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SCREENING EVALUATION OF RADIONUCLIDE GROUNDWATER CONCENTRATIONS FOR THE END STATE BASEMENT FILL MODEL

ZION NUCLEAR POWER STATION DECOMMISSIONING PROJECT

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Informal Report

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1) Introduction

ZionSolutions is in the process of decommissioning the Zion Nuclear Power Plant. The site contains two reactor Containment Buildings, a Fuel Building, an Auxiliary Building, and a Turbine Building that may be contaminated. The current decommissioning plan involves removing all above grade structures to a depth of 3 feet below grade. The remaining underground structures will be backfilled with clean material. The final selection of fill material has not been made.

Remaining structures will contain low amounts of residual licensed radioactive material. The bulk of the source term will be contained in the concrete floors which are twenty to thirty feet below grade. Current interior demolition plans are to remove all concrete in the Unit 1 and Unit 2 Reactor Buildings inside the steel liner.. Based upon concrete characterization data, the highest end state source term is anticipated to be contained in the Auxiliary Building floor located approximately 50 feet below grade. Thus the end state source term will be well below grade and below the water table eliminating conventional pathways such as direct radiation and inhalation rendering groundwater related pathways the most significant potential sources of future exposure.

An important component of the decommissioning process is the demonstration that any remaining activity will not cause a hypothetical individual to receive a dose in excess of 25 mrem/y^{-1} as specified in 10CFR 20 Subpart E.
To demonstrate compliance with 10CFR 20 Subpart E requires modeling of the fate and transport of radioactive material to a receptor. This involves characterization of the buildings on site to quantify the amount of residual radioactivity, modeling the release of radioactivity from the concrete and mixing with the water contained in the fill material. Transport away from the fill through the groundwater to a receptor well outside of the basement or to a nearby water body may also be a relevant pathway. As the first step in this process, a screening calculation is performed to determine the maximum concentration in the basement fill. Using this maximum concentration an estimate of the dose a potential future resident could receive will be made and only nuclides that contribute significantly to dose will be included in more detailed calculations.

This report addresses the release of contamination to the interstitial water of the fill material and transport to a well located in the middle of the subsurface remains of the Auxiliary Building at the site. ZionSolutions is in the process of analyzing the characterization data from the below grade structures to estimate the residual contamination (source term).
Calculation of the release of radioactive material from the Auxiliary Building basement requires site-specific information on the hydrogeologic transport properties (effective porosity, bulk density, hydraulic) and chemical transport properties (sorption). Conestoga-Rovers & Associates (CRA) has collected a substantial amount of site-specific hydrogeologic data (CRA, 2014).

However, this screening calculation estimates only the water concentration in the basement fill. No transport away from the basements is assumed which would result in lower concentrations.

Brookhaven National Laboratory has determined site-specific sorption data for five nuclides and four soil types, two concrete construction demolition debris, two cinder block materials, and one grout material that are under consideration for the fill (Yim, 2012, Milian, 2014). In addition, sand from the local region could be used as part or all of the backfill.

The objectives of this report are:

a) Develop a simplified conceptual model for release from the Auxiliary Building end state structures that can be used to provide an upper bound on contaminant concentrations in the fill material.
b) Provide maximum water concentrations and the amount of mass sorbed to the solid fill material that could occur in the Auxiliary Building for use in dose assessment calculations.

2) Conceptual Model

Figure 1 provides the site layout at the Zion Nuclear Power Station located on the shores of Lake Michigan. Major features include two reactor Containment Buildings (U-1 and U-2 in Figure 1), a Fuel Building, Auxiliary Building, and Turbine Building.

The proposed plan involves characterization of the residual contamination in the below grade structures at Zion. High-levels of contamination will be removed through a remediation process. There will be surface contamination and volumetric contamination left in place. This contamination will provide a potential source of radioactivity to the groundwater. These structures will be filled with non-contaminated material. Fills that have been under consideration include:

- Clean concrete construction debris (CCDD);
- Clean cinder block material;
- Clean Sand
- Clean Grout

Recently, grout has been eliminated from consideration. The fill may contain a combination of the three remaining choices or it could only include sand. The total capacity of the underground structures (basements) for placement of fill is approximately 6 million cubic feet.

