Introduction

Groundwater contaminated above release criteria will be extracted from subsurface aquifers, piped to treatment facilities, and treated to remove the contaminants by ion-exchange and/or bio-remediation processes as needed. Effluent water from treatment processes will be either reinjected into the ground or discharged to surface water in accordance with an Oklahoma Pollutant Discharge Elimination System (OPDES) permit. Resulting contaminated waste (spent resin) will be processed, packaged and disposed in accordance with applicable requirements. The resin matrix will consist of a hydrocarbon based resin (DOWEX 1); it becomes loaded with low-enriched uranium during the groundwater treatment process. Prior to packaging the resin matrix, non-resin material will be mixed with the resin as needed to absorb free liquid to satisfy transportation and waste disposal requirements. Since the waste will contain enriched uranium, consideration has been given to the design and conduct of the processing operations to ensure that an inadvertent nuclear criticality incident is not credible.

Waste processing operations and storage of packaged waste were evaluated in three separate areas, operating on two different criticality safety limits. There are two treatment systems and a separate secure storage facility for packaged waste. The two processing locations, although separated by over ½ mile, will be treated as a combined safe mass unit with a limit of 1,200 grams U-235 and a maximum enrichment of 5% U-235. The secure storage facility for packaged waste will be operated on a "safe concentration limit" basis to assure nuclear criticality safety, in which the packaged waste stored in this building (awaiting shipment for disposal) will not exceed the fissile exempt concentration limit of 1 gram of U-235 per 2,000 grams of non-fissile material. The possession of U-235 for the entire site will be further constrained to a total mass limit of 0.5 effective kilograms of Special Nuclear Material (SNM).

A series of calculations were performed based on the assumption that the administrative controls to maintain the safe mass limit for the processing operations and the concentration limit for packaged waste are not effective. The calculations, assuming a uranium enrichment of 7.33% and utilizing an Upper Safety Limit (USL) of [k_{eff} plus 3 sigma] <0.9, demonstrate that the maximum allowable safe fissile concentration is 8 g U-235/kg Resin. This Appendix describes the basis for these input values, presents the calculations performed, and explains why the maximum allowable safe fissile concentration cannot be attained.

This evaluation concludes that it not conceivable that any combinations of upset conditions could occur that would result in a [k_{eff} plus 3 sigma] exceeding 0.9. Therefore, an inadvertent criticality incident is not credible.

Criticality Calculation Overview

The criticality calculations prepared for the study incorporate the following conservative assumptions:

1) All fissile material on the site is located in one contiguous area even though there are three physically separate locations planned.
2) The enrichment of the uranium is assumed to be 7.33% U-235, even though on average the enrichment is at a maximum of approximately 4.5% U-235 in two areas of the site and about 1.5% in another area.
3) The criticality model is based on an infinite slab model with a thickness of 7 feet.
4) The composition of the fissile material mixture is low-enriched uranium (maximum of 7.33% U-235) adsorbed on a hydrocarbon resin material.
5) No credit is taken for the administrative controls that will be implemented to maintain the safe mass limit and concentration limits specified in the license.

The analysis is based on a highly conservative value of 7.33% enriched uranium and a conservative Upper Safety Limit (USL) of k_{eff} + 3 sigma > 0.9. The analysis establishes an allowable safe fissile concentration of 8 g U-235/kg Resin.

Groundwater Processing Overview

Concentration of fissile material will occur on the ion-exchange resin as the groundwater is treated to remove the uranium. The relationship between the groundwater concentration of uranium and the uranium concentration on the resin is based on tests that were conducted using the selected resin material and using actual groundwater samples from the site.

