	~~3.00E-05~~	~~0.00E+00~~
-	~~Xe-135m~~	~~1.06E-02~~	~~0.1540~~	-	-	~~6.53E+01~~	-	-	~~0.0E+00~~	~~NA[6]~~	-
-	~~Xe-135~~	~~3.79E-01~~	-	~~0.8460~~	~~1.0000~~	~~1.83E+00~~	-	-	~~0.0E+00~~	~~NA[6]~~	-
~~Cs-134~~	-	~~7.53E+02~~	-	-	-	~~9.21E-04~~	~~7.36E+01~~	~~1.99E-03~~	~~3.7E-04~~	~~9.00E-07~~	~~4.07E+02~~
~~Cs-136~~	-	~~1.31E+01~~	-	-	-	~~5.29E-02~~	~~7.25E+00~~	~~1.96E-04~~	~~1.1E-46~~	~~6.00E-06~~	~~1.87E-41~~
~~Cs-137~~	-	~~1.10E+04~~	-	-	-	~~6.30E-05~~	~~2.09E+02~~	~~5.65E-03~~	~~5.0E-03~~	~~1.00E-06~~	~~5.03E+03~~
-	~~Ba-137m~~	~~1.77E-03~~	~~0.9460~~	-	-	~~3.91E+02~~	~~3.71E-03~~	~~1.00E-07~~	~~4.8E-03~~	~~NA[6]~~	-
~~Cs-138~~	-	~~2.24E-02~~	-	-	-	~~3.09E+01~~	~~5.62E+00~~	~~1.52E-04~~	~~0.0E+00~~	~~4.00E-04~~	~~0.00E+00~~
~~Ba-140~~	-	~~1.27E+01~~	-	-	-	~~5.46E-02~~	~~1.75E+02~~	~~4.73E-03~~	~~1.3E-46~~	~~8.00E-06~~	~~1.58E-41~~
-	~~La-140~~	~~1.68E+00~~	~~1.0000~~	-	-	~~4.13E-01~~	~~2.62E+01~~	~~7.08E-04~~	~~1.5E-46~~	~~9.00E-06~~	~~1.62E-41~~
~~Ce-141~~	-	~~3.25E+01~~	-	-	-	~~2.13E-02~~	~~2.97E+01~~	~~8.03E-04~~	~~7.6E-21~~	~~3.00E-05~~	~~2.52E-16~~
~~Ce-144~~	-	~~2.84E+02~~	-	-	-	~~2.44E-03~~	~~7.86E+00~~	~~2.12E-04~~	~~2.4E-06~~	~~3.00E-06~~	~~7.97E-01~~

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Table 2.4-206 ~~Results of Groundwater Transport Analysis Considering Radioactive Decay Only~~ Groundwater Concentrations at Point of Discharge to Lake Anna

~~Parent Radionuclide~~	~~Progeny in Chain~~	~~Half-life[1] (days)~~	~~Branching Fraction[1]~~ d_{42}	d_{43}	d_{23}	~~Decay Rate[2] ($days^{-1}$)~~	~~Collection Tank Conc[3] (MBq/m^3)~~	~~Collection Tank Conc ($\mu Ci/cm^3$)~~	~~Ground Water Conc[4] ($\mu Ci/cm^3$)~~	~~ECL[5] ($\mu Ci/cm^3$)~~	~~Ground Water Conc / ECL~~
-	~~Pr-144m~~	~~5.07E-03~~	~~0.0178~~	-	-	~~1.37E+02~~	-	-	~~4.3E-08~~	~~NA[6]~~	-
-	~~Pr-144~~	~~1.20E-02~~	-	~~0.9822~~	~~0.9990~~	~~5.78E+01~~	~~1.03E-03~~	~~2.78E-08~~	~~2.4E-06~~	~~6.00E-04~~	~~3.99E-03~~
~~W-187~~	-	~~9.96E-01~~	-	-	-	~~6.96E-01~~	~~1.15E+01~~	~~3.11E-04~~	~~0.0E+00~~	~~3.00E-05~~	~~0.00E+00~~
~~Np-239~~	-	~~2.36E+00~~	-	-	-	~~2.94E-01~~	~~7.17E+02~~	~~1.94E-02~~	~~6.5E-237~~	~~2.00E-05~~	~~3.24E-232~~
-	~~Pu-239~~	~~8.79E+06~~	~~1.0000~~	-	-	~~7.89E-08~~	-	-	~~5.2E-09~~	~~2.00E-08~~	~~2.60E-01~~

~~1. Values from Table E.1, NUREG/CR-5512 (Reference 2.4-214) and ICRP Publication 38 (Reference 2.4-211) for Sr-92, Rh-106, Ag-110, Ba-137m, Xe-133m, Xe-133, Xe-135m, Xe-135, and Pr-144m.~~

~~2. Values calculated from Equation 2.4.13-4.~~

~~3. Values from DCD Table 12.2-13a.~~

~~4. Values calculated from Equation 2.4.13-8, Equation 2.4.13-13, or Equation 2.4.13-18 depending on position in decay chain for a travel time of 5.03 years.~~

~~5. Values from 10 CFR 20, Appendix B, Table 2, Column 2.~~

~~6. ECL is not available.~~

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Table 2.4-206 ~~Results of Groundwater Transport Analysis Considering Radioactive Decay Only~~ Groundwater Concentrations at Point of Discharge to Lake Anna

