ENCLOSURE 2
ATTACHMENT 3

SHINE MEDICAL TECHNOLOGIES, INC.

SHINE MEDICAL TECHNOLOGIES, INC. APPLICATION FOR CONSTRUCTION PERMIT RESPONSE TO REQUEST FOR ADDITIONAL INFORMATION 6B.3-30

ATKINS-NS-DAC-SHN-15-02, REVISION 0
CRITICALITY SAFETY CALCULATIONS FOR THE PRELIMINARY DESIGN OF ANNULAR TANKS FOR THE SHINE MEDICAL ISOTOPE FACILITY

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1 INTRODUCTION

1.1 Background/Purpose

The SHINE Medical Technologies project will use uranium sulfate solution as a subcritical neutron fission target to produce ^{99}Mo for medical uses. In addition, the facility will handle uranium metal as a feed material and uranium oxide for recycling uranium during the process.

Tanks containing fissile material will be necessary throughout the process. Tank volumes have been determined for those tanks which must contain all material in a single vessel. Through discussion with the designers, an annular tank design was decided upon. The height of the tank was defined by the designers. Therefore using the assumed height and defined volume, the tank diameters were calculated. Preference was given to minimizing the footprint area of the tank. Criticality safety calculations were then performed to determine if the design met the Upper Subcritical Limit (USL).

1.2 Limits of Applicability

The results of this report are only applicable to the material types and tank designs that have been studied at the enrichment limit assumed.

2 CONCLUSIONS

The following tank designs have been shown to meet the k_{eff} limit:

- [Proprietary Information] [Security-Related Information] tall annular tank with an outer diameter of[Proprietary Information] [Security-Related Information].
- [Proprietary Information] [Security-Related Information] tall annular tank with an outer diameter of [Proprietary Information] [Security-Related Information].
- [Proprietary Information] [Security-Related Information] tall annular tank with an outer diameter of [Proprietary Information] [Security-Related Information].

The tanks all have a fissile material thickness of [Proprietary Information] [Security-Related Information] and a tank wall thickness of no greater than [Proprietary Information] [Security-Related Information]. The tank wall is modeled as fissile material effectively making the fissile thickness [Proprietary Information] [Security-Related Information]. A [Proprietary Information] [Security-Related Information] neutron absorber plate consisting of PPC-B is present on the outside and inside diameters of the tank. The acceptable gap size between the neutron absorber and the tank wall is discussed in the report.

3 ANALYSIS/PROCESS METHODOLOGY

This DAC does not model a process. See Section 7.1 for description of the models and calculation methodology.

4 COMPUTER CODES USED IN DAC

MCNP is a general-purpose Monte Carlo N–Particle code that can be used for neutron, photon, electron, or coupled neutron/photon/electron transport, including the capability to calculate eigenvalues for critical systems (Reference 1).

MCNP 6.1 was run on the Atkins' Linux computer cluster. All computers have 64-bit hardware and use the 64-bit version of Linux. Distribution of the calculation jobs among the individual CPUs is controlled by the Sun Grid Engine queue software running on the master Linux computer. Additional Linux execution hosts run calculation jobs at the command of the queue master. MCNP 6.1 has been installed in the read only disk area; the installation has been verified with the execution of the sample problems. This disk is shared with the execution hosts. Hardware and software used with the Atkins Linux computer cluster is managed with the Atkins NS System's configuration control.

MCNP models a physical system with a three-dimensional configuration of geometric cells bounded by first and second-degree surfaces and fourth-degree elliptical tori. Each geometric cell contains a material or void as specified by the user to model the physical system. Material characteristics (i.e., cross sections) are represented by point-wise continuous cross-section data. For neutrons, all reactions given in a particular cross-section library (such as ENDF/B-VII) are taken into account. Thermal neutrons are described by the free gas and $S(\alpha, \beta)$ models. The MCNP neutron data library based on Evaluated Neutron Data File B-VII.1 (ENDF/B-VII.1) is the default for continuous energy neutron transport.

