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DTE Energy

10 CFR 52.3
10 CFR 52.79
10 CFR 100.20(c)

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November 11, 2008
NRC3-08-0008

U. S. Nuclear Regulatory Commission
Attention: Document Control Desk
Washington D C 20555-0001

References: Letter from Jack M. Davis (Detroit Edison) to USNRC, "Detroit Edison Company Submittal of Application for a Combined License for Fermi 3 (NRC Project No. 757)", NRC3-08-0003, dated September 18, 2008

Subject: Detroit Edison Company Submittal of Fermi 3 FSAR Section 2.4.13 Analysis (NRC Project No. 757)

In the referenced letter, the Detroit Edison Company submitted an application for a combined license (COLA) for Fermi 3. As part of the Acceptance Review, the NRC staff raised questions relating to the content of Part 2 of the COLA, Final Safety Analysis Report (FSAR) Section 2.4.13. Specifically, The NRC noted an analysis of accidental release of radioactive liquid effluent in ground and surface water was not included.

Detroit Edison did not include this analysis in the Fermi 3 COLA due to mitigating design features employed in the Economic Simplified Boiling Water Reactor (ESBWR) design that preclude accidental release of radioactive liquid to ground and surface waters. However, Detroit Edison agreed to provide an analysis to the NRC by November 14, 2008.

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The information provided in Attachment 1 to this letter addresses the NRC staff's question relative to the content of this section. Applicable changes to FSAR Section 2.4.13 will be incorporated into Submission 2 of the Fermi 3 COLA, currently scheduled for February 2009.

If you have any questions, or need additional information, please contact Mr. Peter W. Smith at (313)235-3341.

Sincerely,

Jack M Davis

Jack M. Davis
Senior Vice President and Chief Nuclear Officer
Detroit Edison Company

Attachments: 1) Analysis of Accidental Release of Radioactive Effluent into Ground and Surface Water.

cc: NRC Fermi 3 Project Manager
Fermi 2 Resident Inspector
NRC Region III Regional Administrator
NRC Region II Regional Administrator
Supervisor, Electric Operators, Michigan Public Service Commission

I, Jack M. Davis, do hereby affirm that the foregoing statements are based on facts and circumstances which are true and accurate to the best of my knowledge and belief.

Jack M Davis

JACK M. DAVIS
Senior Vice President
and Chief Nuclear Officer

On this 11th day of November 2008 before me personally appeared Jack M. Davis, being first duly sworn and says that he executed the foregoing as his free act and deed.

Notary Public

**ATTACHMENT 1 TO
NRC3-08-0008**

DETROIT EDISON RESPONSE TO NRC ACCEPTANCE REVIEW QUESTION RELATING TO FSAR SECTION 2.4.13

Detroit Edison provides the following response that will incorporated in FSAR 2.4.13.

Accidental Releases of Liquid Effluents to Ground and Surface Waters

Mitigating design features specified in NUREG 0800 Branch Technical Position (BTP) 11-6 (Reference 1) are incorporated into the design of Fermi 3 to preclude an accidental release of liquid effluents. Descriptions of these features are provided below.

Below-grade tanks containing radioactivity are located on levels B1F and B2F of the Radwaste Building. The Radwaste Building is designed to seismic requirements as specified in DCD Table 3.2-1. In addition, as described in DCD Section 11.2.2.3, compartments containing high level liquid radwaste are steel lined up to a height capable of containing the release of all liquid radwaste in the compartment. Leaks as a result of major cracks in tanks result in confinement of the liquid radwaste in the compartment and the building sump system for containment in other tanks or emergency tanks. Because of these design capabilities, it is not considered feasible that any major event involving the release of liquid radwaste into these volumes results in the release of these liquids to the groundwater environment via the liquid pathway.

The Condensate Storage Tank (CST), part of the Condensate Storage and Transfer System (CS&TS), is the only above-grade tank that potentially could contain radioactivity outside of containment, the reactor building, or the radwaste building. The CS&TS, described in DCD Section 9.2.6, meets GDC 60 by compliance with RG 1.143, Position C.1.2 for design features provided to control the release of liquid effluents containing radioactive material. The basin surrounding the tank is designed to prevent uncontrolled runoff in the event of a tank failure. The basin volume is sized to contain the total tank capacity. Tank overflow is also collected in this basin. A sump located inside the retention basin has provisions for sampling collected liquids prior to routing them to the Liquid Waste Management System (LWMS) or the storm sewer as per sampling and release requirements. These design features are intended to preclude the release of liquids from the CST to either the ground or surface water environment via the liquid pathway.