The maximum enrichment value of 7.33% U-235 was also conservatively established using historic groundwater monitoring data based on analytical measurements over a 16 year period by the alpha spectrometry (HASL-300) method.[1] It was based on the maximum enrichment measured plus 2 sigma (95% Upper Confidence Level (UCL)) for the highest single historic measurement of any well that will

[1]A comparative evaluation of alternate analytical methods concluded that the ICP-MS (EPA 200.8) would be used for project measurements of the U-235 and U-238 mass concentrations for liquid and solids. An evaluation of groundwater measurement data by ICP-MS since December 2016 demonstrated that the maximum enrichment at the 95% confidence level for the site is 4.76%. Since this value is less than the 7.33% value used for the criticality safety evaluation, it was determined that the criticality safety evaluation is conservative and no change is required. (Reference: Enercon Technical Memo titled "Determination of Maximum Conservative U-235 Enrichment Levels for Groundwater at Cimarron Site Utilizing ICP-MS Data Collected December 2016 Through the 1st Quarter 2018" dated April 12, 2018.)

feed the three treatment trains. Samples where the uranium concentration was less than 30 pCi/L were not included because the uncertainty associated with laboratory analysis of isotope measurement value significantly increases and is not reliable.

During operations, the groundwater feed to each treatment train will consist of a blend of groundwater from a many different extraction wells. An evaluation was made of the historic values of calculated enrichment values for the wells that are located within each of the three areas that will feed the treatment trains. Table 1 presents the results for the average and maximum enrichment at the 95% upper confidence level (UCL) anticipated in each of the three treatment trains. Note that the current design of the Treatment System will combine the feed from Areas 1 and 2 into one storage tank which will result in an averaging of the groundwater concentration and enrichment for Trains 1 and 2. The analysis presented in this Appendix is based on not combining the two areas into one feed stream.

Table 1: Projected Maximum Enrichments During Initial Operations

	Concentration (pCi/L)	Average Enrichment	Average Propagated Uncertainty	Maximum Enrichment at 95% UCL
Train 1	≥30	3.48%	0.71%	4.19%
Train 2	≥30	2.69%	1.14%	3.82%
Combined flow to Trains 1 & 2	≥30	3.09%	0.93%	4.01%
Train 3	≥30	1.51%	0.37%	1.88%

These maximum enrichments are less than the enrichment assumed for the criticality calculations.

<u>Criticality Calculation Methodology and Results</u>

Criticality calculations were performed for the following 3 cases:

- Infinite 7-foot Slab of Homogenous Resin-UO_2 Mixture
    - Enrichment of 7.33 wt% U-235
    - Fissile Concentrations ranging from 1 to 10 g U-235/kg resin
- Infinite 7-foot Slab of Homogenous Resin-UO_2 Mixture for the conditions expected during initial operations.
- Transportation Model from NUREG/CR-4382 (see Appendix I of the NUREG)
    - Enrichment of 7.33 wt.% U-235
    - Fissile Concentration of 0.5 g U-235/kg matrix material

- Matrix Material is modeled as both resin and SiO_2

Table 2 provides the uranium enrichments and fissile concentrations used in the three cases.

Table 2: Enrichments and Fissile Concentrations used for Criticality Safety Evaluations

Cases for Nuclear Criticality Safety Evaluation		Enrichment (% U-235)	Fissile Concentration (g U-235/kg)
Bounding Case		7.33	1 to 10
Operational Cases	Train 1	4.19	2.3
	Train 2	3.82	1.5
	Train 3	1.88	4.2
Transportation Case		7.33	0.5

For the bounding case, the infinite slab is modeled in Monte Carlo N-Particle Transport Code (MCNP) by filling a 7-foot tall rectangular prism with the homogenized resin-UO_2 mixture. The x and y dimensions are 100 cm in width and have reflecting boundary conditions to simulate an infinite slab. There is a 1-foot water reflector modeled in the z dimension. The fissile concentration was varied from 1 to 10 g U-235/kg Resin. The results for these calculations are provided below in Table 3 and Figure 1.

The following additional modeling assumptions are made for the infinite 7-foot slab calculations:

1. The resin is assumed to be composed of carbon and hydrogen with an atomic ratio of 1.
2. The resin is assumed to have a theoretical density of 1.1 g/cm^3 with a 70% packing fraction.
3. The resin is assumed to be dry and there is no additional groundwater present. Previous calculations have shown that the resin-UO_2 mixture is over-moderated and additional groundwater reduces the reactivity.