The specific elements and isotopes used in this evaluation are listed here with their library identifiers:

H	1001.80c
^{10}B	5010.80c
^{11}B	5011.80c
C	6000.80c
O	8016.80c
Na	11023.80c
Al	13027.80c
Si-28	14028.80c
Si-29	14029.80c
Si-30	14030.80c
S-32	16032.80c
S-33	16033.80c
S-34	16034.80c
S-36	16036.80c
Ca-40	20040.80c
Ca-42	20042.80c
Ca-43	20043.80c
Ca-44	20044.80c
Ca-46	20046.80c
Ca-48	20048.80c
Fe-54	26054.80c
Fe-56	26056.80c
Fe-57	26057.80c
Fe-58	26058.80c
U-235	92235.80c
U-238	92238.80c

The light water $S(\alpha,\beta)$ correction (lwtr.20t) is used for water (both in the solution and interstitial in the concrete) and the polyethylene $S(\alpha,\beta)$ correction (poly.20t) is used for PPC-B.

5 ASSUMPTIONS & OPEN ITEMS

5.1 Assumptions

1. Temperature of all cases is assumed to be 20°C. Higher temperatures will result in lower reactivity due to the increase in neutron absorption due to Doppler broadening of the resonance region within ^{238}U.
2. Solute saturation is assumed to be unlimited. Realistic saturation behavior is ignored in favor of showing the peak reactivity for the various materials regardless of concentration.
3. Uranyl sulfate is modeled assuming no excess acid as a conservative simplification. Excess acid will increase neutron absorption.
4. Uranium is assumed to be enriched to 21 wt% ^{235}U.
5. Uranium dioxide theoretical density is 10.96 g/cc.
6. Water theoretical density is 0.9982 g/cc.
7. Density of PPC-B is assumed to be 0.955 g/cc.
8. Density of KENO Regular Concrete is 2.3 g/cc.
9. The following atom masses are assumed for the modeled isotopes and molecules.

^{235}U:	235.04392 g/mole
^{238}U:	238.05079 g/mole
U (21 wt%):	237.42 g/mole
S:	32.064388 g/mole
O:	15.999 g/mole
H:	1.0079 g/mole
H_2O:	18.0148 g/mole
H_2SO_4:	98.076 g/mole
UO_2SO_4:	365.478 g/mole
UO_2:	269.418 g/mole
B:	10.811 g/mole
C:	12.0107 g/mole

10. The atomic percentage of ^{10}B in boron is assumed to be 19.9%.
11. Avogadro's number is assumed to be 0.6022 atom-cm^2/bn.
12. Heterogeneous effects within the solution are not considered in these calculations. The evaluation of the process for which these tanks are used will determine if heterogeneous particles are present and the analysis will be updated accordingly during final design.

5.2 Open Items

There are no open items.

6 ACCEPTANCE CRITERIA

6.1 Biases and Uncertainties

The methodology and results for the MCNP 6.1 code system validation for its use with the SHINE Medical Technologies applications are documented in Reference 2. Criticality safety experiments were selected from the International Handbook of Evaluated Criticality Safety Benchmark Experiments that adequately match the uranium enrichment, geometry, moderator, reflector, and neutron energy relevant to the processes within the SHINE facility. The bias results demonstrate that the calculated values sufficiently matched the reality of the experiments. The final validation is expressed as an Upper Subcritical Limit (USL) calculated using the statistical accumulation of the experiments' bias and bias uncertainty.

The Upper Subcritical Limit (USL) is calculated using the following equation:

USL = 1.0 + Bias - Bias Uncertainty - MOS

where,

MOS = Margin of Subcriticality = 0.05 Δk, and

Bias = 0.0025 Δk (positive bias is set to zero in the equation)

Bias Uncertainty = 0.0109 Δk

Therefore the USL = 0.9391.

For an acceptable result, the MCNP k_{eff} + 2σ must be less than the USL value.

6.2 Area of Applicability (AoA)

The AoA derived in Reference 2 is compared to the calculations performed here in Table 2. All parameters are within the AoA of the MCNP 6.1 validation. Therefore, no additional AoA margin is necessary.