The mitigating design features described above demonstrate that the radioactive waste management systems, structures, and components for Fermi 3, as defined in RG 1.143, include features to preclude accidental releases of radionuclides into potential liquid pathways. Nevertheless, an analysis of accidental releases of radioactive liquid effluents in groundwater is performed. Descriptions and results of these analyses are provided herein.

The source term provided in DCD Table 12.2-13a, Liquid Waste Management System Equipment Drain Collection Tank Activity, is used in the analysis of an accidental release of liquid effluents from an equipment drain collection tank and the radwaste building structure to the groundwater system. This source term is appropriate because these tanks collect radioactive liquids from various pieces of plant equipment and are upstream of liquid processing by the LWMS.

Groundwater Analysis

The purpose of this section is to provide a conservative analysis of a postulated accidental release of radioactive liquid effluents to the groundwater at the Fermi 3 site. The accident scenario is described. The model used to evaluate radionuclide transport is presented, along with potential pathways of contamination to water users. The radionuclide transport analysis is described, and the results are summarized. The radionuclide concentrations to which a water user might be exposed are compared against the regulatory limits.

Accident Scenario

A liquid radwaste tank outside of containment is postulated to rupture with its contents released to the groundwater. The volume of the liquid assumed to be released and the associated radionuclide concentrations 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 Tables 2 and 3.

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 conservative because the radwaste building is seismically designed in accordance with RG 1.143, Class RW-lla, 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 DCD Section 11.2.2.3, to prevent any potential liquid releases to the environment.

Model

FSAR Section 2.4.12.3 describes the model used to evaluate transport of groundwater. This transport model is used to evaluate the accidental release of radioactive liquid effluent to groundwater. Key elements and assumptions embodied in this evaluation 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 approximately 540 feet NAVD88 (FSAR Figure 2.5.4-204). 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 (Reference 1). 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 conservative because it requires failure of the floor drain system, plus it ignores the barriers presented by the basemat concrete 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 2.4-246 through Figure 2.4-249 of the FSAR indicate that the ambient water table in the vicinity of the radwaste building is about 567 feet NAVD88, or 27 ft above the radwaste building 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 confined Bass Islands aquifer and migrate with the groundwater in the direction of decreasing hydraulic head. FSAR Section 2.4.12.3.1 describes potential pathways in the bedrock (Bass Islands aquifer). As described in FSAR Section 2.4.12.3.1 there are two potential pathways for groundwater:

- The documented present day condition, in which the groundwater flow direction in the Bass Islands aquifer is westward off-site.
- A possible future condition in which the flow direction has returned to flow toward Lake Erie.

The present day condition is attributed to dewatering associated with quarrying operations westward of the site. The possible future condition is intended to account for the case where the quarrying operations were to cease. For the purposes of this evaluation, both potential flow paths are considered. For each potential flow path, the flow path is assumed to be a straight line between the radwaste building and the receptor. To the westward off-site, the assumed receptor is a well located therein. To the east, the receptor is Lake Erie. Additional analysis conservatism exists in that no credit is taken for dilution at the receptor.

Radionuclide Transport Analysis

The radionuclide transport analysis is conducted, using conservative assumptions and coefficients, 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.

Radionuclide concentrations resulting from the analysis are compared against the effluent concentration limits (ECLs) identified in 10 CFR 20, Appendix B, Table 2, Column 2, to determine acceptability. It is noted that using the ECLs identified in 10 CFR 20, Appendix B, Table 2, is conservative as (per 10 CFR 20, Appendix B) "the concentration values given in Columns 1 and 2 of Table 2 are equivalent to the radionuclide concentrations which, if inhaled or ingested continuously over the course of a year, would produce a total effective dose equivalent of 0.05 rem (50 millirem or 0.5 millisieverts)." In the case of this postulated release of the radioactive liquid to the groundwater at the Fermi site, it is not expected that the radioactivity will be present at the receptor continuously over the course of the year. As the radioactivity reaches the receptor, it is flowing either in the lake water (for the postulated release eastward to Lake Erie) or in the groundwater (postulated release westward off-site). This flow mechanism does not simply cease at the receptor, but would continue to flow past the receptor.