Source Term Characteristics										Advection and Decay					Advection, Decay, and Adsorption			
Parent Radio-nuclide	Progeny in Chain	Half-life[a] (days)	Branching Fraction[a] d_{12}	d_{13}	d_{23}	Decay Rate[b] ($days^{-1}$)	ECL[c] ($\mu Ci/cm^3$)	Collection Tank Conc[d] (MBq/m^3)	Collection Tank Conc ($\mu Ci/cm^3$)	K1	K2	K3	Ground Water Conc[e] ($\mu Ci/cm^3$)	Ground Water Conc/ ECL	Distribution Coefficient (cm^3/g)	Retardation Factor[f]	Ground Water Conc[g] ($\mu Ci/cm^3$)	Ground Water Conc/ ECL
H-3		4.51E+03				1.54E-04	1.00E-03	9.73E+01	2.63E-03	2.63E-03			2.39E-03	2.39E+00	0	1.0	2.39E-03	2.39E+00
Na-24		6.25E-01				1.11E+00	5.00E-05	4.74E+01	1.28E-03	1.28E-03			1.09E-307	0.00E+00				
P-32		1.43E+01				4.85E-02	9.00E-06	1.98E+01	5.35E-04	5.35E-04			2.75E-17	0.00E+00				
Cr-51		2.77E+01				2.50E-02	5.00E-04	2.61E+03	7.05E-02	7.05E-02			9.72E-09	1.94E-05				
Mn-54		3.13E+02				2.21E-03	3.00E-05	9.83E+01	2.66E-03	2.66E-03			6.56E-04	2.19E+01	4.5	33.9	6.81E-24	0.00E+00
Mn-56		1.07E-01				6.48E+00	7.00E-05	7.59E+01	2.05E-03	2.05E-03			0.00E+00	0.00E+00				
Fe-55		9.86E+02				7.03E-04	1.00E-04	3.08E+03	8.32E-02	8.32E-02			5.34E-02	5.34E+02	4504	32943.3	0.00E+00	0.00E+00
Fe-59		4.45E+01				1.56E-02	1.00E-05	3.82E+01	1.03E-03	1.03E-03			5.54E-08	5.54E-03				
Co-58		7.08E+01				9.79E-03	2.00E-05	1.76E+02	4.76E-03	4.76E-03			9.84E-06	4.92E-01	6.5	48.5	2.41E-133	0.00E+00
Co-60		1.93E+03				3.59E-04	3.00E-06	6.25E+02	1.69E-02	1.69E-02			1.35E-02	4.49E+03	6.5	48.5	2.80E-07	9.35E-02
Ni-63		3.51E+04				1.97E-05	1.00E-04	3.24E+00	8.76E-05	8.76E-05			8.65E-05	8.65E-01	12.7	93.9	2.72E-05	2.72E-01
Cu-64		5.29E-01				1.31E+00	2.00E-04	5.92E+01	1.60E-03	1.60E-03			0.00E+00	0.00E+00				
Zn-65		2.44E+02				2.84E-03	5.00E-06	2.65E+03	7.16E-02	7.16E-02			1.19E-02	2.38E+03	11.8	87.3	7.17E-70	0.00E+00
Rb-89		1.06E-02				6.54E+01	9.00E-04	1.25E+00	3.38E-05	3.38E-05			0.00E+00	0.00E+00	3.6	27.3		
	Sr-89	5.05E+01	1.0000			1.37E-02	8.00E-06	1.43E+02	3.86E-03	-7.09E-09	3.86E-03		6.67E-07	8.33E-02	3.6	27.3	5.44E-106	0.00E+00
Sr-90		1.06E+04				6.54E-05	5.00E-07	2.23E+01	6.03E-04	6.03E-04			5.78E-04	1.16E+03	3.6	27.3	1.95E-04	3.90E+02
	Y-90	2.67E+00	1.0000			2.60E-01	7.00E-06	6.95E-01	1.88E-05	6.03E-04	-5.84E-04		5.78E-04	8.26E+01	3.6	27.3	1.95E-04	2.79E+01
Sr-91		3.96E-01				1.75E+00	2.00E-05	5.68E+01	1.54E-03	1.54E-03			0.00E+00	0.00E+00	3.6	27.3		
	Y-91m	3.45E-02	0.5780			2.01E+01	2.00E-03			9.72E-04	-9.72E-04		0.00E+00	0.00E+00	3.6	27.3		
	Y-91	5.85E+01		0.4220	1.0000	1.18E-02	8.00E-06	6.28E+01	1.70E-03	-1.10E-05	5.74E-07	1.71E-03	9.63E-07	1.20E-01	3.6	27.3	2.79E-92	0.00E+00
Sr-92		1.13E-01				6.14E+00	4.00E-05	3.25E+01	8.78E-04	8.78E-04			0.00E+00	0.00E+00				
	Y-92	1.48E-01	1.0000			4.68E+00	4.00E-05	2.67E+01	7.22E-04	-2.83E-03	3.55E-03		0.00E+00	0.00E+00				
Y-93		4.21E-01				1.65E+00	2.00E-05	5.98E+01	1.62E-03	1.62E-03			0.00E+00	0.00E+00				
Zr-95		6.40E+01				1.08E-02	2.00E-05	1.34E+01	3.62E-04	3.62E-04			3.89E-07	1.94E-02	6.13	45.8	2.67E-140	0.00E+00
	Nb-95m	3.61E+00	0.0070			1.92E-01	3.00E-05			2.69E-06	-2.69E-06		2.88E-09	9.61E-05	6.13	45.8		
	Nb-95	3.52E+01		0.9930	1.0000	1.97E-02	3.00E-05	8.76E+00	2.37E-04	8.05E-04	3.07E-07	-5.69E-04	8.62E-07	2.87E-02	6.13	45.8	5.95E-140	0.00E+00
Mo-99		2.75E+00				2.52E-01	2.00E-05	2.07E+02	5.59E-03	5.59E-03			4.37E-72	0.00E+00				