Table 1: Area of Applicability Summary

Parameter	Area of Applicability from Validation	Area of Applicability for Calculations
Fissile Material	UO_2, UH_3, Metal, $UO_2(NO_3)_2$, UF_4, U-ZrH, UO_2F2, U_xO_y, UO_2SO_4	UO_2, Metal, UO_2SO_4
Fissile Material Form	Solid and Solution	Solid and Solution
$H/^{235}U$ ratio	$0 \leq H/^{235}U \leq 1400$	$64.7 \leq H/^{235}U \leq 223.7$
Average Neutron Energy Causing Fission (MeV)	0.0027 < ANECF < 1.46	0.0279 < ANECF < 0.0952
Enrichment	10 to 36 wt.% ^{235}U	21 wt.% ^{235}U
Moderating Materials	None, Water, nitric acid, sulfuric acid, Hydrocarbon, CF_2	Water, sulfuric acid
Reflecting Materials	None, Water, Concrete, BeO, Hydrocarbon Material, Iron, Graphite	Water
Absorber Materials	Boron, Cadmium, Aluminium, Steel, Stainless Steel, Hydrocarbon Material	None
Geometry	Homogeneous and Heterogeneous Spheres, Hemispheres, Cylinders, Cuboids Single Units and Arrays	Cylinders

7 CALCULATIONS

7.1 Method Discussion

7.1.1 Geometry Model

The annular tank model is defined based on the following design.

[

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Security-Related Information

]

Figure 1: Sketch of MCNP Model of Annular Tank

Tank height is varied based on the specific design requirement. The fissile material thickness is unchanged at [Proprietary Information] [Security-Related Information]. The tank walls are modeled as [Proprietary Information] [Security-Related Information] of fissile material making the effective fissile material thickness [Proprietary Information] [Security-Related Information]. The inner and outer gap between the PPC-B and tank wall are varied to determine the effect on reactivity. The PPC-B is [Proprietary Information] [Security-Related Information] in thickness. The thickness of the concrete is 36 inches on all sides. The distance between the outside diameter of the outer neutron absorber panel and the concrete reflector walls is 6 inches. The distance between the top and bottom of the tank to the top and bottom concrete reflector walls is 3 inches.

7.1.2 Material Specification

Uranyl sulfate and uranium oxide mixed with water were modeled in this report. The following equations were used to determine the MCNP number density input. MCNP inputs are noted with italics.

<u>Uranyl Sulfate</u>

Uranyl sulfate density is based on an empirical correlation which is specified in Reference 3. No excess acid (molarity = 0, normality = 0) is assumed for conservatism. The temperature is set at 20°C. The following equation was used to determine the uranyl sulfate density:

$$\boldsymbol{\rho_{sol'n}} = \left[\frac{(\boldsymbol{C_U} + \boldsymbol{A})}{\boldsymbol{B} \times \mathbf{10}^{-0.013\boldsymbol{N}}}\right] + \mathbf{0.0003}(\mathbf{25} - \boldsymbol{T})$$

Where:

$\boldsymbol{\rho_{sol'n}} =$ $\boldsymbol{Solution\ density\ at\ T}$ ℃, $\frac{\boldsymbol{g}}{\boldsymbol{cm^3}}$

$\boldsymbol{C_U} =$ $\boldsymbol{Uranium\ concentration}, \frac{\boldsymbol{g}}{\boldsymbol{l}}$

$\boldsymbol{T} =$ $\boldsymbol{Temperature}$, ℃

$\boldsymbol{N} =$ $\boldsymbol{moles\ free\ acid\ in\ solution}\ (\frac{\boldsymbol{H+}}{\boldsymbol{L}})$

$\boldsymbol{Constants}$	$\leq \mathbf{150}\frac{\boldsymbol{gU}}{\boldsymbol{l}}$	$> \mathbf{150}\frac{\boldsymbol{gU}}{\boldsymbol{l}}$
$\boldsymbol{A}$	$\mathbf{735.4}$	$\mathbf{743.7}$
$\boldsymbol{B}$	$\mathbf{737.4}$	$\mathbf{745.4}$

The uranium concentration is specified which allows the uranyl sulfate solution density to be calculated. Then the number densities for all isotopes can be determined using the following equations:

^{235}U atom density (atoms/bn-cm) = uran_conc/1000 * 235U_wo / 235U_amu * avog
^{238}U atom density (atoms/bn-cm) = uran_conc/1000 * 238U_wo / 238U_amu * avog
U atom density (atoms/bn-cm) = ^{235}U atom density + ^{238}U atom density

UO_2SO_4 density (g/cc) = U atom density/avog * UO2SO4_amu

H_2O density in mixture (g/cc) = solution_dens – UO_2SO_4 density

S atom density (atoms/bn-cm) = U atom density
O atom density (atoms/bn-cm) = 6 * (U atom density) + (H_2O density in mixture/H2O_amu) * avog
H atom density (atoms/bn-cm) = 2 * (H_2O density in mixture/H2O_amu) * avog

where,

uran_conc = uranium concentration in g/liter,
235U_wo = mass fraction of ^{235}U in uranium,
238U_wo = mass fraction of ^{238}U in uranium,
235U_amu = atomic mass of ^{235}U,
238U_amu = atomic mass of ^{238}U,
UO2SO4_amu = atomic mass of UO_2SO_4,
H2O_amu = atomic mass of H_2O,
solution_dens = uranyl sulfate density based on uranium concentration, and
avog = Avogadro's number.

Uranium Oxide and Water

Uranium oxide was modeled as UO_2. This molecule has the least number of oxygen atoms per uranium atoms which will result in the highest reactivity when compared other oxide compounds (ie. UO_3, U_3O_8, etc.). A simple volume additive relation is used to derive the constituent element atom densities assuming a given uranium density within the mixture. The following equations were used to derive the number densities:

^{235}U atom density (atoms/bn-cm) = uran_dens * 235U_wo / 235U_amu * avog

^{238}U atom density (atoms/bn-cm) = uran_dens * 238U_wo / 238U_amu * avog

UO_2 density in mixture (g/cc) = uran_dens/U_amu * UO2_amu

H_2O density in mixture (g/cc) = (1 – (UO_2 density in mixture/10.96)) * 0.9982

Total density of mixture (g/cc) = UO_2 density in mixture + H_2O density in mixture

O atom density (atoms/bn-cm) = (H_2O density in mixture/H2O_amu) * avog + (2 * UO_2 density in mixture/UO2_amu) * avog

H atom density (atoms/bn-cm) = 2 * (H_2O density in mixture/H2O_amu) * avog

where,

uran_dens = uranium density in g/cc,
235U_wo = mass fraction of ^{235}U in uranium,
238U_wo = mass fraction of ^{238}U in uranium,
235U_amu = atomic mass of ^{235}U,
238U_amu = atomic mass of ^{238}U,
U_amu = atomic mass of U,
UO2_amu = atomic mass of UO_2,
H2O_amu = atomic mass of H_2O,
UO_2 density in mixture = uranium dioxide mass density in mixture,
H_2O density in mixture = water mass density in mixture, and
avog = Avogadro's number.

PPC-B

PPC-B is a neutron shielding material manufactured by Liberty Pultrusions (Ref. 5) and primarily used by the Nuclear Navy. The material specification sheet is provided in Figure 2 (Ref. 6).

Liberty *Polyglas*®, Inc.
1575 Lebanon School Rd.
W. Mifflin, PA 15122
Phone (412) 466-8611
Fax (412) 466-8640

Properties of PPC (Colymer Sheets)*
(Neutron Shielding Material)

	PPC-V	PPC-B
Specific Gravity	.940 g/cc^3 minimum	.955 g/cc^3 minimum
Hydrogen Concentration	12.4% minimum	12.0% minimum
Carbon plus Hydrogen Concentration	99.0% minimum	96.2% minimum
Boron Concentration	--------	2% +.7% -.2%
Thermal Stability - After 24 Hours @ 550° F	Shall not melt, flow, crack, blister, bulge or otherwise distort.	Shall not melt, flow, crack, blister, bulge or otherwise distort.
Weight Loss - After 24 Hours @ 550° F	1.5% maximum	1.5% maximum
Thermal Expansion		
70° F to 350° F Thickness	2.4×10^{-4} in/in/F	2.4×10^{-4} in/in/F
70° F to 350° F Width & Length	1.5×10^{-4} in/in/F	1.5×10^{-4} in/in/F

* Typical properties.