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. References 2 and 3 were 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, 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, which is given as:

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

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

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

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:

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

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

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

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

Using the method of characteristics approach in Reference 4, the material derivative of concentration can be written as:

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

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

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

$$\frac{dx}{dt} = \frac{v}{R} \tag{7}$$

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

$$C_1 = C_{10} \exp(-\lambda_1 t) \tag{8}$$

$$t = R_1 L / v \tag{9}$$

where: C_1 = concentration of the parent radionuclide; C_{10} = initial 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:

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

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

$$\frac{dC_2}{dt} = d_{12} \lambda_1' C_1 - \lambda_2 C_2 \tag{11}$$

$$\frac{dx}{dt} = \frac{v}{R_2} \tag{12}$$

Where: $\lambda'_1 = \lambda_1 R_1 / R_2$. Recognizing that Equation (11) is formally similar to Equation B.43 of Reference 3, these equations can be integrated to yield:

$$C_2 = K_1 \exp(-\lambda_1' t) + K_2 \exp(-\lambda_2 t) \tag{13}$$

$$t = R_2 L / v \tag{14}$$

For which:

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

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

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

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

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 (15), again conservatively neglecting hydrodynamic dispersion, can be derived as

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

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

where: $\lambda'_1 = \lambda_1 R_1/R_3$; and $\lambda'_2 = \lambda_2 R_2/R_3$. Considering the formal similarity of Equation (16) to Equation B.54 of Reference 3, Equation (16) and Equation (17) can be integrated to yield:

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

$$t = R_3 L / v \qquad (19)$$

For which:

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

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

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

To estimate the radionuclide concentrations in groundwater discharging to the receptor, Equation (8), Equation (13), and Equation (18) were applied as appropriate along the groundwater pathline that would originate at the radwaste building and terminate at the receptor.

Transport Considering Radioactive Decay Only

This analysis is conservatively performed considering radioactive decay only. This analysis also conservatively assumes that all radionuclides migrate at the same rate as groundwater and considers 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 are decayed for a period equal to the groundwater travel time from the point of release to the receptor, using Equation (8), Equation (13), or Equation (18) as appropriate with $R_1 = R_2 = R_3 = 1$.

As discussed above, per Equation (2), the Retardation Factor (R) is a function of the material properties. As discussed in FSAR Section 2.5.1.2.4.3, the Bass Islands formation is highly fractured with a variable frequency of fracturing. During the on-site investigation, some of the fractures were observed to be filled, while others had no filling. Groundwater travel through the Bass Islands aquifer would tend to follow the open fractures as this provides the path of least resistance. Flow through the open fractures would also provide the lower values for distribution coefficients and retardation factors. Literature values for distribution coefficients that would conservatively represent the conditions at the site were not identified. Due to the presence of the fractures, testing methods are considered to be limited in their capability to conservatively represent the sub-surface conditions. Thus, overall, determination of appropriate values for distribution coefficients, accounting for the fractures, may introduce a level of uncertainty to the results. In order to bound these potential uncertainties, a value of Kd is used that results in a value of one (1) for the Retardation Factors (Equation (2)).

Evaluating transport considering radioactive decay only requires an estimate of the groundwater travel time. In FSAR Section 2.4.12.3.2 the groundwater travel time between the radwaste building and the two possible sources is estimated based on site-specific hydrogeologic characteristics. The following table summarizes the pertinent results from Section 2.4.12.3.2.

Table 1
Groundwater Flow Parameters

Flow Path	Distance (feet)	Velocity (feet/day)	Travel Time (Days)
Eastward to Lake Erie	1476	1.76	839
Westward Off-Site	4756	3.5	1359

Maximum flow velocities from FSAR Section 2.4.12.3.2, as reflected in Table 1, are used to provide bounding results.

Using Equation (8), Equation (13), or Equation (18) as appropriate with R = 1, the initial concentrations were decayed for a period of the travel times reflected in Table 1 for each potential flow path. Radioactive decay data and decay chain specifications were taken from NUREG/CR-5512, Vol. 1, Table E.1 (Reference 3). Radioactive decay data for some of the shorter-lived radionuclides were obtained from Reference 2. Table 2 and Table 3 summarize the results and identify those radionuclides for which the ratio of groundwater concentration to ECL would exceed 1 (i.e., unity). These radionuclides are H-3, Mn-54, Fe-55, Co-60, Zn-65, Sr-90, Y-90, Ru-106, Ag-110m, Cs-134, Cs-137 and Ce-144.