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Table 2.4-206 ~~Results of Groundwater Transport Analysis Considering Radioactive Decay Only~~ Groundwater Concentrations at Point of Discharge to Lake Anna

Source Term Characteristics										Advection and Decay					Advection, Decay, and Adsorption			
Parent Radio-nuclide	Progeny in Chain	Half-life[a] (days)	Branching Fraction[a] d_{12}	d_{13}	d_{23}	Decay Rate[b] ($days^{-1}$)	ECL[c] ($\mu Ci/cm^3$)	Collection Tank Conc[d] (MBq/m^3)	Collection Tank Conc ($\mu Ci/cm^3$)	K1	K2	K3	Ground Water Conc[e] ($\mu Ci/cm^3$)	Ground Water Conc/ ECL	Distribution Coefficient (cm^3/g)	Retardation Factor[f]	Ground Water Conc[g] ($\mu Ci/cm^3$)	Ground Water Conc/ ECL
	Tc-99m	2.51E-01	0.8760			2.76E+00	1.00E-03	1.72E+01	4.65E-04	5.39E-03	-4.93E-03		4.22E-72	0.00E+00				
Ru-103		3.93E+01				1.76E-02	3.00E-05	2.39E+01	6.46E-04	6.46E-04			9.43E-09	3.14E-04				
	Rh-103m	3.90E-02	0.9970			1.78E+01	6.00E-03	2.33E-02	6.30E-07	6.45E-04	-6.44E-04		9.41E-09	1.57E-06				
Ru-106		3.68E+02				1.88E-03	3.00E-06	8.17E+00	2.21E-04	2.21E-04			6.72E-05	2.24E+01	272	1990.4	0.00E+00	0.00E+00
	Rh-106	3.45E-04	1.0000			2.01E+03	NA[h]	2.95E-05	7.97E-10	2.21E-04	-2.21E-04		6.72E-05					
Ag-110m		2.50E+02				2.77E-03	6.00E-06	2.67E+00	7.22E-05	7.22E-05			1.25E-05	2.09E+00	2.5	19.3	1.58E-19	0.00E+00
	Ag-110	2.85E-04	0.0133			2.43E+03	NA[h]			9.60E-07	-9.60E-07		1.67E-07					
Te-129m		3.36E+01				2.06E-02	7.00E-06	4.29E+01	1.16E-03	1.16E-03			2.56E-09	3.66E-04				
	Te-129	4.83E-02	0.6500			1.44E+01	4.00E-04		0.00E+00	7.55E-04	-7.55E-04		1.67E-09	4.17E-06				
Te-131m		1.25E+00				5.55E-01	8.00E-06	4.85E+00	1.31E-04	1.31E-04			1.21E-156	0.00E+00				
	Te-131	1.74E-02	0.2220			3.98E+01	8.00E-05			2.95E-05	-2.95E-05		2.72E-157	0.00E+00				
	I-131	8.04E+00		0.7780	1.0000	8.62E-02	1.00E-06	6.89E+02	1.86E-02	-2.42E-05	6.40E-08	1.86E-02	4.30E-26	0.00E+00				
Te-132		3.26E+00				2.13E-01	9.00E-06	1.21E+00	3.27E-05	3.27E-05			1.66E-63	0.00E+00				
	I-132	9.58E-02	1.0000			7.24E+00	1.00E-04	6.58E+01	1.78E-03	3.37E-05	1.74E-03		1.71E-63	0.00E+00				
I-133		8.67E-01				7.99E-01	7.00E-06	5.51E+02	1.49E-02	1.49E-02			9.45E-222	0.00E+00				
	Xe-133m	2.19E+00	0.0290			3.17E-01	NA			-2.83E-04	2.83E-04		3.94E-91					
	Xe-133	5.25E+00		0.9710	1.0000	1.32E-01	NA			-2.81E-03	-2.03E-04	3.01E-03	1.76E-39					
I-134		3.65E-02				1.90E+01	4.00E-04	4.38E+01	1.18E-03	1.18E-03			0.00E+00	0.00E+00				
I-135		2.75E-01				2.52E+00	3.00E-05	2.19E+02	5.92E-03	5.92E-03			0.00E+00	0.00E+00				
	Xe-135m	1.06E-02	0.1540			6.53E+01	NA			9.48E-04	-9.48E-04		0.00E+00					
	Xe-135	3.79E-01		0.8460	1.0000	1.83E+00	NA			-1.57E-02	2.73E-05	1.57E-02	0.00E+00					
Cs-134		7.53E+02				9.21E-04	9.00E-07	7.36E+01	1.99E-03	1.99E-03			1.11E-03	1.24E+03	64.9	475.7	1.76E-123	0.00E+00
Cs-136		1.31E+01				5.29E-02	6.00E-06	7.25E+00	1.96E-04	1.96E-04			6.09E-19	0.00E+00				
Cs-137		1.10E+04				6.30E-05	1.00E-06	2.09E+02	5.65E-03	5.65E-03			5.43E-03	5.43E+03	64.9	475.7	3.42E-11	3.42E-05
	Ba-137m	1.77E-03	0.9460			3.91E+02	NA	3.71E-03	1.00E-07	5.34E-03	-5.34E-03		5.14E-03					
Cs-138		2.24E-02				3.09E+01	4.00E-04	5.62E+00	1.52E-04	1.52E-04			0.00E+00	0.00E+00				
Ba-140		1.27E+01				5.46E-02	8.00E-06	1.75E+02	4.73E-03	4.73E-03			5.14E-18	0.00E+00				