Figure 2: Manufacturer Information on PPC-B

The following properties of PPC-B are assumed in the calculation of the number densities.

- The boron weight percent is 5% (it was confirmed with the manufacturer that 5% was well within the capability of the manufacturing process).
- The hydrogen weight percent is 12% minimum as specified by the manufacturer. Minimum hydrogen density will result in the least amount of scattering in the absorber and thus the least amount of neutron absorption.
- The remaining material is carbon which has a weight percent of 83%.
- The density of PPC-B is 0.955 g/cc.
- Only 75% of the calculated number density for both ^{10}B and ^{11}B are used.

Therefore the following number densities inputs were used in the modeling of PPC-B.

12% hydrogen

6000.80c	3.97433e-02
1001.80c	6.84728e-02
5010.80c	3.96984e-04
5011.80c	1.59791e-03

15% hydrogen

6000.80c	3.83068e-02
1001.80c	8.55909e-02
5010.80c	3.96984e-04
5011.80c	1.59791e-03

All units are atoms/bn-cm^2.

Concrete

Concrete was modeled using the "KENO Regular Concrete Standard Mix" as specified in Reference 4. Water content in the concrete will be evaluated in final design to ensure that reactivity is properly bounded for final concrete composition. The following weight fraction input was used in MCNP:

1001.80c -1.0000E-02
8016.80c -5.3200E-01
14028.80c -3.0959E-01
14029.80c -1.6289E-02
14030.80c -1.1121E-02
13027.80c -3.4000E-02
11023.80c -2.9000E-02
20040.80c -4.2531E-02
20042.80c -2.9804E-04
20043.80c -6.3670E-05
20044.80c -1.0066E-03
20046.80c -2.0180E-06
20048.80c -9.8446E-05
26054.80c -8E-04
26056.80c -1.29E-02
26057.80c -3E-04
26058.80c -4E-05

7.2 Inputs

7.2.1 Model Dimensions

Tanks designs were based on the following requirements:

- A [Proprietary Information] [Security-Related Information] tall tank capable of holding [Proprietary Information] [Security-Related Information] of uranyl sulfate,
- A [Proprietary Information] [Security-Related Information] tall tank capable of holding [Proprietary Information] [Security-Related Information] of uranyl sulfate, and

- A [Proprietary Information] [Security-Related Information] tank capable of holding [Proprietary Information] [Security-Related Information] of uranyl sulfate or uranium dioxide and water.

As discussed in 7.1.1 a fissile material thickness of [Proprietary Information] [Security-Related Information] was modeled. Assuming this the following tank outer diameters are necessary to meet the volume requirements.

- A [Proprietary Information] [Security-Related Information] tall tank with an outer diameter of [Proprietary Information] [Security-Related Information] has a volume of [Proprietary Information] [Security-Related Information],
- A [Proprietary Information] [Security-Related Information] tall tank with an outer diameter of [Proprietary Information] [Security-Related Information] has a volume of [Proprietary Information] [Security-Related Information], and
- A [Proprietary Information] [Security-Related Information] tall tank with an outer diameter of [Proprietary Information] [Security-Related Information] has a volume of [Proprietary Information] [Security-Related Information].

The remaining dimensions of the tank are based on these dimensions.

As discussed previously, the gap size between the PPC-B neutron absorber and the tank wall was varied. The values modeled were [Proprietary Information] [Security-Related Information]. All combinations of gap sizes were considered.

7.2.2 Material Concentrations/Densities

All three tanks were evaluated with uranyl sulfate as the fissile material of interest. The [Proprietary Information] [Security-Related Information] tall tank was also modeled with uranium dioxide since that tank design will be used to dissolve uranium oxide powder with sulfuric acid to create uranyl sulfate.

Uranyl sulfate densities of 500 to 1100 gU/l were modeled for both void and water flooded conditions. This range was chosen to include the most reactive concentration for each set of conditions. Uranium dioxide densities of 0.8 to 1.6 g/cc were modeled.