Comparison with 10 CFR 20 ECL

The radionuclide transport analysis presented above indicates that several of the radionuclides that could be accidentally released to groundwater could exceed their corresponding ECL for the conservative conditions modeled.

It is recognized that 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"). Given that several of the radionuclides exceed their corresponding ECL, the sum of all of the ratios would also be greater than unity.

As described above, this analysis is based on multiple conservatisms that are used to provide a bounding result. To summarize these conservatisms are as follows.

- The assumption that the tank ruptures is considered to be very conservative. Minor tank leakage would be expected to occur prior to a significant leak occurring. Plant operators would be alerted to leakage during walkdowns and would take actions to minimize the impacts from such leakage. As described in DCD, Section 15.3.16.1, a liquid radwaste release caused by operator error is also considered a remote possibility. Operating techniques and administrative procedures emphasize detailed system and equipment operating instructions. A positive action interlock system is also provided to prevent inadvertent opening of a drain valve.

- The radwaste building is designed to seismic requirements as specified in DCD Table 3.2-1. The compartments that contain these tanks are steel lined up to a height capable of containing the release of all liquid radwaste in the tank. This design and additional barrier are not credited in the analysis.
- The poteniometric head is approximately 27 ft above the radwaste building floor elevation. Thus, if leakage should occur due to a crack in the building floor or wall, it would be expected that the leakage would be into the building and not out of the building. These hydrogeologic conditions are not credited in the analysis.
- The analysis is based on the maximum groundwater flow velocity based on FSAR Section 2.4.12. Using the maximum groundwater flow velocity results in the minimum decay time and thus the maximum radionuclide concentrations.
- For the postulated release to Lake Erie, no credit is taken for dilution in the lake water as the release traverses to a drinking water intake. The closest drinking water intake from Lake Erie is more than 1500 meters to the South. Thus, significant dilution would be expected for the postulated release to Lake Erie. It is noted that this same dilution factor would not be present for the postulated release westward off-site (i.e., where the receptor is a well).
- The limits (ECLs) to which the groundwater concentrations are compared are conservative as the 10 CFR 20, Appendix B, ECLs are based on continuous ingestion over a year. In this case of this postulated release of the radioactive liquid to the groundwater, it is expected that the radioactivity will not be present at the receptor continuously over the course of the year.

It is noted that reducing the extent of the analytical conservatisms discussed above (specifically the last three bullets) would not be expected to produce results that are less than the 10 CFR 20, Appendix B, ECLs. Thus, additional measures (as discussed below) are implemented as part of the Fermi 3 design to ensure that the ECLs are not exceeded.

Mitigation Measures

BTP 11-6 (Reference 1), Section D, discusses two different alternatives for supporting a conclusion that the postulated failure of a tank and its associated components has been evaluated and the design is acceptable and meets the requirements of General Design Criteria 60 and 61 for the control of releases of radioactive materials to the environment and provides an adequate level of safety during normal reactor operation. One alternative for supporting this conclusion is an analysis determining radionuclide concentrations in the applicable failed components and the effect of site hydrology for those systems that have not been provided with special design features to mitigate the effects of failures. As discussed above, such an analysis using conservative inputs and assumptions indicates that the results for some radionuclides are greater than the respective limits.

Per Reference 1, a second alternative for supporting a conclusion that the postulated failure of a tank is acceptable and meets the requirements of General Design Criteria 60 and 61 is to provide design features to mitigate the consequences of the postulated tank failure. The Fermi 3 design supports the conclusion that the design features provided are acceptable in mitigating the effects of tank failure involving radioactive liquids. Therefore, based on these design features, a postulated liquid release to the environment at Fermi 3 is mitigated in a manner consistent with regulatory guidance to preclude the possible release.

References

1. NUREG 0800, Branch Technical Position (BTP) 11-6, Postulated Releases Due to Liquid-Containing Tank Failures, dated March 2007.

2. National Nuclear Data Center, http://www.nndc.bnl.gov/mird/, accessed November 6, 2008.

3. NUREG/CR-5512, Volume 1, Residual Radioactive Contamination from Decommissioning.

4. Konikow, L. F., and J. D. Bredehoeft, Computer Model of Two-Dimensional Solute Transport and Dispersion in Ground Water, Chapter C2, Book 7, Techniques of Water-Resources Investigations of the United States Geological Survey, 1978.