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Table 2.4-206 ~~Results of Groundwater Transport Analysis Considering Radioactive Decay Only~~ Groundwater Concentrations at Point of Discharge to Lake Anna

Source Term Characteristics										Advection and Decay					Advection, Decay, and Adsorption			
Parent Radio-nuclide	Progeny in Chain	Half-life[a] (days)	Branching Fraction[a] d_{12}	d_{13}	d_{23}	Decay Rate[b] ($days^{-1}$)	ECL[c] ($\mu Ci/cm^3$)	Collection Tank Conc[d] (MBq/m^3)	Collection Tank Conc ($\mu Ci/cm^3$)	K1	K2	K3	Ground Water Conc[e] ($\mu Ci/cm^3$)	Ground Water Conc/ ECL	Distribution Coefficient (cm^3/g)	Retardation Factor[f]	Ground Water Conc[g] ($\mu Ci/cm^3$)	Ground Water Conc/ ECL
	La-140	1.68E+00	1.0000			4.13E-01	9.00E-06	2.62E+01	7.08E-04	5.45E-03	-4.74E-03		5.92E-18	0.00E+00				
Ce-141		3.25E+01				2.13E-02	3.00E-05	2.97E+01	8.03E-04	8.03E-04			1.14E-09	3.80E-05				
Ce-144		2.84E+02				2.44E-03	3.00E-06	7.86E+00	2.12E-04	2.12E-04			4.55E-05	1.52E+01	329.1	2408.0	0.00E+00	0.00E+00
	Pr-144m	5.07E-03	0.0178			1.37E+02	NA			3.78E-06	-3.78E-06		8.10E-07					
	Pr-144	1.20E-02		0.9822	0.9990	5.78E+01	6.00E-04	1.03E-03	2.78E-08	2.12E-04	2.76E-06	-2.15E-04	4.55E-05	7.58E-02	329.1	2408.0	0.00E+00	0.00E+00
W-187		9.96E-01				6.96E-01	3.00E-05	1.15E+01	3.11E-04	3.11E-04			4.84E-195	0.00E+00				
Np-239		2.36E+00				2.94E-01	2.00E-05	7.17E+02	1.94E-02	1.94E-02			5.76E-83	0.00E+00	5.3	39.8		
	Pu-239	8.79E+06	1.0000			7.89E-08	2.00E-08			-5.20E-09	5.20E-09		5.20E-09	2.60E-01	5.3	39.8	5.19E-09	2.60E-01

a. Obtained from ICRP Publication 38 (Reference 2.4-211).
b. Calculated using Equation 2.4.13-4.
c. Obtained from 10 CFR 20, Appendix B, Table 2, Column 2.
d. Obtained from DCD Table 12.2-13a.
e. Calculated using Equations 2.4.13-8, 2.4.13-13, or 2.4.13-18 depending on position in decay chain and assuming no retardation.
f. Calculated using Equation 2.4.13-2.
g. Calculated using Equations 2.4.13-8, 2.4.13-13, or 2.4.13-18 depending on position in decay chain.
h. ECL is not available.

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Table 2.4-207 ~~Comparison of~~ Site-Specific K_d Values ~~Against NUREG/CR-6697 Derived Values~~

	K_d (cm^3/g)										
Sample	**Mn**	**Fe**	**Co**	**Ni**	**Zn**	**Sr**	**Ru**	**Ag**	**Cs**	**Ce**	**Pu**
B-949/R3	>8,145	>45,497	>15,765	>1,616	>5,110	68.5	>1,148	>31,091	>19,504	>10,422	8,680
B-951/R5	>12,196	>20,291	>18,778	>892	>4,217	60.2	>1,200	>12,729	6,863	>10,232	443
B-901/R20	>7,858	>5,146	2,364	>615	>2,411	14.8	>632	>12,792	387	>6,753	295
B-901/R22	5,499	>14,207	5,459	>811	>4,147	33	>988	>9,903	574	>7,073	351
B-901/S5	4.5	>13,456	6.5	40.6	11.8	3.9	>272	28.6	68	329.1	5.3
B-901/S8	>6,525	>5,646	>9,423	12.7	>7,190	166.4	>1,448	28.6	181	>9,572	34.3
B-904/S10	36.9	>12,489	58.3	342	136	3.6	>328	73.2	241	4,175	96.5
B-913/S9	12,492	>14,397	13,082	129	>5,901	14.5	>1,429	43.4	796	>10,149	177
B-913/S10	7,903	>6,505	5,711	162	>6,702	8.4	>1,080	6	141	>9,182	735
B-917/S12	8,046	>30,209	5,747	643	>5,511	7.6	>1,171	25.7	154	>8,831	305
B-917/S14	>10,470	>16,121	6,559	17.7	>4,563	6.6	>936	32.6	118.9	>6,893	209
B-917/S15	4,692	>4,504	3,991	53.3	>2,764	3.8	>524	16.6	64.9	>5,419	192
B-919/S8	>4,121	>40,524	3,840	387	>3,426	14.8	>1,007	232	378	>7,750	896
B-920/S11	>15,785	>19,392	8,768	>623	>7,905	25.5	>1,593	>482	379	>12,056	311
B-928/S7	3,801	>6,104	3,244	>424	>8,103	7.6	>1,212	>304	104	>11,468	528
B-929/S12	3,453	>19,967	5,331	45	>6,270	7.1	>1,264	2.5	104.9	>8,887	536
B-931/S11	3,988	>28,132	5,151	>369	>6,070	4.7	>1,149	44.4	67.5	>10,519	333
B-932/S6	9,013	>16,288	6,739	766	>5,684	11.2	>1,367	>12,665	159	10,449	2,488
B-951/S7	>21,374	>25,330	>20,653	>806	>6,991	26.8	>1,665	>12,716	3,406	>12,914	3,874
B-951/S9	6,143	>24,220	8,818	>658	>6,162	12.7	>1,472	>8,190	336	>13,194	3,603