For the operational cases, the k_{eff} value was calculated for each of the three treatment trains using the maximum expected enrichment (95% UCL) and the maximum expected uranium concentration (95% UCL) on the resin. These calculated values are provided in Table 4 and are shown in Figure 1. At the Upper Safe Limit (USL) of $k_{eff\ plus}$ 3 sigma of 0.9, the interpolated value for the fissile concentration on the resin is 7.978 g U-235/ kg resin. This value has been rounded to 8 g U-235/ kg resin.

As shown above in Table 2, the maximum expected U-235 loading on a resin bed is 4.2 g U-235 per kg of resin. This fissile uranium concentrations on the resin is approximately half of the maximum fissile concentration of 8 g U-235 per kg of resin established as the conservative limit by the bounding case evaluation.

The results for the third case (the transportation evaluation) are presented in Appendix I.

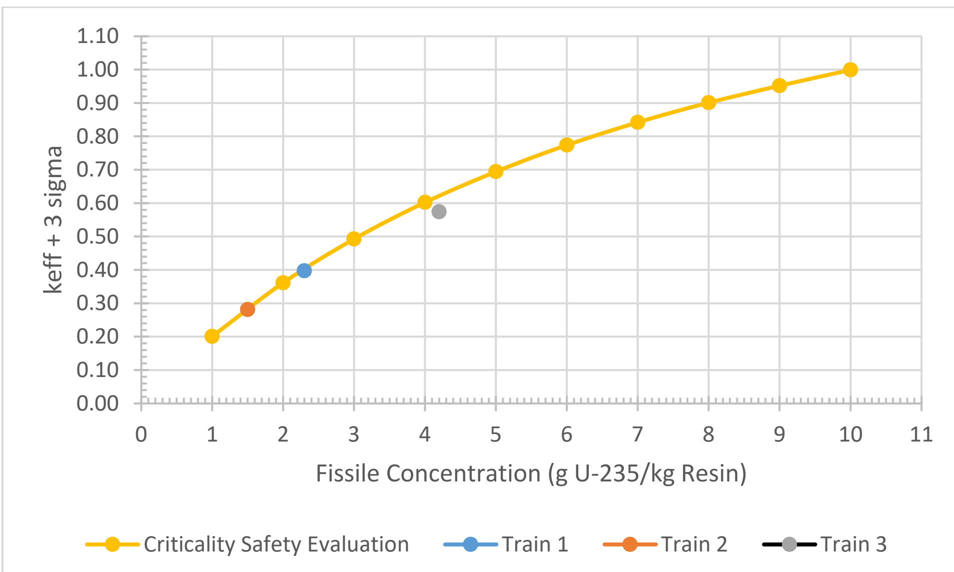
Table 3: k_{eff} Results for an Infinite 7-foot thick Slab of Resin and UO_2 at 7.33 wt% U-235

g U-235/kg Resin	g U/kg Resin	k_{eff}	σ	$k_{eff} + 3\sigma$
1	13.6	0.20069	0.00009	0.20096
2	27.3	0.36111	0.00013	0.36150
3	40.9	0.49222	0.00018	0.49276
4	54.6	0.60176	0.00021	0.60239
5	68.2	0.69380	0.00024	0.69452
6	81.9	0.77332	0.00026	0.77410
7	95.5	0.84140	0.00029	0.84227
8	109.1	0.90034	0.00031	0.90127
9	122.8	0.95089	0.00031	0.95182
10	136.4	0.99842	0.00035	0.99947

Table 4: k_{eff} Results for Resin in Three Trains

Train	Enrichment (wt. % U-235)	Fissile Concentration (g U-235/kg Resin)	k_{eff}	σ	k_{eff} + 3σ
1	4.19	2.3	0.39689	0.00016	0.39737
2	3.82	1.5	0.28120	0.00012	0.28156
3	1.88	4.2	0.57345	0.00025	0.57420

Figure 1. k_{eff} Results for an Infinite 7' Slab of Resin and UO_2 at 7.33 wt% U-235