Table 2
Results Based on Eastward Flow Path to Lake Erie

Radio-nuclide	Progeny	Half-Life (days)	Branching Fraction			Decay Rate (days-1)	Initial Concentration (µCi/cm³)	Groundwater Concentration (µCi/cm³)	ECL (µCi/cm³)	GW/ECL
			d12	d13	d23					
H-3		4.51E+03				1.54E-04	2.63E-03	2.31E-03	1.00E-03	2.31E+00
Na-24		6.25E-01				1.11E+00	1.28E-03	0.00E+00	5.00E-05	0.00E+00
P-32		1.43E+01				4.85E-02	5.35E-04	1.20E-21	9.00E-06	1.33E-16
Cr-51		2.77E+01				2.50E-02	7.05E-02	5.46E-11	5.00E-04	1.09E-07
Mn-54		3.13E+02				2.21E-03	2.66E-03	4.15E-04	3.00E-05	1.38E+01
Mn-56		1.07E-01				6.48E+00	2.05E-03	0.00E+00	7.00E-05	0.00E+00
Fe-55		9.86E+02				7.03E-04	8.32E-02	4.62E-02	1.00E-04	4.62E+02
Fe-59		4.45E+01				1.56E-02	1.03E-03	2.20E-09	1.00E-05	2.20E-04
Co-58		7.08E+01				9.79E-03	4.76E-03	1.30E-06	2.00E-05	6.48E-02
Co-60		1.93E+03				3.59E-04	1.69E-02	1.25E-02	3.00E-06	4.17E+03
Ni-63		3.51E+04				1.97E-05	8.76E-05	8.61E-05	1.00E-04	8.61E-01
Cu-64		5.29E-01				1.31E+00	1.60E-03	0.00E+00	2.00E-04	0.00E+00
Zn-65		2.44E+02				2.84E-03	7.16E-02	6.62E-03	5.00E-06	1.32E+03
Rb-89		1.06E-02				6.54E+01	3.38E-05	0.00E+00	9.00E-04	0.00E+00
	Sr-89	5.05E+01	1.0000			1.37E-02	3.86E-03	3.88E-08	8.00E-06	4.86E-03
Sr-90		1.06E+04				6.54E-05	6.03E-04	5.71E-04	5.00E-07	1.14E+03
	Y-90	2.67E+00	1.0000			2.60E-01	1.88E-05	5.71E-04	7.00E-06	8.15E+01
Sr-91		3.96E-01				1.75E+00	1.54E-03	0.00E+00	2.00E-05	0.00E+00
	Y-91m	3.45E-02	0.5780			2.01E+01	0.00E+00	0.00E+00	2.00E-03	0.00E+00
	Y-91	5.85E+01		0.4220	1.0000	1.18E-02	1.70E-03	8.28E-08	8.00E-06	1.04E-02
Sr-92		1.13E-01				6.13E+00	8.78E-04	0.00E+00	4.00E-05	0.00E+00
	Y-92	1.48E-01	1.0000			4.68E+00	7.22E-04	0.00E+00	4.00E-05	0.00E+00
Y-93		4.21E-01				1.65E+00	1.62E-03	0.00E+00	2.00E-05	0.00E+00
Zr-95		6.40E+01				1.08E-02	3.62E-04	4.12E-08	2.00E-05	2.06E-03
	Nb-95m	3.61E+00	0.0070			1.92E-01	0.00E+00	3.06E-10	3.00E-05	1.02E-05
	Nb-95	3.52E+01		0.9930	1.0000	1.97E-02	2.37E-04	9.16E-08	3.00E-05	3.05E-03