Preliminary characterization data suggest that the reactor Containment Buildings have the highest level of contamination. It is planned to remove the concrete inside the liner due to non-radiological contaminants of the containment building. Characterization data indicates there is no significant liner contamination or concrete activation past the liner, leaving the Auxiliary Building with the highest residual contamination. Low-levels of contamination were found in the Turbine Building. The Spent Fuel Pool and Transfer Canal floors are at 576’ 7” elevation, and therefore below the water table, and have not been characterized yet. The total surface area of the walls and floors below the 588' elevation is one third that of the Auxiliary Building floor surface area.

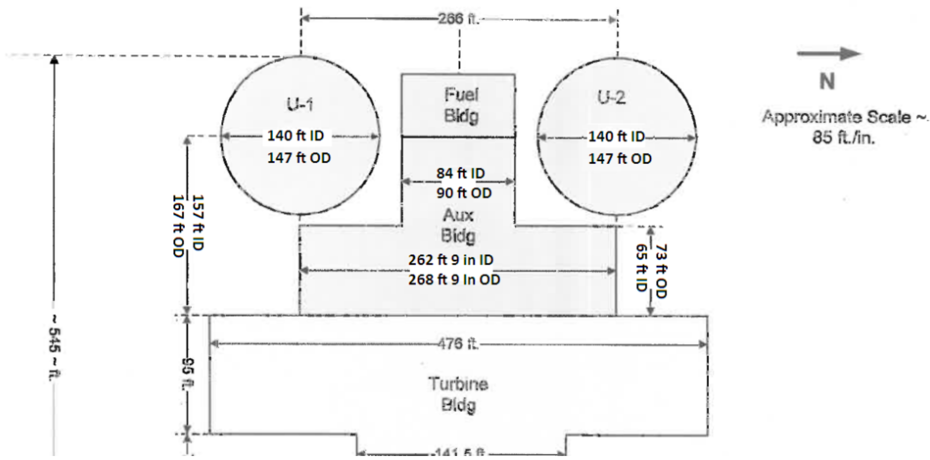

Figure 1 Zion Site building layout.

The natural groundwater flow at the site is towards the lake and perpendicular to the lake front (Figure 1). The conceptual site model is based on release from the Auxiliary Building end state structure. The conceptual model assumes a unit source term that can be scaled to match the levels measured during characterization. The unit source level was selected as a concentration of 1 dpm/100 cm^2 (45.05 pCi/m^2). For the Auxiliary building there is approximately 2424 m^2 of floor surface area. This leads to a modeled inventory of 1.09-07 Ci. The final source term data, after all remediation is completed, will be used to scale the model results by the ratio of the measured activity to the modeled activity to estimate groundwater concentrations for compliance with 10CFR20 Subpart E criteria.

Note that the activity in all parts of the structure, not just the floor, will be used in determining the total activity when the final Basement Fill dose assessment is performed. This assumption means that releases from building walls and sumps, which are at different elevations than the floor, are not modeled directly but are included into the floor inventory. Lumping the entire inventory into the floor is expected to provide a conservative estimate of peak concentration at the receptor locations based on current understanding of the distribution of residual contamination in the Auxiliary Building. The ability to scale results to the total activity is a major advantage of the unit source term approach. Figure 2 is the top view of the Auxiliary Building and Containment Buildings. The Auxiliary Building is irregular in shape and has approximately 2424 m^2 in floor area.

The DUST-MS computer code has been selected to calculate the source term release and equilibrium water concentration at the receptor well which for the screening estimates is assumed to be in the center of the backfilled Auxiliary Building basement. DUST-MS has received wide-spread use in subsurface radionuclide release calculations and undergone model validation studies (Sullivan, 1993; 2006).

The modeled geometry considers contamination of the floor of Auxiliary Building at Zion, Figure 2. The contaminated zone is covered with backfill placed into the structure. Outside of the contaminated zone, a mixture of fill sand and native soil is simulated. Although simulation of this region is not important for the screening calculation it is retained for consistency with the more detailed calculations that may be required. The sand/native soil mixture is consistent with the materials that form the aquifer that will be simulated to transport the radionuclides to various receptor sites if more detailed modeling is necessary

Material properties were chosen to match site-specific values to the extent possible. Sorption coefficient, K_d, values were based on the measured values for Zion soils, concrete, cinder block, and grout (Yim, 2012, Milian, 2014) when available and literature values when site-specific values were not available. A review of literature values and rationale for selecting K_d for dose assessment was performed (Sullivan, 2014). The K_d values selected from the literature were chosen to give a conservative estimate of groundwater concentration (highest value) for dose assessment.