All three tank designs were modeled with void in all spaces where tank material is not present including the gap between the tank wall and neutron absorber and between the absorber and the concrete reflector. The tank designs were also modeled with water in all these locations to determine whether void or water is more reactive.

7.3 Evaluations, Analysis, and Detailed Calculations

The results of the annular tank calculations are listed in the following sections. All cases were inspected for convergence and found to be acceptable. The average uncertainty associated with MCNP calculations was 0.00064 Δk.

7.3.1 [Proprietary Information] [Security-Related Information] Tall Tanks

Calculations were performed with the previously descripted MCNP annular tank model using uranyl sulfate as the fissile material. Both void and water were used to fill the gaps and space outside the tanks. Results are shown in Figures 1 – 4 for void and Figures 5 - 8 for water.

[Proprietary Information
Security-Related Information]

Figure 1: [Proprietary Information] [Security-Related Information] annular tank with void, Inner Gap [Proprietary Information] [Security-Related Information]

[Proprietary Information
Security-Related Information]

Figure 2: [Proprietary Information] [Security-Related Information] annular tank with void, Inner Gap [Proprietary Information] [Security-Related Information]

Proprietary Information
Security-Related Information

Figure 3: [Proprietary Information] [Security-Related Information] annular tank with void, Inner Gap [Proprietary Information] [Security-Related Information]

Proprietary Information
Security-Related Information

Figure 4: [Proprietary Information] [Security-Related Information] annular tank with void, Inner Gap [Proprietary Information] [Security-Related Information]

[
Proprietary Information
Security-Related Information
]

Figure 5: [Proprietary Information] [Security-Related Information] annular tank with water, Inner Gap [Proprietary Information] [Security-Related Information]

[
Proprietary Information
Security-Related Information
]

Figure 6: [Proprietary Information] [Security-Related Information] annular tank with water, Inner Gap [Proprietary Information] [Security-Related Information]

[

Proprietary Information
Security-Related Information

]

Figure 7: [Proprietary Information] [Security-Related Information] annular tank with water, Inner Gap [Proprietary Information] [Security-Related Information]

[

Proprietary Information
Security-Related Information

]

Figure 8: [Proprietary Information] [Security-Related Information] annular tank with water, Inner Gap [Proprietary Information] [Security-Related Information]

For each inner/outer gap unique combination in the voided condition, the peak $k_{eff} + 2\sigma$ value is summarized in Table 2. For each inner/outer gap unique combination in the water flooded condition, the peak $k_{eff} + 2\sigma$ value is summarized in Table 3.

Table 2: [Proprietary Information] [Security-Related Information] Annular Tanks Voided Condition Results Summary

[Proprietary Information
Security-Related Information]

Table 3: [Proprietary Information] [Security-Related Information] Annular Tanks Water Flooded Condition Results Summary

[Proprietary Information
Security-Related Information]

Results show that largest value for the inner gap is the worst case for both void and water flooded. Results also show that the smallest value for the outer gap is generally the worst case for voided conditions but the largest value for the outer gap is the worst case for water flooded conditions. This behavior is expected. In the voided conditions, moving the neutron absorber closer to the fissile material will increase the neutron reflection caused by the neutron absorber thus increasing the k_{eff}. However, with water flooded conditions, moving the neutron absorber further from the fissile material will increase the thickness of water next to the fissile material and increase the neutron reflection provided to the tank.

Therefore, when manufactured, the inner gap must be kept to a minimum size of no greater than [Proprietary Information] [Security-Related Information] to meet the USL of 0.9391. Outer gap size must be limited to [Proprietary Information] [Security-Related Information] to meet the USL of 0.9391. Design tolerances will be defined during final design and comparison to these calculations will be made at that time. Adjustments to the models and calculations will be done, as necessary, to support final design.

7.3.2 [Proprietary Information] [Security-Related Information] Tall Tanks

Calculations were performed with the previously descripted MCNP annular tank model using uranyl sulfate as the fissile material. Both void and water were used to fill the gaps and space outside the tanks. Results are shown in Figures 9 – 12 for void and Figures 13 - 16 for water.