Table 2
Results Based on Eastward Flow Path to Lake Erie

Radio-nuclide	Progeny	Half-Life (days)	Branching Fraction d12	d13	d23	Decay Rate (days-1)	Initial Concentration (µCi/cm^3)	Groundwater Concentration (µCi/cm^3)	ECL (µCi/cm^3)	GW/ ECL
Mo-99		2.75E+00				2.52E-01	5.59E-03	9.31E-95	2.00E-05	4.66E-90
	Tc-99m	2.51E-01	0.8760			2.76E+00	4.65E-04	8.98E-95	1.00E-03	8.98E-92
Ru-103		3.93E+01				1.76E-02	6.46E-04	2.44E-10	3.00E-05	8.15E-06
	Rh-103m	3.90E-02	0.9970			1.78E+01	6.30E-07	2.44E-10	6.00E-03	4.06E-08
Ru-106		3.68E+02				1.88E-03	2.21E-04	4.55E-05	3.00E-06	1.52E+01
	Rh-106	3.45E-04	1.0000			2.01E+03	7.97E-10	4.55E-05		
Ag-110m		2.50E+02				2.77E-03	7.22E-05	7.06E-06	6.00E-06	1.18E+00
	Ag-110	2.85E-04	0.0133			2.43E+03	0.00E+00	9.39E-08		
Te-129m		3.36E+01				2.06E-02	1.16E-03	3.57E-11	7.00E-06	5.10E-06
	Te-129	4.83E-02	0.6500			1.44E+01	0.00E+00	2.32E-11	4.00E-04	5.81E-08
Te-131m		1.25E+00				5.55E-01	1.31E-04	1.60E-206	8.00E-06	2.00E-201
	Te-131	1.74E-02	0.2220			3.98E+01	0.00E+00	3.61E-207	8.00E-05	4.51E-203
	I-131	8.04E+00		0.7780	1.0000	8.62E-02	1.86E-02	7.57E-34	1.00E-06	7.57E-28
Te-132		3.26E+00				2.13E-01	3.27E-05	1.24E-82	9.00E-06	1.38E-77
	I-132	9.58E-02	1.0000			7.24E+00	1.78E-03	1.28E-82	1.00E-04	1.28E-78
I-133		8.67E-01				7.99E-01	1.49E-02	1.16E-293	7.00E-06	1.66E-288
	Xe-133m	2.19E+00	0.0290			3.17E-01	0.00E+00	1.60E-119		
	Xe-133	5.25E+00		0.9710	1.0000	1.32E-01	0.00E+00	2.53E-51		
I-134		3.65E-02				1.90E+01	1.18E-03	0.00E+00	4.00E-04	0.00E+00
I-135		2.75E-01				2.52E+00	5.92E-03	0.00E+00	3.00E-05	0.00E+00
	Xe-135m	1.06E-02	0.1540			6.54E+01	0.00E+00	0.00E+00		
	Xe-135	3.79E-01		0.8460	1.0000	1.83E+00	0.00E+00	0.00E+00		
Cs-134		7.53E+02				9.21E-04	1.99E-03	9.19E-04	9.00E-07	1.02E+03
Cs-136		1.31E+01				5.29E-02	1.96E-04	1.06E-23	6.00E-06	1.77E-18
Cs-137		1.10E+04				6.30E-05	5.65E-03	5.36E-03	1.00E-06	5.36E+03
	Ba-137m	1.77E-03	0.9460			3.92E+02	1.00E-07	5.07E-03		

Table 2
Results Based on Eastward Flow Path to Lake Erie

Radio-nuclide	Progeny	Half-Life (days)	Branching Fraction d12	d13	d23	Decay Rate (days-1)	Initial Concentration ($\mu Ci/cm^3$)	Groundwater Concentration ($\mu Ci/cm^3$)	ECL ($\mu Ci/cm^3$)	GW/ ECL
Cs-138		2.24E-02				3.09E+01	1.52E-04	0.00E+00	4.00E-04	0.00E+00
Ba-140		1.27E+01				5.46E-02	4.73E-03	6.33E-23	8.00E-06	7.91E-18
	La-140	1.68E+00	1.0000			4.13E-01	7.08E-04	7.30E-23	9.00E-06	8.11E-18
Ce-141		3.25E+01				2.13E-02	8.03E-04	1.38E-11	3.00E-05	4.59E-07
Ce-144		2.84E+02				2.44E-03	2.12E-04	2.74E-05	3.00E-06	9.15E+00
	Pr-144m	5.07E-03	0.0178			1.37E+02	0.00E+00	4.89E-07		
	Pr-144	1.20E-02		0.9822	1.0000	5.78E+01	2.78E-08	2.74E-05	6.00E-04	4.57E-02
W-187		9.96E-01				6.96E-01	3.11E-04	1.22E-257	3.00E-05	4.08E-253
Np-239		2.36E+00				2.94E-01	1.94E-02	2.20E-109	2.00E-05	1.10E-104
	Pu-239	8.79E+06	1.0000			7.89E-08	0.00E+00	5.20E-09	2.00E-08	2.60E-01