<u>Possible Upset Conditions for Groundwater Extraction and Process Operations</u>

The following process upset condition could potentially occur, either individually or in conjunction:

1. Major resin spill
2. Major groundwater spill
3. Equipment rearranged to consolidate all within one building including waste containers from storage location

4. External event such as earthquake or high winds disrupts building integrity and process equipment integrity and location
5. Operational errors during the operation of the process equipment such as misaligned valves

The geometric model for the criticality calculations assumes that the configuration of the fissile unit is a 7-foot thick infinite slab at the maximum concentration allowable on the resin matrix. None of the above events would result in a configuration of fissile material outside the model used in the evaluation.

Possible Upset Conditions for Resin Loading

The normal operational condition is that the groundwater feeds to each treatment train as a combined flow from a number of extraction wells such that the uranium mass concentration and the U-235 enrichment is a composite average of many extraction wells.

In order to address an upset condition in which all of the groundwater comes from a single well location at the highest uranium mass concentration, the well sample data was reviewed, and the highest mass concentration sample was identified. The value is further increased by the 2-sigma uncertainty to obtain the maximum groundwater concentration at the 95% confidence level. The concentration of the uranium on the resin is then calculated using the Upper Bound equation for the loading of the resin. This Upper Bound value is then further increased by adding the 2-sigma value to obtain the maximum uranium concentration on the resin at the 95% confidence level. The U-235 enrichment for this groundwater stream is taken as the maximum enrichment at the 95% confidence level for the particular well. These calculation results are presented in Table 5 for each of the three areas that feed the three Trains.

Table 5: Resin Loading Calculation Results

Treatment Area and Well	Maximum Influent Uranium Concentration	Maximum Influent Uranium Concentration at 95% UCL (µg/l)	Maximum Uranium Loading on Resin 95% UCL (g/kg)	95% UCL Uranium Enrichment (% U-235)	Maximum U-235 Loading on resin at 95% UCL (g/kg)
Train 1 Well MWWA-03	562	593	55	5.50%	3.0
Train 2 Well T-63	127	139	39	3.40%	1.3
Train 3 Well TMW-13	4,560	4,841	221	1.55%	3.4

This approach is conservative because it adds the 2-sigma uncertainty to each measured and calculated parameter. These U-235 loadings are bounded by the assumption in the criticality calculations in that the U-235 enrichment is 7.33% and the safe resin concentration is 8 g U-235/kg resin.

The results show that for all three treatment trains both the maximum fissile uranium concentration on the resin and the maximum U-235 enrichment are well within the conservative assumptions utilized in the criticality calculations. The postulated upset condition has an extremely low probability of occurring and the extended time frame over which it would have to continue without detection, but regardless the upset condition would not exceed the bounding assumptions utilize in the criticality calculations. Based on this information, it is concluded that no process operations equipment or management measures are required to be identified as items relied on for safety (IROFS).

Conclusions:

The criticality calculations described here demonstrate that the process will remain subcritical for loadings of up to 8 grams U-235 per kg of resin. A review of potential upset conditions indicates that it not considered credible that a combination of upset conditions could occur that would exceed both the U-235 enrichment and the uranium mass loading utilized in the calculations. Therefore, the probability of an inadvertent criticality incident is not credible. The following list summarizes the primary reasons that support the conclusion stated.

1. The enrichment in the groundwater would have to exceed 7.33% U-235 which is significantly higher than that measured on the site.
2. The uranium fissile concentration in the resin would have to exceed the limits calculated. Historical data of uranium concentration from groundwater sampling data and the tests conducted on the resin materials provides the information to show this is not feasible.
3. The infinite slab geometry of the model bounds any possible configuration of SNM on the site.
4. The resins provide a limiting concentration of fissile buildup dependent on the concentration of uranium in the groundwater.
5. The higher enrichment in the groundwater is limited to a different and physically separate area from that where the higher groundwater concentrations of uranium are present. It is not physically possible to introduce these two separate groundwater sources into one treatment system.
6. No specific operations systems or management measures are IROFS.