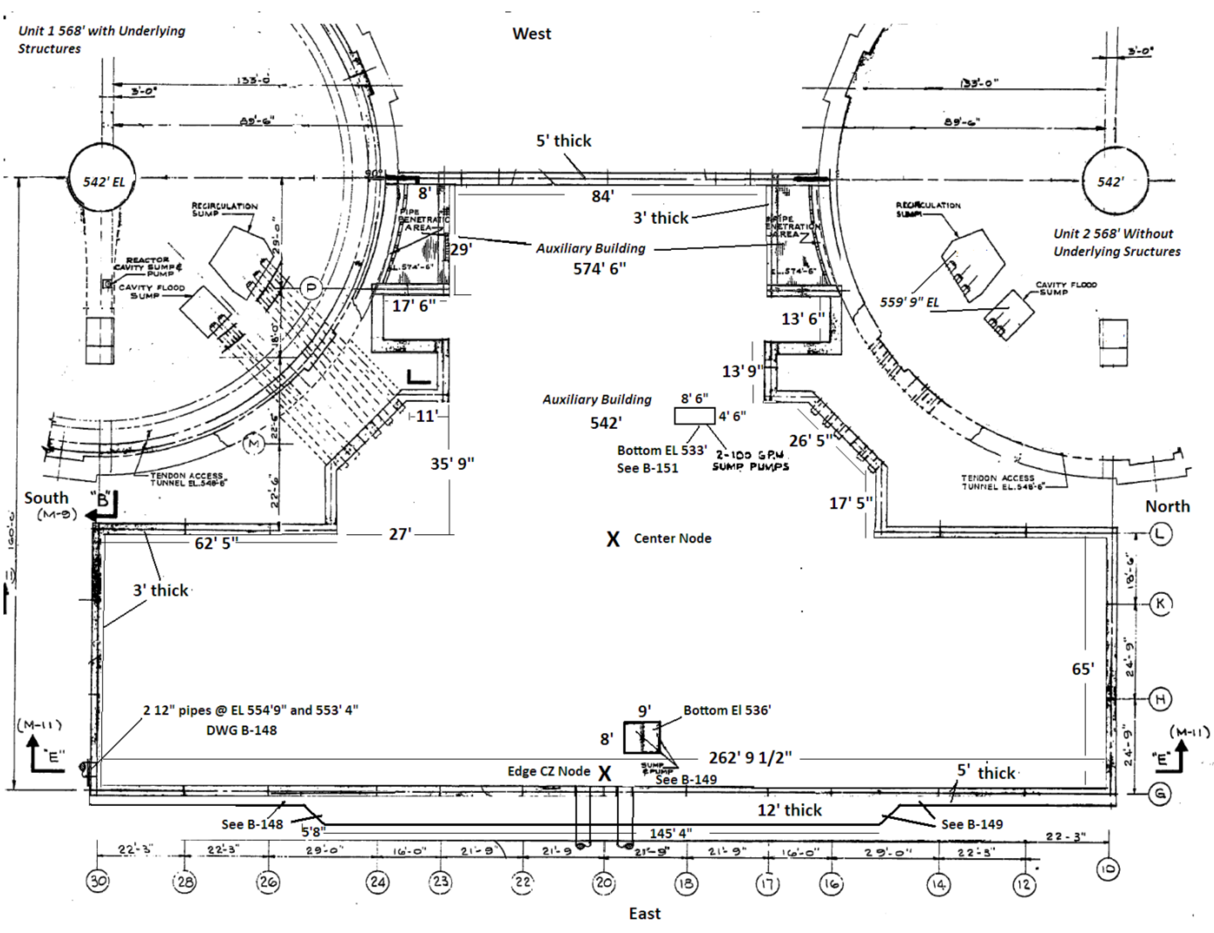

Figure 2. Geometry of the Auxiliary Building.

A key parameter in the 1-D model is the amount of water that will be assumed to mix with the released contaminants. The water table is 11.2 m above the existing floor of the Auxiliary

Building and the floor area for the Auxiliary Building is approximately 2424 m^2. Thus there is 27150 m^3 of volume that will be backfilled and hold water. The porosity of the backfill is not known as it will depend on the final choice of materials used and the emplacement of the backfill. For this analysis, a void space of 25% is assumed. This makes the mixing volume 6790 m^3.