Table 3
Results Based on Westward Flow Path

Radio-nuclide	Progeny	Half-Life (days)	Branching Fraction d12	d13	d23	Decay Rate (days-1)	Initial Concentration (µCi/cm^3)	Groundwater Concentration (µCi/cm^3)	ECL (µCi/cm^3)	GW/ ECL
H-3		4.51E+03				1.54E-04	2.63E-03	2.13E-03	1.00E-03	2.13E+00
Na-24		6.25E-01				1.11E+00	1.28E-03	0.00E+00	5.00E-05	0.00E+00
P-32		1.43E+01				4.85E-02	5.35E-04	1.38E-32	9.00E-06	1.53E-27
Cr-51		2.77E+01				2.50E-02	7.05E-02	1.23E-16	5.00E-04	2.46E-13
Mn-54		3.13E+02				2.21E-03	2.66E-03	1.31E-04	3.00E-05	4.38E+00
Mn-56		1.07E-01				6.48E+00	2.05E-03	0.00E+00	7.00E-05	0.00E+00
Fe-55		9.86E+02				7.03E-04	8.32E-02	3.20E-02	1.00E-04	3.20E+02
Fe-59		4.45E+01				1.56E-02	1.03E-03	6.71E-13	1.00E-05	6.71E-08
Co-58		7.08E+01				9.79E-03	4.76E-03	8.00E-09	2.00E-05	4.00E-04
Co-60		1.93E+03				3.59E-04	1.69E-02	1.04E-02	3.00E-06	3.46E+03
Ni-63		3.51E+04				1.97E-05	8.76E-05	8.53E-05	1.00E-04	8.53E-01
Cu-64		5.29E-01				1.31E+00	1.60E-03	0.00E+00	2.00E-04	0.00E+00
Zn-65		2.44E+02				2.84E-03	7.16E-02	1.51E-03	5.00E-06	3.02E+02
Rb-89		1.06E-02				6.54E+01	3.38E-05	0.00E+00	9.00E-04	0.00E+00
	Sr-89	5.05E+01	1.0000			1.37E-02	3.86E-03	3.10E-11	8.00E-06	3.88E-06
Sr-90		1.06E+04				6.54E-05	6.03E-04	5.51E-04	5.00E-07	1.10E+03
	Y-90	2.67E+00	1.0000			2.60E-01	1.88E-05	5.52E-04	7.00E-06	7.88E+01
Sr-91		3.96E-01				1.75E+00	1.54E-03	0.00E+00	2.00E-05	0.00E+00
	Y-91m	3.45E-02	0.5780			2.01E+01	0.00E+00	0.00E+00	2.00E-03	0.00E+00
	Y-91	5.85E+01		0.4220	1.0000	1.18E-02	1.70E-03	1.75E-10	8.00E-06	2.19E-05
Sr-92		1.13E-01				6.13E+00	8.78E-04	0.00E+00	4.00E-05	0.00E+00
	Y-92	1.48E-01	1.0000			4.68E+00	7.22E-04	0.00E+00	4.00E-05	0.00E+00
Y-93		4.21E-01				1.65E+00	1.62E-03	0.00E+00	2.00E-05	0.00E+00
Zr-95		6.40E+01				1.08E-02	3.62E-04	1.48E-10	2.00E-05	7.41E-06
	Nb-95m	3.61E+00	0.0070			1.92E-01	0.00E+00	1.10E-12	3.00E-05	3.67E-08