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Table 2.4-207 ~~Comparison of~~ Site-Specific K_d Values ~~Against NUREG/CR-6697 Derived Values~~

	K_d (cm^3/g)										
Sample	**Mn**	**Fe**	**Co**	**Ni**	**Zn**	**Sr**	**Ru**	**Ag**	**Cs**	**Ce**	**Pu**
Min =	4.5	4504	6.5	12.7	11.8	3.6	272	2.5	64.9	329.1	5.3
10% =	3111.4	5596.0	2133.4	38.3	2183.5	3.9	504.4	15.5	68.0	5294.6	90.3
25% =	4087.8	10993.0	3953.3	110.1	3966.8	7.0	975.0	28.6	115.4	7028.0	204.8
50% =	7191.5	16204.5	5729.0	405.5	5597.5	12.0	1160.0	152.6	211.0	9377.0	342.0
Max =	21374	45497	20653	1616	8103	166.4	1665	31091	19504	13194	8680
Mean =	7577.3	18421.3	7474.4	470.6	4963.7	25.1	1094.3	5070.3	1701.4	8813.4	1204.6
~~NUREG K_d =~~	~~8.37~~	~~6.81~~	~~9.19~~	~~65.3~~	~~3.63~~	~~2.08~~	~~28.75~~	~~14.71~~	~~22.51~~	~~138.99~~	~~84.59~~
~~Percentile[a] =~~	~~0.60%~~	~~< Min~~	~~0.20%~~	~~21.80%~~	~~< Min~~	~~< Min~~	~~< Min~~	~~9.50%~~	~~< Min~~	~~< Min~~	~~9.50%~~

~~a. Rank of NUREG K_d value as a percentage of the site-specific K_d data.~~

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Table 2.4-208 ~~Results of Groundwater Transport Analysis Considering Radioactive Decay and Adsorption~~ [Deleted]

~~Parent Radionuclide~~	~~Progeny in Chain~~	~~Decay Rate[1] (days^{-1})~~	~~Branching Fraction[2]~~	~~Initial Conc (μCi/cm^3)~~	~~Literature Kd[3]~~ ~~m~~	~~s~~	~~10% Kd (cm^3/g)~~	~~Retard Factor[4]~~	~~Ground Water Conc[5] (μCi/cm^3)~~	~~ECL[6] (μCi/cm^3)~~	~~Ground Water Conc / ECL~~
~~H-3~~	-	~~1.54E-04~~	-	~~2.63E-03~~	-	-	-	~~1.00~~	~~1.98E-03~~	~~1.00E-03~~	~~1.98E+00~~
~~Mn-54~~	-	~~2.21E-03~~	-	~~2.66E-03~~	~~5.06~~	~~2.29~~	~~8.37~~	~~62.25~~	~~2.30E-113~~	~~3.00E-05~~	~~7.68E-109~~
~~Fe-55~~	-	~~7.03E-04~~	-	~~8.32E-02~~	~~5.34~~	~~2.67~~	~~6.81~~	~~50.80~~	~~2.57E-30~~	~~1.00E-04~~	~~2.57E-26~~
~~Co-60~~	-	~~3.59E-04~~	-	~~1.69E-02~~	~~5.46~~	~~2.53~~	~~9.19~~	~~68.19~~	~~4.76E-22~~	~~3.00E-06~~	~~1.59E-16~~
~~Ni-63~~	-	~~1.97E-05~~	-	~~8.76E-05~~	~~6.05~~	~~1.46~~	~~65.30~~	~~478.58~~	~~2.50E-12~~	~~1.00E-04~~	~~2.50E-08~~
~~Zn-65~~	-	~~2.84E-03~~	-	~~7.16E-02~~	~~6.98~~	~~4.44~~	~~3.63~~	~~27.57~~	~~2.16E-64~~	~~5.00E-06~~	~~4.32E-59~~
~~Sr-90~~	-	~~6.54E-05~~	-	~~6.03E-04~~	~~3.45~~	~~2.12~~	~~2.08~~	~~16.22~~	~~8.57E-05~~	~~5.00E-07~~	~~1.71E+02~~
-	~~Y-90~~	~~2.60E-01~~	~~1.0000~~	~~1.88E-05~~	~~6.84~~	~~3.22~~	~~15.08~~	~~111.30~~	~~8.57E-05~~	~~7.00E-06~~	~~1.22E+01~~
~~Ru-106~~	-	~~1.88E-03~~	-	~~2.21E-04~~	~~7.37~~	~~3.13~~	~~28.75~~	~~211.30~~	~~0.00E+00~~	~~3.00E-06~~	~~0.00E+00~~
~~Ag-110m~~	-	~~2.77E-03~~	-	~~7.22E-05~~	~~5.38~~	~~2.10~~	~~14.71~~	~~108.61~~	~~2.82E-245~~	~~6.00E-06~~	~~4.70E-240~~
~~Cs-134~~	-	~~9.21E-04~~	-	~~1.99E-03~~	~~6.10~~	~~2.33~~	~~22.51~~	~~165.64~~	~~3.73E-125~~	~~9.00E-07~~	~~4.14E-119~~
~~Cs-137~~	-	~~6.30E-05~~	-	~~5.65E-03~~	~~6.10~~	~~2.33~~	~~22.51~~	~~165.64~~	~~2.63E-11~~	~~1.00E-06~~	~~2.63E-05~~
~~Ce-144~~	-	~~2.44E-03~~	-	~~2.12E-04~~	~~7.60~~	~~2.08~~	~~138.99~~	~~1017.54~~	~~0.00E+00~~	~~3.00E-06~~	~~0.00E+00~~
~~Np-239~~	-	~~2.94E-01~~	-	~~1.94E-02~~	~~2.84~~	~~2.25~~	~~0.96~~	~~8.00~~	~~0.00E+00~~	~~2.00E-05~~	~~0.00E+00~~
-	~~Pu-239~~	~~7.89E-08~~	~~1.0000~~	~~0.00E+00~~	~~6.86~~	~~1.89~~	~~84.59~~	~~619.72~~	~~3.68E-07~~	~~2.00E-08~~	~~1.84E+01~~