[Proprietary Information
Security-Related Information]

Figure 9: [Proprietary Information] [Security-Related Information] annular tank with void, Inner Gap [Proprietary Information] [Security-Related Information]

[Proprietary Information
Security-Related Information]

Figure 10: [Proprietary Information] [Security-Related Information] annular tank with void, Inner Gap [Proprietary Information] [Security-Related Information]

[

Proprietary Information
Security-Related Information

]

Figure 11: [Proprietary Information] [Security-Related Information] annular tank with void, Inner Gap [Proprietary Information] [Security-Related Information]

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Proprietary Information
Security-Related Information

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Figure 12: [Proprietary Information] [Security-Related Information] annular tank with void, Inner Gap [Proprietary Information] [Security-Related Information]

Proprietary Information
Security-Related Information

Figure 13: [Proprietary Information] [Security-Related Information] annular tank with water, Inner Gap [Proprietary Information] [Security-Related Information]

Proprietary Information
Security-Related Information

Figure 14: [Proprietary Information] [Security-Related Information] annular tank with water, Inner Gap [Proprietary Information] [Security-Related Information]

[Proprietary Information
Security-Related Information]

Figure 15: [Proprietary Information] [Security-Related Information] annular tank with water, Inner Gap [Proprietary Information] [Security-Related Information]

[Proprietary Information
Security-Related Information]

Figure 16: [Proprietary Information] [Security-Related Information] annular tank with water, Inner Gap [Proprietary Information] [Security-Related Information]

For each inner/outer gap unique combination in the voided condition, the peak k_{eff} + 2σ value is summarized in Table 4. For each inner/outer gap unique combination in the water flooded condition, the peak k_{eff} + 2σ value is summarized in Table 5.

Table 4: [Proprietary Information] [Security-Related Information] Annular Tanks Voided Condition Results Summary

[Proprietary Information
Security-Related Information]

Table 5: [Proprietary Information] [Security-Related Information] Annular Tanks Water Flooded Condition Results Summary

[Proprietary Information
Security-Related Information]

Results show a similar k_{eff} behavior with regards to the gap size as in the [Proprietary Information] [Security-Related Information] annular tanks. The inner gap must be kept to a minimum size of no greater than [Proprietary Information] [Security-Related Information] to meet the USL of 0.9391. Outer gap size must be limited to [Proprietary Information] [Security-Related Information] to meet the USL of 0.9391. Again, the final design phase will set the values and calculations will be modified, as needed.

7.3.3 [Proprietary Information] [Security-Related Information] Tall Tanks

Calculations were performed with the previously descripted MCNP annular tank model using uranyl sulfate and uranium dioxide as the fissile material. Both void and water were used to fill the gaps and space outside the tanks. Results are shown in Figures 17 – 20 for sulfate and void, Figures 21 - 24 for sulfate and water, Figures 25 – 28 for oxide and void, and Figures 29 – 32 for oxide and water.

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Proprietary Information
Security-Related Information

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Figure 17: [Proprietary Information] [Security-Related Information] annular tank with sulfate and void, Inner Gap [Proprietary Information] [Security-Related Information]

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Proprietary Information
Security-Related Information

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Figure 18: [Proprietary Information] [Security-Related Information] annular tank with sulfate and void, Inner Gap [Proprietary Information] [Security-Related Information]

[

Proprietary Information
Security-Related Information

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Figure 19: [Proprietary Information] [Security-Related Information] annular tank with sulfate and void, Inner Gap [Proprietary Information] [Security-Related Information]

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Proprietary Information
Security-Related Information

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Figure 20: [Proprietary Information] [Security-Related Information] annular tank with sulfate and void, Inner Gap [Proprietary Information] [Security-Related Information]

[

Proprietary Information
Security-Related Information

]

Figure 21: [Proprietary Information] [Security-Related Information] annular tank with sulfate and water, Inner Gap [Proprietary Information] [Security-Related Information]

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Figure 22: [Proprietary Information] [Security-Related Information] annular tank with sulfate and water, Inner Gap [Proprietary Information] [Security-Related Information]