Table 3
Results Based on Westward Flow Path

Radio-nuclide	Progeny	Half-Life (days)	Branching Fraction			Decay Rate (days-1)	Initial Concentration (μCi/cm³)	Groundwater Concentration (μCi/cm³)	ECL (μCi/cm³)	GW/ECL
			d12	d13	d23					
	Nb-95	3.52E+01		0.9930	1.0000	1.97E-02	2.37E-04	3.30E-10	3.00E-05	1.10E-05
Mo-99		2.75E+00				2.52E-01	5.59E-03	1.22E-151	2.00E-05	6.10E-147
	Tc-99m	2.51E-01	0.8760			2.76E+00	4.65E-04	1.18E-151	1.00E-03	1.18E-148
Ru-103		3.93E+01				1.76E-02	6.46E-04	2.56E-14	3.00E-05	8.52E-10
	Rh-103m	3.90E-02	0.9970			1.78E+01	6.30E-07	2.55E-14	6.00E-03	4.25E-12
Ru-106		3.68E+02				1.88E-03	2.21E-04	1.71E-05	3.00E-06	5.70E+00
	Rh-106	3.45E-04	1.0000			2.01E+03	7.97E-10	1.71E-05		
Ag-110m		2.50E+02				2.77E-03	7.22E-05	1.67E-06	6.00E-06	2.79E-01
	Ag-110	2.85E-04	0.0133			2.43E+03	0.00E+00	2.22E-08		
Te-129m		3.36E+01				2.06E-02	1.16E-03	7.89E-16	7.00E-06	1.13E-10
	Te-129	4.83E-02	0.6500			1.44E+01	0.00E+00	5.13E-16	4.00E-04	1.28E-12
Te-131m		1.25E+00				5.55E-01	1.31E-04	0.00E+00	8.00E-06	0.00E+00
	Te-131	1.74E-02	0.2220			3.98E+01	0.00E+00	0.00E+00	8.00E-05	0.00E+00
	I-131	8.04E+00		0.7780	1.0000	8.62E-02	1.86E-02	2.65E-53	1.00E-06	2.65E-47
Te-132		3.26E+00				2.13E-01	3.27E-05	1.29E-130	9.00E-06	1.43E-125
	I-132	9.58E-02	1.0000			7.24E+00	1.78E-03	1.33E-130	1.00E-04	1.33E-126
I-133		8.67E-01				7.99E-01	1.49E-02	0.00E+00	7.00E-06	0.00E+00
	Xe-133m	2.19E+00	0.0290			3.17E-01	0.00E+00	5.97E-191		
	Xe-133	5.25E+00		0.9710	1.0000	1.32E-01	0.00E+00	4.05E-81		
I-134		3.65E-02				1.90E+01	1.18E-03	0.00E+00	4.00E-04	0.00E+00
I-135		2.75E-01				2.52E+00	5.92E-03	0.00E+00	3.00E-05	0.00E+00
	Xe-135m	1.06E-02	0.1540			6.54E+01	0.00E+00	0.00E+00		
	Xe-135	3.79E-01		0.8460	1.0000	1.83E+00	0.00E+00	0.00E+00		
Cs-134		7.53E+02				9.21E-04	1.99E-03	5.70E-04	9.00E-07	6.33E+02
Cs-136		1.31E+01				5.29E-02	1.96E-04	1.21E-35	6.00E-06	2.02E-30
Cs-137		1.10E+04				6.30E-05	5.65E-03	5.19E-03	1.00E-06	5.19E+03

Table 3
Results Based on Westward Flow Path

Radio-nuclide	Progeny	Half-Life (days)	Branching Fraction d12	d13	d23	Decay Rate (days-1)	Initial Concentration (µCi/cm^3)	Groundwater Concentration (µCi/cm^3)	ECL (µCi/cm^3)	GW/ ECL
	Ba-137m	1.77E-03	0.9460			3.92E+02	1.00E-07	4.91E-03		
Cs-138		2.24E-02				3.09E+01	1.52E-04	0.00E+00	4.00E-04	0.00E+00
Ba-140		1.27E+01				5.46E-02	4.73E-03	3.05E-35	8.00E-06	3.81E-30
	La-140	1.68E+00	1.0000			4.13E-01	7.08E-04	3.52E-35	9.00E-06	3.91E-30
Ce-141		3.25E+01				2.13E-02	8.03E-04	2.12E-16	3.00E-05	7.05E-12
Ce-144		2.84E+02				2.44E-03	2.12E-04	7.72E-06	3.00E-06	2.57E+00
	Pr-144m	5.07E-03	0.0178			1.37E+02	0.00E+00	1.37E-07		
	Pr-144	1.20E-02		0.9822	1.0000	5.78E+01	2.78E-08	7.72E-06	6.00E-04	1.29E-02
W-187		9.96E-01				6.96E-01	3.11E-04	0.00E+00	3.00E-05	0.00E+00
Np-239		2.36E+00				2.94E-01	1.94E-02	1.14E-175	2.00E-05	5.72E-171
	Pu-239	8.79E+06	1.0000			7.89E-08	0.00E+00	5.20E-09	2.00E-08	2.60E-01