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Table 2.4-208 ~~Results of Groundwater Transport Analysis Considering Radioactive Decay and Adsorption~~ [Deleted]

~~Parent Radionuclide~~	~~Progeny in Chain~~	~~Decay Rate[1] (days^{-1})~~	~~Branching Fraction[2]~~	~~Initial Conc (μCi/cm^3)~~	~~Literature Kd[3]~~ ~~m~~	~~s~~	~~10% Kd (cm^3/g)~~	~~Retard Factor[4]~~	~~Ground Water Conc[5] (μCi/cm^3)~~	~~ECL[6] (μCi/cm^3)~~	~~Ground Water Conc / ECL~~

~~1. Values calculated from Equation 2.4.13-4.~~
~~2. Values from Table E.1, NUREG/CR-5512 (Reference 2.4-214).~~
~~3. Mean and standard deviation from NUREG/CR-6697, Attachment C, Table 3.9-1 (Reference 2.4-215); Sc values used as surrogates for Y.~~
~~4. Values calculated from Equation 2.4.13-2.~~
~~5. Values calculated from Equation 2.4.13-8 for parent and Equation 2.4.13-13 for progeny.~~
~~6. Values from 10 CFR 20, Appendix B, Table 2, Column 2.~~

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Table 2.4-209 ~~Results of Groundwater Transport Analysis Considering Radioactive Decay, Adsorption, and Dilution~~ [Deleted]

~~Radionuclide~~	~~Groundwater Concentration[4] (μCi/cm^3)~~	~~Surface Water Concentration[2] (μCi/cm^3)~~	~~ECL[3]~~	~~Surface Water Concentration / ECL~~
~~H-3~~	~~1.98E-03~~	~~5.08E-07~~	~~1.00E-03~~	~~5.08E-04~~
~~Sr-90~~	~~8.57E-05~~	~~2.20E-08~~	~~5.00E-07~~	~~4.40E-02~~
~~Y-90~~	~~8.57E-05~~	~~2.20E-08~~	~~7.00E-06~~	~~3.14E-03~~
~~Pu-239~~	~~3.68E-07~~	~~9.45E-11~~	~~2.00E-08~~	~~4.72E-03~~

~~1. Values from Table 2.4-208.~~

~~2. Surface water concentration = groundwater concentration * dilution factor of 2.56×10^{-4}.~~

~~3. Values from 10 CFR 20, Appendix B, Table 2, Column 2.~~

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Table 2.4-210 ~~Compliance with 10 CFR Part 20 for an Accidental Release of Radioactive Liquid Effluent in Groundwater~~ [Deleted]