The compliance assessment requires prediction of the release and transport of contaminants to the hypothetical individual. Characterization studies by ZionSolutions have identified the following nuclides as being of potential concern (Table 1). All nuclides in Table 1 were used in the simulation of maximum groundwater concentration.

Table 1. Potential Radionuclides of Concern at the Zion Power Plant

Radionuclides
H-3
C-14
Fe-55
Ni-59
Co-60
Ni-63
Sr-90
Nb-94
Tc-99
Ag-108m
Sb-125
Cs-134
Cs-137
Pm-147
Eu-152
Eu-154
Eu-155
Np-237
Pu-238
Pu-239/240
Pu-241
Am-241
Am-243
Cm-243/244

The DUST-MS model is a one-dimensional finite-difference representation of the advective-dispersion transport in porous media. It can model time-dependent release of contamination into the groundwater and subsequent transport through various geologic regions (e.g. different transport properties) to a downstream location (receptor well). Although there is volumetric contamination that will release over time, for conservatism the conceptual model begins with the assumption that the entire inventory is released at the start of the simulation. This assumption is highly conservative and may be relaxed to simulate time-dependent release if necessary to show that dose limits will be met.

3) Screening Model

The screening model is established using the unit source term and grounded in conservative estimates of site-specific measured values for the model parameters where available. The screening model will be used as the comparison point for more detailed analyses in which transport effects may be considered. The screening model is meant to provide a conservative upper bound estimate for groundwater concentration.

3.1) Parameters

Key input parameters are provided in Appendix 1. These include the initial inventory, and transport properties for the backfill (distribution coefficient, bulk density, effective porosity), and the area available for flow. Soil properties were taken from measurements performed by Conestoga- Rovers and Associates for this plant (CRA, 2013). The effective porosity is derived from the site-specific total porosity and an assumption that 0.8 of the total porosity is available for transport (CRA, 2014).

Initial conditions assumed that the groundwater concentration of each contaminant was zero everywhere. The source term is modeled using a unit inventory approach that can be scaled to the actual inventory of the various buildings on site. For this modeling scenario, the Auxiliary Building was modeled with the assumption of uniform contamination across the floor of the entire building. The source term was simulated as an instantaneous release of the entire modeled inventory in the floor at the start of the problem. This will provide an upper bound on predicted groundwater contamination concentrations per unit inventory.

The exact constitution of the backfill has not been decided yet. Therefore, the bulk density and porosity are unknown. A bulk density of 1.5 g/cm^3 and an effective porosity of 0.25 were selected for the screening model. With any of the fill materials it is difficult to conceive of reducing the packing material below this value. The effective porosity helps determine the amount of water available for mixing and through selecting a low value for this parameter the estimates of concentration in the water will be biased high (e.g. conservative with respect to dose estimates).

The distribution coefficients (K_d) are important parameters in controlling the equilibrium concentrations and transport (if modeled). A study (Sullivan, 2014) reviewed the literature and provided conservative values for K_d in assessing groundwater dose. In selecting values from the literature, environmental conditions with high pH (cement sorption data) as well as environmental data (soil sorption) data were considered. For conservatism the minimum value from these conditions was selected.

Table 2 Selected distribution coefficients (Sullivan, 2014)

Radionuclide	Half Life (years)	Basement Fill K_d to Be Used ml/g
H-3	12.4	0
C-14	5730	1.2
Fe-55	2.7	2857
Ni-59	75000	62
Co-60	5.27	223
Ni-63	96	62
Sr-90	29.1	2.3
Nb-94	20300	45
Tc-99	213000	0
Ag-108m	127	27
Sb-125	2.77	17
Cs-134	2.06	45
Cs-137	30	45
Pm-147	2.62	95
Eu-152	13.3	96
Eu-154	8.8	96
Eu-155	4.96	96
Np-237	2140000	1
Pu-238	87.7	174
Pu-239	24100	174
Pu-240	65400	174
Pu-241	14.4	174
Am-241	432	177
Am-243	7380	177
Cm-243	28.5	891
Cm-244	18.1	891

3.2) Peak Groundwater Concentration Results

The conceptual model assumes that the entire inventory is released instantly at time = 0 on contact with the water and instantly comes to equilibrium with the fill material through the sorption process as controlled by the value of K_d. Thus, the maximum concentrations occur at time = 0 before any radioactive decay or transport in this model. The results of this model are presented in Table 3. In addition to the maximum groundwater concentration, the table provides the amount of radioactivity (Curies) in solution, the amount sorbed to the solid material (Ci) and the fraction of the inventory that is in the water phase. The total inventory was 1.09E-07 Ci for each nuclide modeed.