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Figure 23: [Proprietary Information] [Security-Related Information] annular tank with sulfate and water, Inner Gap [Proprietary Information] [Security-Related Information]

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Figure 24: [Proprietary Information] [Security-Related Information] annular tank with sulfate and water, Inner Gap [Proprietary Information] [Security-Related Information]

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Figure 25: [Proprietary Information] [Security-Related Information] annular tank with oxide and void, Inner Gap [Proprietary Information] [Security-Related Information]

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Figure 26: [Proprietary Information] [Security-Related Information] annular tank with oxide and void, Inner Gap [Proprietary Information] [Security-Related Information]

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Figure 27: [Proprietary Information] [Security-Related Information] annular tank with oxide and void, Inner Gap [Proprietary Information] [Security-Related Information]

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Figure 28: [Proprietary Information] [Security-Related Information] annular tank with oxide and void, Inner Gap [Proprietary Information] [Security-Related Information]

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Figure 29: [Proprietary Information] [Security-Related Information] annular tank with oxide and water, Inner Gap [Proprietary Information] [Security-Related Information]

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Figure 30: [Proprietary Information] [Security-Related Information] annular tank with oxide and water, Inner Gap [Proprietary Information] [Security-Related Information]

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Figure 31: [Proprietary Information] [Security-Related Information] annular tank with oxide and water, Inner Gap [Proprietary Information] [Security-Related Information]

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Figure 32: [Proprietary Information] [Security-Related Information] annular tank with oxide and water, Inner Gap [Proprietary Information] [Security-Related Information]

For each inner/outer gap unique combination in the voided condition, the peak $k_{eff} + 2\sigma$ value is summarized in Table 6 and Table 8. For each inner/outer gap unique combination in the water flooded condition, the peak $k_{eff} + 2\sigma$ value is summarized in Table 7 and Table 9.

Table 6: [Proprietary Information] [Security-Related Information] Annular Tanks Voided Condition Uranyl Sulfate Results Summary

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Table 7: [Proprietary Information] [Security-Related Information] Annular Tanks Water Flooded Condition Uranyl Sulfate Results Summary

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Table 8: [Proprietary Information] [Security-Related Information] Annular Tanks Voided Condition Uranium Dioxide Results Summary

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Table 9: [Proprietary Information] [Security-Related Information] Annular Tanks Water Flooded Condition Uranium Dioxide Results Summary

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Results show a similar k_{eff} behavior with regards to the gap size as in the [Proprietary Information] [Security-Related Information] annular tanks. These results show more margin to the USL limit of 0.9391. There is enough margin to allow the outer gap to be [Proprietary Information] [Security-Related Information]. The inner gap may not exceed [Proprietary Information] [Security-Related Information]. Again, the final design phase will set the values and calculations will be modified, as needed.

7.3.4 Study of Hydrogen Content in PPC-B

Calculations were performed with the ten foot annular tanks for both void and water conditions. The worst case inner and outer gap thickness model was chosen to see the effect of increasing the PPC-B hydrogen content. The hydrogen density was increased to 15% in the new cases. For the void condition, the inner gap was [Proprietary Information] [Security-Related Information] and the outer gap was [Proprietary Information] [Security-Related Information]. For the water condition, the inner gap was [Proprietary Information] [Security-Related Information] and the outer gap was [Proprietary Information] [Security-Related Information]. Results are plotted in Figure 33. The results demonstrate that higher hydrogen density in the PPC-B results in lower k_{eff} values. Therefore a minimum hydrogen density of 12%, as specified by the manufacturer, will ensure the USL is met.

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Figure 33: Increased Hydrogen Density with [Proprietary Information] [Security-Related Information] Annular Tanks

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APPENDIX 1: REPRESENTATIVE INPUT FILES

Annular tank model with voided conditions

All annular tank models with voided conditions inputs are a variation of the model described in this input file with tank diameters, tank height, gap thicknesses (and corresponding diameters) and material #1 changed as appropriate.

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Annular tank model with water flooded conditions

All annular tank models with water flooded conditions inputs are a variation of the model described in this input file with tank diameters, tank height, gap thicknesses (and corresponding diameters) and material #1 changed as appropriate.

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