		~~Concentration/ECL~~			
~~Parent Radionuclide~~	~~Progeny in Chain~~	~~Decay[1]~~	~~Decay and Adsorption[2]~~	~~Decay, Adsorption, and Dilution[3]~~	~~Minimum~~
~~H-3~~	-	~~1.98E+00~~	~~1.98E+00~~	~~5.08E-04~~	~~5.08E-04~~
~~Na-24~~	-	~~0.00E+00~~	-	-	~~0.00E+00~~
~~P-32~~	-	~~1.20E-37~~	-	-	~~1.20E-37~~
~~Cr-51~~	-	~~1.49E-18~~	-	-	~~1.49E-18~~
~~Mn-54~~	-	~~1.51E+00~~	~~7.68E-109~~	-	~~7.68E-109~~
~~Mn-56~~	-	~~0.00E+00~~	-	-	~~0.00E+00~~
~~Fe-55~~	-	~~2.29E+02~~	~~2.57E-26~~	-	~~2.57E-26~~
~~Fe-59~~	-	~~3.79E-11~~	-	-	~~3.79E-11~~
~~Co-58~~	-	~~3.63E-06~~	-	-	~~3.63E-06~~
~~Co-60~~	-	~~2.91E+03~~	~~1.59E-16~~	-	~~1.59E-16~~
~~Ni-63~~	-	~~8.44E-01~~	~~2.50E-08~~	-	~~2.50E-08~~
~~Cu-64~~	-	~~0.00E+00~~	-	-	~~0.00E+00~~
~~Zn-65~~	-	~~7.73E+01~~	~~4.32E-59~~	-	~~4.32E-59~~
~~Rb-89~~	-	~~0.00E+00~~	-	-	~~0.00E+00~~
-	~~Sr-89~~	~~5.33E-09~~	-	-	~~5.33E-09~~
~~Sr-90~~	-	~~1.07E+03~~	~~1.71E+02~~	~~4.40E-02~~	~~4.40E-02~~
-	~~Y-90~~	~~7.64E+01~~	~~1.22E+01~~	~~3.14E-03~~	~~3.14E-03~~
~~Sr-91~~	-	~~0.00E+00~~	-	-	~~0.00E+00~~
-	~~Y-91m~~	~~0.00E+00~~	-	-	~~0.00E+00~~
-	~~Y-91~~	~~7.42E-08~~	-	-	~~7.42E-08~~
~~Sr-92~~	-	~~0.00E+00~~	-	-	~~0.00E+00~~
~~Y-92~~	-	~~0.00E+00~~	-	-	~~0.00E+00~~
~~Y-93~~	-	~~0.00E+00~~	-	-	~~0.00E+00~~
~~Zr-95~~	-	~~4.09E-08~~	-	-	~~4.09E-08~~
-	~~Nb-95m~~	~~2.02E-10~~	-	-	~~2.02E-10~~
-	~~Nb-95~~	~~6.06E-08~~	-	-	~~6.06E-08~~

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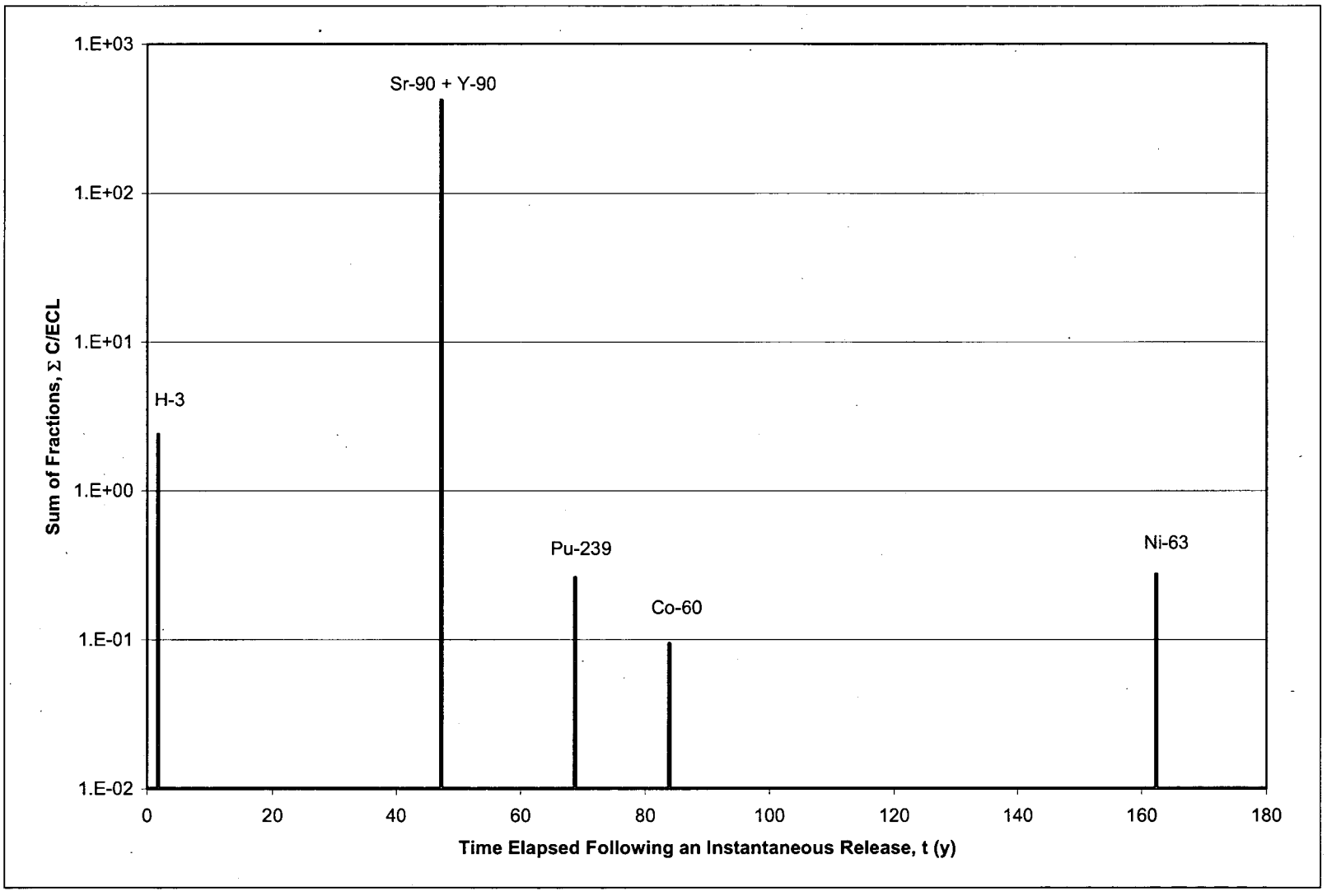
Table 2.4-210 ~~**Compliance with 10 CFR Part 20 for an Accidental Release of Radioactive Liquid Effluent in Groundwater**~~ **[Deleted]**