Table 3 Peak Groundwater Concentrations (pCi/L) per unit source of 1 dpm/100 cm^2

Nuclide	Half-life (years)	K_d (ml/g)	Peak Concentration pCi/L	Radioactivity in Solution Ci	Radioactivity Sorbed Ci	Fraction in Solution
H-3	12.4	0	1.59E-02	1.09E-07	0	1
C-14	5730	1.2	1.97E-03	1.33E-08	9.61E-08	1.22E-01
Fe-55	2.7	2857	9.18E-07	6.30E-12	1.09E-07	5.78E-05
Ni-59	75000	62	4.33E-05	2.93E-10	1.09E-07	2.69E-03
Co-60	5.27	223	1.19E-05	8.07E-11	1.09E-07	7.40E-04
Ni-63	96	62	4.33E-05	2.93E-10	1.09E-07	2.69E-03
Sr-90	29.1	2.3	1.09E-03	7.37E-09	1.02E-07	6.76E-02
Nb-94	20300	45	5.95E-05	4.04E-10	1.09E-07	3.71E-03
Tc-99	213000	0	1.59E-02	1.09E-07	0	1
Ag-108m	127	27	9.90E-05	6.71E-10	1.09E-07	6.16E-03
Sb-125	2.77	17	1.53E-04	1.04E-09	1.08E-07	9.54E-03
Cs-134	2.06	45	5.94E-05	4.03E-10	1.09E-07	3.70E-03
Cs-137	30	45	5.94E-05	4.03E-10	1.09E-07	3.70E-03
Pm-147	2.62	95	2.80E-05	1.90E-10	1.09E-07	1.74E-03
Eu-152	13.3	96	2.78E-05	1.89E-10	1.09E-07	1.73E-03
Eu-154	8.8	96	2.78E-05	1.89E-10	1.09E-07	1.73E-03
Eu-155	4.96	96	2.78E-05	1.89E-10	1.09E-07	1.73E-03
Np-237	2140000	1	2.30E-03	1.56E-08	9.38E-08	1.43E-01
Pu-238	87.7	174	1.54E-05	1.05E-10	1.09E-07	9.63E-04
Pu-239	24100	174	1.54E-05	1.05E-10	1.09E-07	9.63E-04
Pu-240	65400	174	1.54E-05	1.05E-10	1.09E-07	9.63E-04
Pu-241	14.4	174	1.54E-05	1.05E-10	1.09E-07	9.63E-04
Am-241	432	177	1.52E-05	1.03E-10	1.09E-07	9.45E-04
Am-243	7380	177	1.52E-05	1.03E-10	1.09E-07	9.45E-04
Cm-243	28.5	889	3.01E-06	2.04E-11	1.09E-07	1.87E-04
Cm-244	18.11	889	3.01E-06	2.04E-11	1.09E-07	1.87E-04

Examining Table 3 the impact of sorption is clear. For example, consider Sr-90 with a K_d of 2.3 ml/g the solution concentration is less than 7% of the value for $K_d = 0$. Table 3 shows that for most nuclides over 99% of the material is sorbed on the solid media. The exceptions to this are the five nuclides with K_d less than 3 (H-3, C-14, Sr-90, Tc-99, and Np-237).

4.0) Conclusions

A screening model for predicting peak groundwater concentrations at the Zion Nuclear Power Station after decommissioning has been developed. The model uses the DUST-MS simulation model which calculates the release and transport of radioactive contamination in a groundwater system. The analysis is based on a unit source term of 1 dpm/100 cm^2 on the entire floor of the Auxiliary Building which results in 1.09E-07 Ci per nuclide modeled. This inventory is assumed to be instantly released into the groundwater. Conservative assumptions based on existing data were used in the screening model for selecting parameters that impact groundwater concentration (K_d, porosity, bulk density). The results can be combined with characterization data to determine peak groundwater dose for all the nuclides and screen out those that are not significant contributors to dose.

5.0) References

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