		~~Concentration/ECL~~			
~~Parent Radionuclide~~	~~Progeny in Chain~~	~~Decay[1]~~	~~Decay and Adsorption[2]~~	~~Decay, Adsorption, and Dilution[3]~~	~~Minimum~~
~~Mo-99~~	-	~~1.67E-199~~	-	-	~~1.67E-199~~
-	~~Tc-99m~~	~~3.23E-201~~	-	-	~~3.23E-201~~
~~Ru-103~~	-	~~1.79E-13~~	-	-	~~1.79E-13~~
-	~~Rh-103m~~	~~8.93E-16~~	-	-	~~8.93E-16~~
~~Ru-106~~	-	~~2.31E+00~~	~~0.00E+00~~	-	~~0.00E+00~~
-	~~Rh-106~~	~~0.00E+00~~	-	-	~~0.00E+00~~
~~Ag-110m~~	-	~~7.36E-02~~	~~4.70E-240~~	-	~~4.70E-240~~
-	~~Ag-110~~	~~0.00E+00~~	-	-	~~0.00E+00~~
~~Te-129m~~	-	~~5.62E-15~~	-	-	~~5.62E-15~~
-	~~Te-129~~	~~6.41E-17~~	-	-	~~6.41E-17~~
~~Te-131m~~	-	~~0.00E+00~~	-	-	~~0.00E+00~~
-	~~Te-131~~	~~0.00E+00~~	-	-	~~0.00E+00~~
-	~~I-131~~	~~2.78E-65~~	-	-	~~2.78E-65~~
~~Te-132~~	-	~~6.56E-170~~	-	-	~~6.56E-170~~
-	~~I-132~~	~~6.08E-171~~	-	-	~~6.08E-171~~
~~I-133~~	-	~~0.00E+00~~	-	-	~~0.00E+00~~
-	~~Xe-133m~~	~~0.00E+00~~	-	-	~~0.00E+00~~
-	~~Xe-133~~	~~0.00E+00~~	-	-	~~0.00E+00~~
~~I-134~~	-	~~0.00E+00~~	-	-	~~0.00E+00~~
~~I-135~~	-	~~0.00E+00~~	-	-	~~0.00E+00~~
-	~~Xe-135m~~	~~0.00E+00~~	-	-	~~0.00E+00~~
-	~~Xe-135~~	~~0.00E+00~~	-	-	~~0.00E+00~~
~~Cs-134~~	-	~~4.07E+02~~	~~4.14E-119~~	-	~~4.14E-119~~
~~Cs-136~~	-	~~1.87E-41~~	-	-	~~1.87E-41~~
~~Cs-137~~	-	~~5.03E+03~~	~~2.63E-05~~	-	~~2.63E-05~~
-	~~Ba-137m~~	~~0.00E+00~~	-	-	~~0.00E+00~~

~~NAPS COL 2.0-24-A~~

Table 2.4-210 ~~**Compliance with 10 CFR Part 20 for an Accidental Release of Radioactive Liquid Effluent in Groundwater**~~ **[Deleted]**

		~~Concentration/ECL~~			
~~Parent Radionuclide~~	~~Progeny in Chain~~	~~Decay[1]~~	~~Decay and Adsorption[2]~~	~~Decay, Adsorption, and Dilution[3]~~	~~Minimum~~
~~Cs-138~~	-	~~0.00E+00~~	-	-	~~0.00E+00~~
~~Ba-140~~	-	~~1.58E-41~~	-	-	~~1.58E-41~~
-	~~La-140~~	~~1.62E-41~~	-	-	~~1.62E-41~~
~~Ce-141~~	-	~~2.52E-16~~	-	-	~~2.52E-16~~
~~Ce-144~~	-	~~7.97E-01~~	~~0.00E+00~~	-	~~0.00E+00~~
-	~~Pr-144m~~	~~0.00E+00~~	-	-	~~0.00E+00~~
-	~~Pr-144~~	~~3.99E-03~~	-	-	~~3.99E-03~~
~~W-187~~	-	~~0.00E+00~~	-	-	~~0.00E+00~~
~~Np-239~~	-	~~3.24E-232~~	~~0.00E+00~~	-	~~0.00E+00~~
-	~~Pu-239~~	~~2.60E-01~~	~~1.84E+01~~	~~4.72E-03~~	~~4.72E-03~~
				~~Sum of Fractions =~~	~~5.64E-02~~

~~1. Table 2.4-206~~
~~2. Table 2.0-208~~
~~3. Table 2.0-209~~
~~4. No ECLs are published for Rh-106, Ag-110, Xe-133m, Xe-133, Xe-135m, Xe-135, Ba-137m, and~~
~~Pr-144m. However, their half-lives are short (on the order of days or less) and they decay to near zero~~
~~concentrations. Their ratios have been taken as zero.~~

NAPS COL 2.0-24-A **Figure 2.4-218 Sum of Fractions as a Function of Time for Groundwater Discharged to Lake Anna**